Cellular Planning of GSM Network in Rivers State, Nigeria

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***Abstract*— Global system for mobile communication has witnessed tremendous growth. This is due largely to the fact that it enables people to make quality calls, send messages, browse the internet etc. at any time and for any period. The huge number of GSM subscribers has resulted in the system being over-loaded. This research work is aimed at optimizing Global System for Mobile Communication (GSM) network in Rivers State. The behavior of GSM network under four different conditions were examined. The work also aimed to determine the number of base stations required to provide adequate GSM network coverage in Rivers State. Erlang B technique was employed to achieve the aim of this research work. This research work found that when the traffic load is greater than, or too close to, the voice channels (in magnitude), the system denied many callers access from making calls. However, when the voice channels are greater than traffic load, the system performed well. But voice channels must not be far greater than traffic load and should not be too close to it, to avoid under-utilization or over-utilization of the channels. The work also revealed that the number of base stations required in any given place varies inversely proportional to the square of the cell radius. Hence, for Rivers State, the number of base stations to provide 100% network coverage for a cell radius of 3km was found to be 474.**

***Index Terms*—Base Station; Erlang B; GSM Network; Network Coverage; Voice Channels.**

I. INTRODUCTION

A. Background of the Study

The word optimization refers to the act or methodology employed in making an already existing system to function effectively and efficiently while minimizing undesired things like cost and maximizing desired things like coverage. The cost involved in the design of global system for mobile communications (GSM) network, the traffic and coverage issues, and other problems encountered by GSM network providers are enormous, and therefore optimization is the way forward [1].

The global system for mobile (GSM) communications network has a very highly developed architecture that is made up of different kinds of components. The components include base station (BS), base station controller (BSC), base transceiver stations (BTS), mobile switching center (MSC), and so forth. At the core of the network is the mobile switching center (MSC) which performs series of functions such as analyzing call destinations, taking care of signaling, registering and deregistering mobile stations (MSs), routing calls, controlling handover, and locating mobile stations (MS) through paging [1].

For quite a long time now, wireless communication systems have gained popularity. [2] noted that by 2010, GSM services were used by more than three billion people or users worldwide. According to Nigeria Communications Commission sector report, [3], there are over 147, 398, 854 GSM network users throughout Nigeria. Back in the early part of 1980, the first-generation wireless networks were used. The 1G networks were purely based on analog technology. However, it was unable to handle the growing need for capacity. The first generation (1G) wireless networks was followed by the second-generation wireless networks (2G). Unlike the first-generation wireless network, the second-generation wireless networks are based on digital technology. An example of the second-generation network is the global system for mobile (GSM) communications. GSM improved the quality of service (QoS) and gave rise to higher system capacity.

The third generation (3G) of wireless communication systems followed the 2G and it ensures faster internet speed. The application of 3G networks include video calls, mobile internet access, global positioning system (GPS) etc. [4]. Compared to 2G, the 3G provides more security. The fourth generation networks, called the 4G, is gaining popularity. It is expected that the 4G network system will provide bandwidth that is higher than 1200Mbps to the users.

B. Literature Review

A model for optimizing GSM network design was presented in [1]. The model was tagged integer programming model. They observed that GSM network design starts at the planning department, where the engineers use geographic regions to estimate the required coverage area. If the engineers are focusing more on coverage, sites that have high attitudes and without obstacles are preferred. If, however, the focus is on traffic, the engineers distribute hotspots that are equipped with base transceiver stations. The model they developed provided a solution to the problem of the design of base station subsystem. But the area of emphasis was using the integer programming model to reduce the cost of the links between BSC and BTS, the cost of the links between BSC and MSC, the channel dimensioning etc. They used different network sizes, the largest being a network with 50 sites. Simulations made indicated that the model worked very well.

Network dimensioning such as mobile switching center (MSC), base station controller (BSC), and so forth was explained in [5]. Mobile switching center (MSC) is at the core of the GSM network. Transceivers (TRXs) and base transceiver stations (BTSs) are very useful when it comes to frequency planning in global system for mobile communications (GSM). If frequency planning is poorly done, optimal performance of GSM network will not be achieved, and scarce resources will be wasted.

In [6], it was observed that global system for mobile (GSM) communication has seen some level of improvements since its deployment. However, this improvement is not commensurate with the number of subscribers needing the GSM services. The performance of the GSM network has been the concern of both the service provider and the GSM subscribers alike. For this reason, [7] made use of key performance indicator (KPI) to evaluate how an operational GSM network could perform. They used about four major key performance indicators (KPIs) like call drop rate, success rate of call setup, traffic congestion, and handover success to evaluate the network performance. Knowing the performance of GSM network like this helps in designing or redesigning GSM network for optimal performance.

The problem of GSM network optimization, fine turning the system, optimization implementation, sorting of data and analysis were investigated in [5]. In [8], the issue of how to establish and maintain call connections, how to carry out successful handover, retaining calls, and setting up Inter and intro network calls was given attention. The work was very detailed and to some extent addressed some of the issues or challenges facing GSM network providers.

In [9], it was noted that network congestion is a challenge that needs to be tackled. Network congestion is a very serious issue in telecommunication field. This congestion is made more severe due to the huge number of individuals subscribing for GSM network. This is clear as many more people join the list of mobile subscribers daily. Hence, [9] identified four key areas of congestion when it comes to GSM network:

i. Common control channels (CCCH): This is just a set of control channels that sees to the establishment and of course maintenance of links for communication between the base station and the mobile station, as shown in Figure 1.

Figure 1: Link between MS and BS

The common control channel (CCCH) is divided into the following: Paging channels, which notify the mobile station of any incoming calls; access grant channel, which assigns to the mobile station any free dedicated control channel for communication; random access channel, which makes request for network assignment.

ii. Dedicated Control Channel Congestion: This occurs if standalone control channel SDCCH does not provide location update, assignment to traffic channels etc.

iii. Traffic Channels Congestion (TCHC): If an access grant channel fails to get a free TCH to assign to a mobile station upon request, then there is traffic channel congestion.

iv. Pulse Code Modulation Congestion (PCM): Connection between base station and mobile switching center requires pulse code modulation. In any event that pulse code modulation is unavailable to carry call signals between the mobile switching center and base station, the result is pulse code modulation congestion. Every PCM carries between 1 call and 32 calls.

In [10], work was carried out on the design of mobile communications network with the use of GSM technology. He looked at how morphology affects the modeling of GSM network. He used twenty-seven (27) base stations and a cluster of 4 cells. In the network he used, every cell had a radius that was between 2500meters and 3000meters (2.5km and 3km), and the four clusters used did not have any overlapping areas. Celplanner software was deployed at the planning stage and some key parameters like terminal, antenna, and environmental configurations were used to prepare the foundation for the work. The total service area he worked on was 10323 km^2. Almost half of the service area was very crowded, while the rest service area was rural area.

The focus in [10] was on how morphology and topology affect GSM network. However, the use of cluster of four cells is no longer advisable since the reuse distance is so small that it affects good performance.

The objectives of this research are:

i. To determine the minimum number of base stations required for effective GSM network coverage in Rivers State.

ii. To study the behavior of GSM network under different traffic load conditions with a view to optimizing the network.

II. MATERIALS AND METHOD

A. Method

The method of Erlang B technique was used in the work. Erlang B technique is a powerful optimization technique in telecommunication field. It has three key parameters: *a*, *b*, and *n* where *a* is the traffic load during the busy hour, *b* is the Blocking probability and *n* is the number of voice channels.

The steps adopted in the analysis are:

i. Choosing Key Performance Indicator (KPI)
ii. Data collection
iii. Data Analysis
iv. Parameter Fine-tuning
v. Implementation

- Choosing Key Performance Indicator (KPI)

To monitor a GSM network, expert often makes use of some important parameters. These parameters are called Key Performance Indicators (KPIs), and they include: Handover success rate, blocking probability, call setup success rate etc. For this work, blocking probability as KPI was chosen.

- Data Collection

This step of the optimization is very important because if data is not collected appropriately, the optimization will not be achieved. For this work, method of data collection was site visitation within Emohua and Obio/Akpor Local Government Areas. Data was collected from the operation and maintenance center (OMC) of the network.

- Data Analysis

Data collected has no meaning unless it is analyzed. Erlang B formula was used for analysis of the data.

- Parameter Fine-tuning

If the analysis of data reveals that some parameters need to be fine-tuned to achieve optimization, such fine-tuning is done. By parameter fine-tuning, new values appropriate for optimization can be found. This step is the most sensitive for optimization engineers [4] and [13].

- Implementation

This step finalizes the optimization process. The new set of values from parameter fine-tuning are then implemented in the system.

B. Determination of Minimum Base Station Required in Rivers State

The following assumption was made to determine the minimum base stations required in Rivers State. There are no environmental restrictions as to where the base stations can be deployed. A cell, in wireless telephony, is the geographical area that a GSM transmitter covers in its transmission of signals. A base station or cell is modeled as a regular hexagon, as shown in Figure 2.

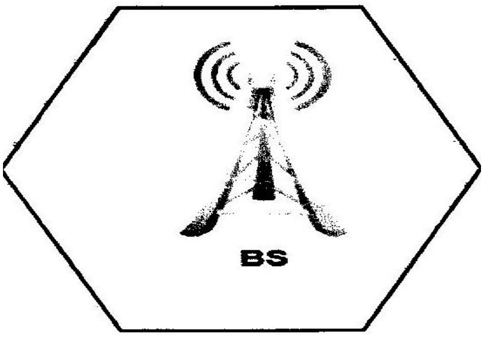

Figure 2: A cell modelled as a hexagon

The area of the hexagon of side R gives the area a GSM transmitted signal covers in the process of transmission. Let a hexagon be divided into 12 equal triangles as shown in Figure 3.

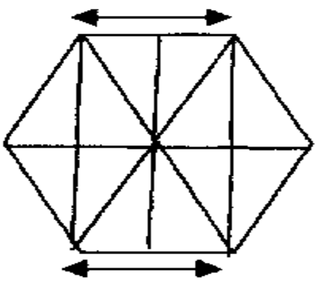

Figure 3: A hexagon divided into 12 parts

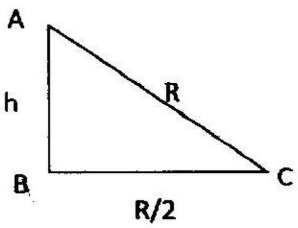

Figure 4: A triangle out of the hexagon

Area of triangle ABC in Figure 4 as in equation (1).

$$A = \frac{1}{2}bh \quad (1)$$

where: b = Base
h = Height

From Pythagoras theorem as in equation (2).

$$h = \frac{\sqrt{3R^2}}{2} \quad (2)$$

where: R = Cell radius

Applying equation (2) into (1) and noting that b = R/2 results in [21]:

$$A = \frac{1}{2} \times \frac{R}{2} \times \frac{\sqrt{3R^2}}{2}$$

$$A = \frac{R^2\sqrt{3}}{8} \quad (3)$$

The area of the cell, A_{cell} is 12A.

$$A_{cell} = \frac{12R^2\sqrt{3}}{8}$$

$$A_{cell} = 2.598R^2 \quad (4)$$

In GSM generally, radius of the cell is influenced by the geographical location [11]. For:

i. Urban areas, radius can be up to 1/2 mile (0.780km).
ii. Residential and business areas (sub-urban areas) radius is between 3 and 4 Km [2], [12-15].
iii. Rural areas, cell radius can be 5 miles (8Km) [11].

A region of total area A_t to be provided with GSM signal will require a certain number of base stations. Let B_{min} be the minimum number of base stations to be deployed, and A_{cell} be the area of one cell, then.

$$B_{min} = \frac{PA_t}{A_{cell}} \quad (5)$$

where: P = Percentage coverage

Putting equation (4) into (5) will become:

$$B_{min} = \frac{PA_t}{2.598R^2} \quad (6)$$

With a knowledge of total area to be provided with GSM network, adequate cell radius and reasonable percentage coverage, then minimum required base station can be found from equation (6).

C. Behaviour of GSM Network Under Different Conditions

Utilizing Erlang B technique helps in determining how GSM network behaves under different conditions. The conditions under which GSM network behavior is to be investigated are:

i. Traffic intensity varies while the number of voice channels remains the same.

ii. Traffic intensity remains constant while the number of voice channels varies.
iii. Traffic intensity is greater than the number of voice channels.
iv. Traffic intensity is less than the number of voice channels.

For the base station that has 56 voice channels with traffic intensity of 20, 30, 40, 50 and 60erl, (CID, 31201), we seek to determine the actual behavior of the system and at what point the system's behavior goes away from normal.

Again, for the five different base stations that have the same traffic intensity of 40erl during a busy hour but with 32, 40 48, 56 and 64 voice channels respectively, we seek to determine the base stations' behavior and the effect on network providers. Also, we seek to determine what happens if traffic intensity is greater than voice channels. Erlang B technique helps to identify what happens under these conditions.

D. Analysis

Erlang B formula states that [2]:

$$b = \frac{a^n}{n!}\sum_{a=0}^{n}\frac{a^i}{i!} \tag{7}$$

where: b = Blocking probability
n = Number of voice channels (resources)
a = Traffic intensity, measured in Erlang

This equation can be used to determine the behavior of GSM network under the conditions listed below.

Condition 1: Traffic intensity varies while voice channels remain the same. Here, we consider a base station with 56 voice channels but the traffic intensity at different times are: 20,30,40,50, and 60erl. Using equation (7), we can find the blocking probability for five different traffic intensity with 56 voice channels each, where $n = 56, a_1 = 20\ erl$.

$$b_1 = \frac{20^{56}}{56!}\sum_{i=0}^{56}\frac{a^i}{i!}$$

Expanding gives $b_1 = 2.09 \times 10^{-11}$. Also, $a_1 = 30, n = 56, b_2 = 6.89 \times 10^{-6}$.

$$b_3 = \frac{40^{56}}{56!}\sum_{i=0}^{56}\frac{40^i}{i!}$$

Expanding gives $b_3 = 3.12 \times 10^{-3}$, $a_4 = 50, n = 56$. Expanding gives $b_4 = 4.58 \times 10^{-2}$, $a_5 = 60, n = 56$.

$$b_5 = \frac{60^{56}}{56!}\sum_{i=0}^{56}\frac{60^i}{i!}$$

Expanding gives $b_5 = 1.40 \times 10^{-1}$.

Condition 2: Traffic intensity remains constant while the number of voice channels varies. Here, we consider five base stations that have the same traffic intensity of 40erl with 32,40,48,56, and 64 voice channels, respectively. Using equation (7), we can calculate the blocking probability for each of the base stations.

$$a_1 = 40, n_1 = 32$$

$$b_1 = \frac{40^{32}}{32!}\sum_{i=1}^{32}\frac{40^1}{1!}$$

From Erlang B table, $b_1 = 2.58 \times 10^{-1}$. Also, $a_2 = 40, n_2 = 40$. Therefore:

$$b_2 = \frac{40^{40}}{40!}\sum_{i=0}^{40}\frac{40^1}{1!}$$

From Erlang B table, $b_2 = 1.16 \times 10^{-1}$. Similarly, $a_3 = 40, n_3 = 48$.

$$b_3 = \frac{40^{48}}{48!}\sum_{i=0}^{48}\frac{40^1}{1!}$$

From Erlang B table, $b_3 = 2.99 \times 10^{-2}$, Also, $a_4 = 40, n_4 = 56$. Therefore:

$$b_4 = \frac{40^{56}}{56!}\sum_{i=0}^{56}\frac{40^1}{1!}$$

Expanding gives $b_4 = 3.12 \times 10^{-3}$.

$$a_5 = 40, n_5 = 64$$

$$b_5 = \frac{40^{64}}{64!}\sum_{i=0}^{64}\frac{40^1}{1!}$$

Expanding gives $b_5 = 1.14 \times 10^{-4}$

Condition 3: Traffic intensity is greater than voice channels. Here, we consider five base stations with 32, 40, 48, 56, and 64 voice channels. Suppose the traffic intensity for each of the base stations is greater than the voice channels in the base stations. Let us assume there are 40,50,60,70 and 80erl traffic intensity respectively for each of the base stations. Using equation (7), we can calculate the blocking probability for each of the base stations.

$$n_1 = 32, n_2 = 40, n_3 = 48, n_4 = 56, n_5 = 64$$
$$a_1 = 40, a_2 = 50, a_3 = 60, a_4 = 70, a_5 = 80$$

Using equation (7) the blocking probability for each base station is:

$$b_1 = \frac{40^{32}}{32!}\sum_{i=0}^{32}\frac{40^i}{i!}$$
$$b_1 = 2.58 \times 10^{-1}$$

$$b_2 = \frac{50^{40}}{40!}\sum_{i=0}^{40}\frac{50^i}{i!}$$
$$b_2 = 2.50 \times 10^{-1}$$

$$b_3 = \frac{60^{48}}{48!}\sum_{i=0}^{48}\frac{60^i}{i!}$$
$$b_3 = 2.44 \times 10^{-1}$$

$$b_4 = \frac{70^{56}}{56!}\sum_{i=0}^{56}\frac{70^i}{i!}$$
$$b_4 = 2.39 \times 10^{-1}$$

$$b_5 = \frac{80^{64}}{64!}\sum_{i=0}^{64}\frac{80^i}{i!}$$
$$b_5 = 2.35 \times 10^{-1}$$

Condition 4: Traffic intensity is less than voice channels. Let us swap the values of voice channels and traffic intensity in condition 3- and see what happens to the network. So, let traffic intensity be 32,40,48,56, and 64 while voice channels be 40, 50, 60, 70, and 80 respectively. Applying equation (7), we can calculate the blocking probability for each base station.

$$a_1 = 32, a_2 = 40, a_3 = 48, a_4 = 56, a_5 = 64$$
$$n_1 = 40, n_2 = 50, n_3 = 60, n_4 = 70, n_5 = 80$$

Using equation (7), the blocking probability for the five base stations will be:

$$b_1 = \frac{32^{40}}{40!}\sum_{i=0}^{40}\frac{32^i}{i!}$$
$$b_1 = 2.68 \times 10^{-2}$$

$$b_2 = \frac{40^{50}}{50!}\sum_{i=0}^{50}\frac{40^!}{i!}$$
$$b_2 = 1.87 \times 10^{-2}$$

$$b_3 = \frac{48^{60}}{60!}\sum_{i=0}^{60}\frac{48^i}{i!}$$
$$b_3 = 1.34 \times 10^{-2}$$

$$b_4 = \frac{56^{70}}{70!}\sum_{i=0}^{70}\frac{56^i}{i!}$$
$$b_4 = 9.71 \times 10^{-3}$$

$$b_5 = \frac{64^{80}}{80!}\sum_{i=0}^{80}\frac{64^i}{i!}$$
$$b_5 = 7.16 \times 10^{-3}$$

III. Results and Discussion

A. GSM Network Behavior at Different Conditions

The behavior of GSM network under different load conditions are presented in Tables 1 through 8 and Figures 5 through 10.

Table 1
Blocking Probability at Various Traffic Load and Constant Voice Channel

BS	a(erl)	N	B
1	20	56	2.09×10^{-11}
2	30	56	6.89×10^{-6}
3	40	56	3.12×10^{-3}
4	50	56	4.58×10^{-2}
5	60	56	1.40×10^{-1}

In Table 1, base stations 1 and 2 have very low blocking probabilities. This means that for traffic load of 20erl or 30erl in a base station, 56 voice channels are too much for that base station, leading to wastage of the voice channels. Base station 3 has blocking probability of 0.00312 which is within NCC recommendation. Therefore, for a base station that has traffic load of 40erl, 56 voice channels are good. However, base stations 4 and 5 have high blocking probabilities that violate NCC recommendation. This happens when voice channels are not enough to take care of the traffic load, leading to over-utilization of the voice channels. Hence, 56 voice channels are small for a traffic load of 50erl and above.

B. Base Stations at Different Level of Coverage

Table 2
Number of Base Stations at 100% Coverage for Different Cell Radius

S/No	R(Km)	$R^2(Km^2)$	Bmin
1	1.00	1.00	4264
2	1.50	2.25	1895
3	2.00	4.00	1066
4	2.50	6.25	682
5	3.00	9.00	474

In Table 2, as the radius increased at 100% network coverage, the number of base stations required reduced. But the decrease in the number of base stations was sharp from 1km radius to 1.5km radius compared to the decrease from 2.5km to 3.0km. So, as the cell radius increases, the decrease in number of base stations reduces.

Table 3
Number of Base Stations at 95% Coverage for Different Cell Radius

S/No	R(Km)	$R^2(Km^2)$	Bmin
1	1.00	1.00	4050
2	1.50	2.25	1800
3	2.00	4.00	1013
4	2.50	6.25	648
5	3.00	9.00	450

Table 3 shows that at 1.00km radius and 95% coverage, base stations required in Rivers State were 4050. At 2km radius the number decreased to 1013 and further decreased to 450 at 3.00km radius.

Table 4
Base Stations at 90% Coverage for Different Cell Radius

S/No	R(Km)	$R^2(Km^2)$	Bmin
1	1.00	1.00	3837
2	1.50	2.25	1706
3	2.00	4.00	959
4	2.50	6.25	614
5	3.00	9.00	426

In Table 4, the number of base stations decreased as the radius increased. At 1.50km radius, base stations required were 1706 but it decreased to 959 at 2.00km radius.

Table 5
Base Stations at 80% Coverage for Different Cell Radius

S/No	R(Km)	$R^2(Km^2)$	Bmin
1	1.00	1.00	3411
2	1.50	2.25	1516
3	2.00	4.00	853
4	2.50	6.25	546
5	3.00	9.00	379

Table 5 shows that with cell radius of 1.00km at 80%, base stations required in Rivers state were 3411 but reduced by about 1895 when radius increased by 0.5km. That is, at 1.5km, base station reduced to 1516.

Table 6
Number of Base Stations at 70% Coverage for Different Cell Radius

S/No	R(Km)	$R^2(Km^2)$	Bmin
1	1.00	1.00	2985
2	1.50	2.25	1326
3	2.00	4.00	746
4	2.50	6.25	478
5	3.00	9.00	332

In Table 6, at 70% coverage number of base stations also decrease as the radius of the cell increases. But the increase is sharp at first but slowly as the radius increases.

Table 7
Number of Base Stations at 60% Coverage for Different Cell Radius

S/No	R(Km)	$R^2(Km^2)$	Bmin
1	1.00	1.00	2558
2	1.50	2.25	1137
3	2.00	4.00	640
4	2.50	6.25	409
5	3.00	9.00	284

Table 7 shows that at 60% coverage and 2.00km radius, about 640 base stations were required in Rivers State. At 2.50km, the base stations were 409, an increase of 231 base stations due to an increase of 0.5km radius.

Table 8
Number of Base Stations at 50% Coverage for Different Cell Radius

S/No	R(Km)	$R^2(Km^2)$	Bmin
1	1.00	1.00	2132
2	1.50	2.25	948
3	2.00	4.00	533
4	2.50	6.25	341
5	3.00	9.00	237

Table 8 shows that at 50% coverage, 1km radius required 2132 base stations while 1.5km cell radius required 948 base stations in Rivers State. At 2.00km radius, the base stations were 533 while at 2.5km radius, 341 base stations were required in Rivers State.

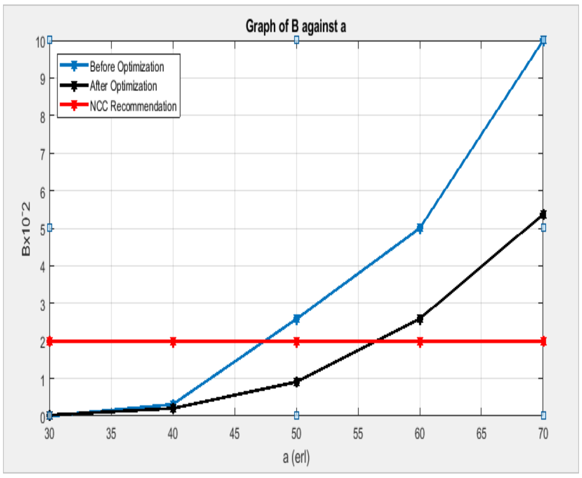

Figure 5: Network behavior for different traffic load at constant voice channel

Figure 5 shows that as traffic load increased at constant voice channel of 56, the blocking probability increased. Before varying the traffic load in the Erlang B equation, there was high number of blocking probability which went above NCC cutoff point, as can be seen from the graph. However, after varying the load in the Erlang B equation, the number of blocking probability dropped considerably, with few numbers of blocking probability above NCC cutoff point.

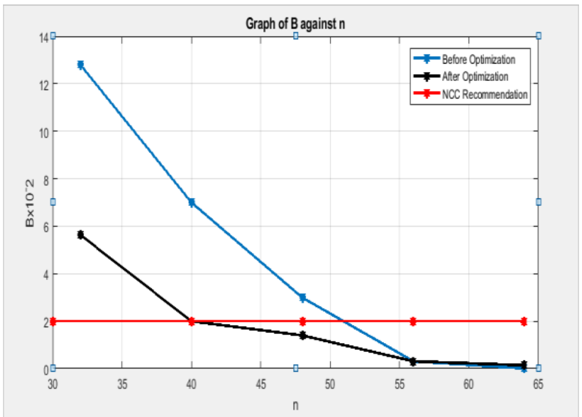

Figure 6: Network behaviour for different voice channels at constant traffic load

Figure 6 shows that the increase in voice channels at constant traffic load reduces the blocking probability and makes the system perform well. As can be seen from the graph, before varying the number of voice channels in the Erlang B equation, the system had high blocking probability far above NCC cutoff point, but the blocking probability dropped after the number of voice channels in the Erlang equation was varied.

Figure 7 shows that the system has minimum blocking probability within the NCC recommendation. The system performed excellently. Therefore, for better performance of GSM network, the graph shows that the voice channels should be greater than the traffic load in any base station. However, the voice channels should not be far greater than or too close to the traffic load.

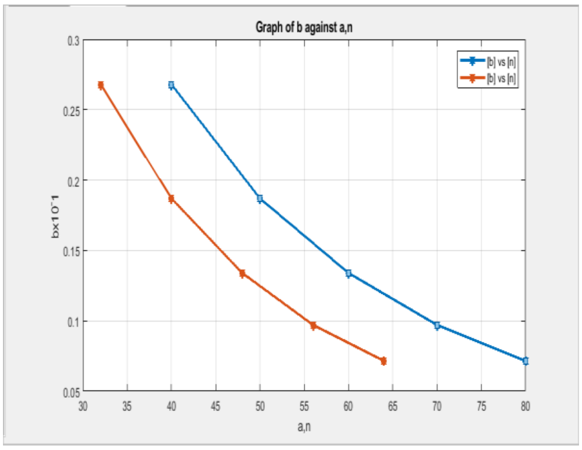

Figure 7: Network behaviour when voice channel is greater than traffic load

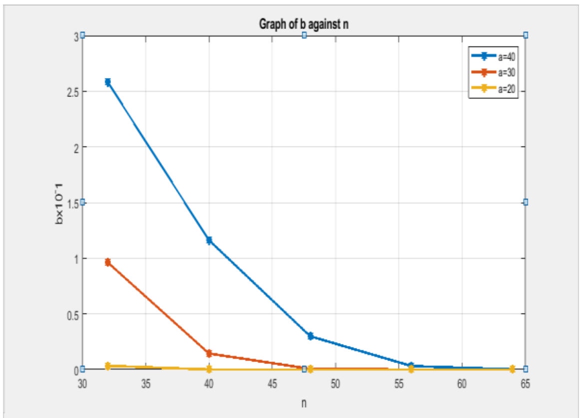

Figure 8: Comparison of network behaviour at different voice channels and constant traffic load

Figure 8 shows that the base station with 56 voice channels has lower blocking probability compared to the base stations with 40 and 50 voice channels. However, up to 35erl of traffic, the base station with 56 voice channels has very insignificant blocking probability, which indicates that 56 voice channels are too much for any base station where traffic load is 35erl. The graph also shows that the base station with 40 voice channels performed poorly beyond 30erl of traffic because blocking probability increased rapidly above NCC recommendation.

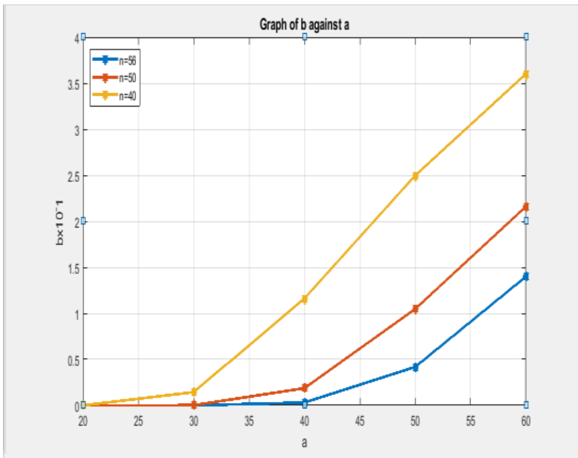

Figure 9: Comparison of network behaviour at different traffic load and constant voice channels

Figure 9 shows that at 20erl of traffic, any base station that has up to 35 voice channels, the channels will be under-utilized, or wasted. However, at 40erl of traffic load, base stations with less than 50 voice channels will result in over-utilization of the channels, causing the system to block many calls.

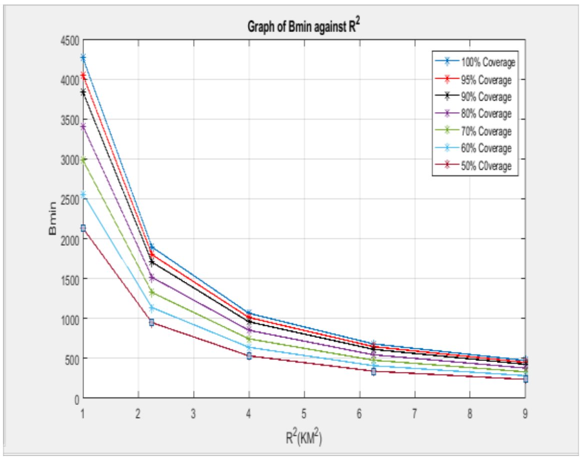

Figure. 10: Comparison of base stations at different level of coverage

Figure 10 shows that 50% coverage has fewest number of base stations followed by 60% coverage, 70% coverage, 80% coverage, 90% coverage and 100% coverage respectively. Therefore, an increase in the level of network coverage increases the number of base stations required in each area. With Rivers State treated as a sub-urban area, and cell radius chosen to be 3km, the graph shows that we could have about 474 base stations to provide 100 percent network coverage.

IV. Conclusion and Recommendation

A. Conclusions

This research work was on optimization of GSM network coverage in Rivers State. The work investigated the behavior of Global System for Mobile Communications Network under different Traffic Load Conditions. The work also aimed to determine the number of base stations required in Rivers State for Effective Network Coverage and to minimize network congestion. The findings showed that the number of base stations required in a place decreases as the cell radius increases. The study showed that at 100% network coverage and the cell radius of 3km, Rivers State would have about 474 base stations.

In the case of network behavior under different conditions, the study found that at constant voice channel, an increase in the traffic load increases the blocking probability, while at constant traffic load, an increase in the voice channels reduce the blocking probability. Furthermore, the study found that for a good GSM network performance, the voice channels in any given base station must be greater than the traffic load. However, the study found that the difference (in magnitude) between traffic load and voice channels should not be too big or too small. If the difference is too small, the voice channels will be over-utilized, leading to blocking probability that violate NCC recommendation; if the difference is too big, the voice channels will be under-utilized or wasted, leading to huge loss to telecom operators and Nigeria.

The study also showed that to fully comply with NCC recommendation, a base station with expected traffic load will have certain range of voice channels. For example, a base station with 20erl of traffic requires between 28-34 voice channels. This will ensure that the channels are neither over-utilized nor under-utilized.

B. Contribution to Knowledge

This research work will guide telecommunication engineers when deploying base stations in each area to avoid flooding the area with base stations where few base stations may be needed. Knowledge of the provided sample computer program to minimize network congestion can really prove helpful to telecom engineers and companies in their quest to improve quality of service (QoS).

C. Recommendations/Suggestions for Further Research

Based on the result of the study, the following recommendations were made:

- Co-location base stations should be very much encouraged as this will ensure effective GSM network coverage without unnecessarily flooding Rivers state with base stations.
- When there is an influx of people to certain area due to crises in other areas, voice channels in area with many people should be increased as quickly as possible.
- Cell-sectoring should be considered in densely populated areas.
- Effort should be made to build base stations in rural areas than flooding urban areas with base stations.

The following suggestions for future research were considered necessary:

- To determine the minimum base stations in Rivers state taking environmental restrictions into account.
- To determine the actual number of base stations in Rivers State.

The urban, sub-urban and rural nature of Rivers state should be taken into consideration rather than treating Rivers state as a sub-urban state only.

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