Improving the Channel Capacity of Wireless Network Using Cell Sectoring

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Abstract: The continuous increase in the cellular mobile users in recent times and the associated impairments in the system has been a lot of concerns to both the users and the network operators. Unlike in global system for mobile communication (GSM) system where the network is bandwidth limited, the universal mobile telecommunication services (UMTS) using CDMA system is interference limited. Both the band limited and interference limited systems has attracted an increase in the number of users that are not given access into the network due to insufficient channels and poor quality of radio channels. This paper looks at the CDMA system and seeks for the appropriate way of enhancing the cellular capacity using cell sectoring. The enhanced cell capacity will go a long way in giving more mobile users access to network by making the optimal use of the available static resource spectrum (channels). The cell sectoring technique utilizes the directional antenna system to reduce the number of interfering users so that co-channel interference which is prevalent in CDMA system is drastically reduced for optimum channel usage. A drive test measurement is carried out on an existing mobile cellular network system with CDMA access technology at the South-East Nigeria. The derived models for the enhancement of cellular capacity through cell sectoring are simulated using Matlab. The results show that the reduction in interference brings about an increase in the number of users that access the network. **Keywords:** CDMA, cell capacity, cell sectorization, co-channel interference reduction, directional antenna, mobility management.

I INTRODUCTION

Cellular system has been the source of joy to many users of communication systems globally because of its ability to provide mobile services to the users. Since system bandwidth is scarce and its capacity cannot be altered, (i.e., increased or decreased) there is the need to make the maximum use of the scarce resource optimally for maximum quality of service (QoS) provision and improved data throughput. The enhancement of cellular capacity network through cell sectoring is one of the techniques used in minimizing the effect of interference in cellular mobile network. In cell sectoring, an already existing cell is partitioned into sectors with each sector being covered by directional antenna that radiates energy in a specified direction unlike the omnidirectional antenna that radiates energy isotropically. The nature of the radiated energy is so defined by the antenna that any user that does not fall within the coverage area (sector) is not affected by the transmitted wave. Therefore any mobile user or base station that is not within the sector covered by the directional antenna cannot interfere with the transmitted signal from the base station being considered [1]. The existing system under study utilizes trisectoral (three-sectored) antenna system where three directional antennas each with beamwidth of 120^0 are deployed. Although appreciable improvement has been attained in terms of network efficiency, there is still the need to further enhance the network capacity and quality of service which have been deteriorating as the number of mobile users continue to increase on daily bases. As the capacity and QoS in CDMA cellular network depend squally on the number of users, it is therefore pertinent to device appropriate technique to be used to further enhance the capacity of the network through the reduction in interference level of the communication channels. To make the system to be more reliable in the provision of efficient cellular system that gives an acceptable grade of service, we deployed hexasectoral (six-sectored) cellular system that utilizes six directional antennas with beamwidth of 60^0. This hexasectoral cellular system provides a good quality of service QoS through the reduction in the interferences which is always prominent in CDMA systems. The models developed to implement the hexasectoral technique is simulated using matlab. The results obtained show that there is appreciable reduction in the interferences in radio channels which result into the enhancement of network capacity in cellular system.

There are other techniques for enhancing the capacity of the network as proposed by [2] where the authors deployed adaptive cell sectoring for improving capacity in the network. They presented an efficient cluster-based Sectoring (CS) algorithm for adaptive cell sectorization to overcome two inefficiencies of computation complexity and frequent boundary crossings by mobile users. From their intensive study, they found that the performance of proposed CS was enhanced while computational complexity was reduced. In their own research, [3] used genetic algorithm approach to dynamically sectorize the microcells to manage the unbalance call distribution in wireless networks. Here the microcell sectorization problem is formulated as an integer linear programming to minimize the call blocking and handoff calls in the network.

II Experimental Setups (Measurements)

In order to achieve the aforementioned objectives, series of measurements are carried out using some existing network infrastructure in Nigeria as a case study. An existing CDMA mobile cellular network is chosen for providing the CDMA technology which this work centres on. Hence the test bed considered is suburban city of Awka South-East Nigeria.

The type of measurement carried is the drive test measurement to obtain some of the parameters that are used in optimizing the channel allocation strategy in this work. The use of an existing network as a case study is to ascertain the performance of the existing mobile infrastructure in Nigeria in a bid to improve on their performance. With the level of performance obtained therein, this work will be able to use the parameters to enhance the capacity of the network in order to optimize the resource spectrum allotted to mobile network providers in South-East Nigeria. The results of the drive test are as shown in Tables 1 and 2 are obtained from the measurement conducted between 29th August and 31st August 2010 respectively.

Table 1: Parameters of the existing base stations (BTs) covered in the drive test

BTs Designation	Transmitter Power (dB)	Remarks
Awka 001	46.0	Transmitting
Awka 002	Not transmitting	Shut down
Awka 003	41.1	Transmitting
Awka 004	38.6	Transmitting
Awka 005	38.6	Transmitting

In the course of the measurement we discovered that one of the five BTs designated to be used was shut for an undisclosed reason. However the transmitting powers of each base station are as obtained from the measurement carried out from the base stations. These power levels shown are the power being transmitted as at the time of taking the measurement. In table 2, R_1X_1 is the received signal strength from one sector, R_1X_2 is the received signal strength from the adjacent sector of the same cell, and SIR is the signal-to-interference ratio of the channels under consideration.

Table 2 Signal measurements at a Single BTs at Awka, (Awka 001)

Distance (m)	R_1x_1 (dB)	R_1x_2 (dB)	TX Power (dB)	$(SIR)_1$ (dB)
100	-71		46.0	-6.54
200	-73		46.0	-6.61
300	-67		46.0	-5.20
400	-64		46.0	-5.85
500	-72		46.0	-7.61
600	-71		46.0	-4.30
700	-78		46.0	-4.69
800	-85		46.0	-7.52
900	-85		46.0	-8.27
1000	-78	-68	46.0	-4.64
1100	-90	-61	46.0	-4.70
1200		-74	46.0	-5.79
1300		-80	46.0	-4.35
1400		-75	46.0	-6.15
1500		-87	46.0	-5.91
1600		-80	46.0	-7.36
1700		-86	46.0	-5.63
1800		-85	46.0	-6.21

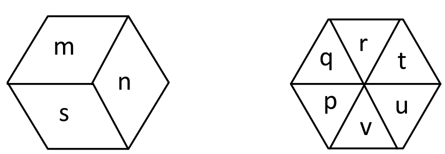
III System Model of the sectored wireless Network

Channel allocation scheme being a technique by which the scarce resource (spectrum) is accessed by mobile users is limited by many factors, prominent among them being interference. The limited scarce resource can be maximized in its usage when all the network users can be serviced at any time with minimal number of channels (resource) used. In order to meet up with the increase in demand (i.e., capacity) of the wireless system resource, there should be the need for efficient work plan for reusing the assigned channels within each band of frequencies. Therefore, channel allocation is always related to the network capacity in terms of number of available channel and system configurations. High capacity systems based on the reuse of allocated channel in a cellular planned network are highly deployed in this work. The capacity of the network which can be influenced by the number of times a channel is reused, will give the optimal allocation of the channels in any cell. For the high capacity to be achieved, several techniques can be developed to achieve its optimality. In this session, some of the techniques that can be used in enhancing the capacity of the network thereby providing adequate allocation strategy in the available scarce resource are treated in this work, cell sectorization inclusive.

The primary objective of this work is to maximize the available network spectrum so that system capacity will be enhanced for optimal assignment. Recent cellular systems employ cell sectoring to improve on the channel capacity by reducing co-channel interference. Cell sectoring is all about dividing the entire existing cell circumference into a number of contagious sectors so that each sector will cover a specific area of the sphere where the users within these spheres will access the network through the sector (see figure 2). Two factors call to mind when sectorization is mentioned. One of the factors is all about the number of sectors that make up a cell, while the second is the beam-width of the antenna that covers the sector of the cell. The antenna that can be used to cover the sector is a directional in nature in the sense that it focuses signals in a specific direction that is always defined by the beam-width. In cell sectorization, one channel can be reused in the other sectors that make up the cell while co-channel interferences are reduced by the number of times the sectoring is made. Hence, the more the number of sectors in a cell, the lesser the number of interfering signals in the system. Most of the recent existing base stations (cells) in use in South Eastern region of Nigeria have three sectors per cell. This means that the hexagonal cell is divided into three sectors, making it possible for each sector to have a beam-width of 120^0. That is to say that beam-width (B_w) is the ratio of 360^0 to the number of sectors (N_s) per cell. Therefore,

$$B_w = \frac{360^0}{N_s} \qquad (1)$$

The recent cellular mobile systems use three (tri-sectoral) 120^0 antennas to cover one cell, while a six- sectored (hexa-sectoral) cellular system using six 60^0 antennas at a cell site is proposed in this work. Alternatively, radiation pattern may be used in finding the beam-width of the sector. As we employ hexasectoral 60^0 antenna system in this work, other factors that can influence the efficiency of the cell sectoring are taken into consideration. Since the more the increase in the number of sectors, the more the reduction in the number of the interfering signals. Therefore, equipment and operational cost of the system (i.e., installation of more antennas and other operation management cost) should always be taken into consideration.



(a) : 120^0 sectored cell (b) : 60^0 sectored cell

Figure 1: Cell sectoring in cellular system with antenna beamwidths of 120^0 and 60^0

The CDMA technology does not require a frequency planning scheme as in the AMPS, FDMA and GSM because each sector uses the same carrier frequency and identifies itself via the pseudo-random number sequences. Softer handoff is used for inter-sector roaming and soft handoff is used for inter-cell roaming. CDMA tele-traffic capacity is interference limited, unlike the conventional technologies whose tele-traffic capacity is limited by the channel allocation. Therefore the CDMA system efficiency can be measured by the number of users that access the network in a particular time simultaneously. Hence it can allow unlimited number of users as long as the signal to interference ratio threshold is not exceeded. Cell sectoring tries to provide the needed strategy to develop the models required to improve the channel allocation efficiency in cellular network [5].

To model the cell sectorization technique in improving the channel allocation in wireless network, several assumptions are made. They include;

(i) There are uniform load in all the sectors; i.e., all the six sectors has equal number of channels at a particular period.

(ii) Only Base station-mobile station (downlink) direction is considered.

(iii) Two tiers of co-channel interferers are considered

(iv) There is a perfect power control, i.e., all the mobile stations receive equal power irrespective of their positions in the cell. Hence near-far effect is neglected.

If the number of co-channel interfering cells is denoted by N_i and I_i be the interference power caused by transmissions from the i th interfering cells. The SIR at the desired mobile receiver is given by

$$\frac{S}{I} = \frac{S}{\sum_{i=1}^{N_I} I_i} \qquad (2)$$

where S is the signal power.

However, the total interference power from co-channel cells and interferences from other sectors constitute the aggregate interference that degrades the QoS. If the distance D_i between the i th interferer and the mobile unit, the received interference power I_i at a given mobile unit due to the i th interfering cells. The SIR at the desired mobile receiver is given by [4]

$$\frac{S}{I} = \frac{r^{-k}}{\sum_{i=1}^{N_I} (D_i)^{-k}} \qquad (3)$$

where D is the distance between the adjacent cell, k is the path loss exponent of the environment, r is the distance between the mobile station and the serving base station, N_I is the number of interfering sectors which is dependent on the type of antenna used. In the hexagonal cell, using omnidirectional antenna, the number of interfering cell is six. But using directional antenna for a six-sector of 60^0 antenna beamwidth, the number of interfering cells is reduced to one. S is the desired received signal power which is proportional to $r^{-3.5}$ if the path loss exponent is taken to be 3.5. The degree of co-channel interferences in a cell is a function of the location of the mobile station within the cell of the serving base station. The worst case of the interference occurs when the mobile unit is at the fringe of the hexagonal cell (i.e., $r = D$). The models derived in terms of interference mitigation for simulation in the course of optimizing the capacity of wireless networks is given by equation 3.

In sectorized cell employing directional antenna, the number of interfering sectors to the transmitting sector is a function of the beamwidth of the antenna. Therefore, in a six sector, 60^0 antennas the $\frac{N_I}{6}$ number of interfering sectors are experienced by the transmitting sector.

In CDMA system, all sectors contain the same frequency spectrum so that all the channels can be accessed by the users from any cell. In this case, any channel that is in use in any sector cannot be used in other sectors of the same cell and other sectors that face the sector being considered simultaneously. Hence reuse factor is unity. Using omnidirectional antennas, the first tier interfering co-channel cells is 6, while in the second tier the number of interfering cells increase to 12 etc. In other words, using directional antenna of 60^0 beamwidth in a sectored cell, the number of interfering cells drastically reduced in the first tier interfering sectors to one, while about three interfering sectors occur in the second tier. Then the SIR in the worst case (where $r = R$), and the co-channel interference from the second and other higher tiers is given by

$$\frac{S}{I} = \frac{\left(D/_R\right)^k}{N_I} = \frac{q^k}{N_I} = \frac{\sqrt{(3N)^k}}{N_I} \quad (4)$$

where $q = D/_R$

Therefore the frequency reuse factor q can be expressed from equation 4 as

$$q^k = N_I \times \frac{S}{I}$$

$$\therefore q = \left(N_I \times \frac{S}{I}\right)^{1/k} \quad (5)$$

For omnidirectional antenna system, $N_I = 6$ for the first tier interferers,

$$q = \left(6 \times \frac{S}{I}\right)^{1/k} \quad (6)$$

It must be noted that identical sectors of adjacent cells in CDMA system contain the same channel frequency. So, interference occurs with only the channels in the identical sectors as shown in figure 2.

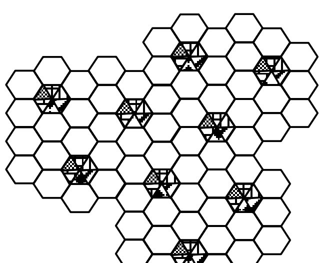


Figure 2: cellular system showing the co-channel sectors in co-channel cells

It is therefore possible to determine the reuse factor for the sectored cell taking the acceptable threshold value of SIR to be 10dB for CDMA network. For a system to work effectively, the SIR must be ≥ 10dB [5]. Therefore, in dynamic channel allocation (DCA), the MSC is always furnished with the signal quality status of all the channels in terms of their SIR. This will hence enhance the ability of MSC to allocate channels to the deserving users when such demands are made. However, an algorithm is developed to dynamically allocate channels when the frequency reuse constraints are met as shown in figure 3 (Call termination and reallocation procedures for distributed DCA).

For evaluating the capacity of a CDMA system, a single cell (Awka 001) is considered. Therefore the analysis of this single cell will represent those of other three BTs in operation. The mobile cellular system consists of a large number of mobile users communicating with a base station through which other mobile users are reached. In multiple cells system, all the BSs are interconnected by the mobile switching centre (MSC). However, for a single cell under consideration, weighting factors are assumed to be equal. It is also assumed that the signals on the reverse channel are received at the same power level at the base station (i.e., perfect power control), and that on the forward channel equal signal power is transmitted by the base station to the mobile stations. Another assumption is that signals are consistently being transmitted.

A signal power received from the candidate mobile station (i.,e., the desired signal power) is

$$S = RE_b \quad (7)$$

where R is the information bit-rate. The interference power is

$$I = B_w I_o \quad (8)$$

where B_w is the system bandwidth and I_o is the interference-plus-noise spectral density. If it is considered that the expression for the number of mobile stations is related to bit-energy-to-interference ratio E_b/I_o based on the conditions stated previously. Therefore, the signal-to-interference ratio is given by

$$\frac{S}{I} = \frac{RE_b}{B_w I_o} \quad (9)$$

$$= \frac{1}{G_p}\frac{E_b}{I_o}$$

Or

$$\frac{E_b}{I_o} = G_p \frac{S}{I} \quad (10)$$

where $\frac{B_w}{R}$ is the processing gain G_p. Remember that interference in the system is the combination of intracell interference, intercell interference and background noise. Therefore, the interference received at the base station from mobile users within the cell $(N_m - 1)$ each interfering user having equal power of S . The intracell interference power from other users is $(N_m - 1)S$, where N_m is the total number of mobile users within the user's base station. Also, considering the number of neighbors in the other tiers of the cellular system, the total interference (intracell interference and intercell interference) normalized to the total intracell interference is give by ε_f . Then the total interference power is

$$I = [(N_m - 1)S] \times \varepsilon_f \quad (11)$$

Thus, the signal-to-interference ratio is given as

$$\frac{S}{I} = \frac{S}{[(N_m - 1)S]\varepsilon_f} \quad (12)$$

If the background noise, n_b, is considered, then, the signal-to-interference plus noise ratio, $\frac{S}{I}$, shall become

$$\frac{S}{I} = \frac{S}{[(N_m - 1)S]\varepsilon_f + n_b} = \frac{1}{(N_m - 1)\varepsilon_f + {}^{n_b}/_S} \quad (13)$$

From equation 10,

$$\frac{E_b}{I_o} = G_p \frac{S}{I} = \frac{G_p}{(N_m - 1)\varepsilon_f + {}^{n_b}/_S} \quad (14)$$

Therefore the number of mobile user, N_m, (capacity of the network) is

$$N_m = 1 + \varepsilon_f \left[\frac{G_p}{E_b/I_o} - \frac{n_b}{S} \right] \quad (15)$$

Equation 15 assumes an omnidirectional (only one sector) antenna and the same type of traffic in the same cell. However, with imperfect power control, variation in voice activity factor, α, and the number of cell sectors, N_S, that results in the use of directional antenna taken into consideration, the total interference is reduced drastically but the background noise remain the same. Therefore, the new total interference and noise, I_T, shall be

$$I_T = \alpha[(N_m - 1)S \times \varepsilon_f] + n_b \quad (16)$$

When the number of sectors, N_S, are also considered, the average interference power and noise received from the mobile station will give the new signal-to-interference plus noise, I_{in}, which shall be

$$I_{in} = \frac{I_T}{N_S} = {}^{\{\alpha[(N_m - 1)S \times \varepsilon_f] + n_b\}}/_{N_S} \quad (17)$$

Then signal-to-interference plus noise ratio SINR (S/I_{in}) is

$$\frac{S}{I_{in}} = \frac{S}{{}^{\{\alpha[(N_m - 1)S \times \varepsilon_f] + n_b\}}/_{N_S}} \quad (18)$$

$$N_m = 1 + \frac{\varepsilon_f}{\alpha} \left[\frac{N_S G_p}{E_b/I_o} - \frac{n_b}{S} \right] \quad (19)$$

Besides if the capacity degradation factor, c_d, due to imperfect power control in CDMA system, the number of mobile users in the cellular setup shall be obtained by modifying equation 19 to arrive at

$$N_m = 1 + \frac{c_d \varepsilon_f}{\alpha} \left[\frac{N_S G_p}{E_b/I_o} - \frac{n_b}{S} \right] \quad (20)$$

When the background noise is neglected, the number of the mobile users is given by

$$N_m = 1 + \frac{c_d \varepsilon_f}{\alpha} \left[\frac{N_S G_p}{E_b/I_o} \right] \quad (21)$$

The voice activity factor α in cellular networks is assumed to be $3/8$ sectored cells inclusive [4]. This shows that equation 21 demonstrates that the SIR increases by the factor of eight, which leads to an eightfold increase in the number of users compared to an omnidirectional antenna system without voice activity detection.

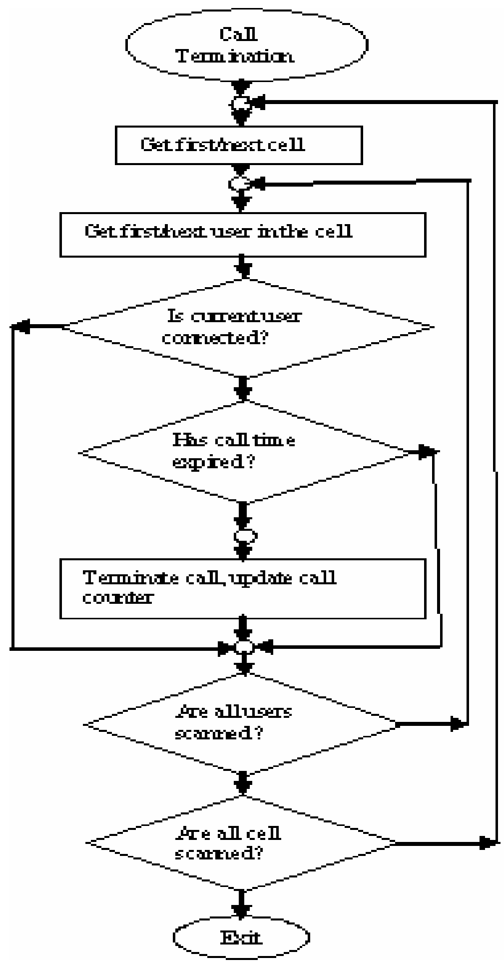


Figure 3(a) Call Termination

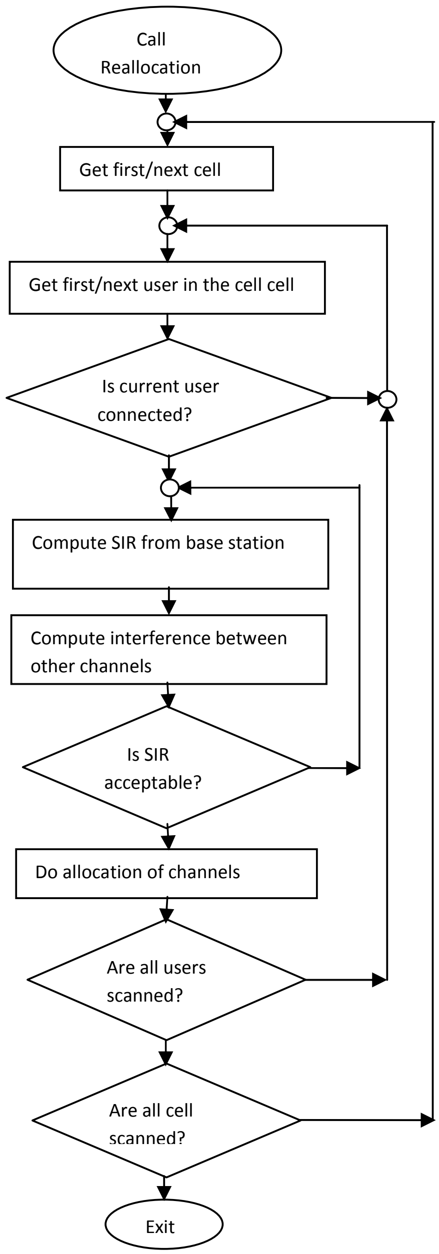


Figure 3(b) Call Reallocation

IV Simulations Results and analysis

In simulating the cell sectoring technique for the improvement of channel capacity, the main aim of achieving the goal is to monitor the interference levels of all the mobile users in the network. This will help in forming the building blocks for which the least interfered channel is allocated to the mobile user under consideration. The developed matlab codes are used to arrive at the SIR Vs number of mobile users' relationship graphically as shown in figure 5. From the graph it can be found that when the SIR is improved as a result of the reduction in interference without necessarily increasing the signal power will definitely allow more users to access the network. Therefore, the number of mobile users is shown to increase as the SIR is improved upon. It is important to note at this juncture that only one cell site is considered in this analysis although four base stations are covered during the measurement.

Comparatively, the study of the tri-sectored and hexa-sectored cells can be done in relation to non-sectored (omnidirectional) cells when a number of interfering base stations are considered. In this work a 7 cell cluster where the number of interfering cells is reduced to two is considered. The graph of figure 4 gives the vivid analysis of the comparison between the effects of interfering signals on the mobile users in wireless networks (i.e., the effect of the frequency reuse factor over the SIR). It can therefore be inferred that as the beamwidth decreases, the interfering users from other sectors are reduced thereby enhancing the capacity of the network. Figure 5 shows the variation of channel capacity with SIR with respect to various types of sectored cell when background noise is taken into consideration. Besides, figure 6 shows how the channel capacity is enhanced with the six-sectored antenna system without the background noise taken into consideration.

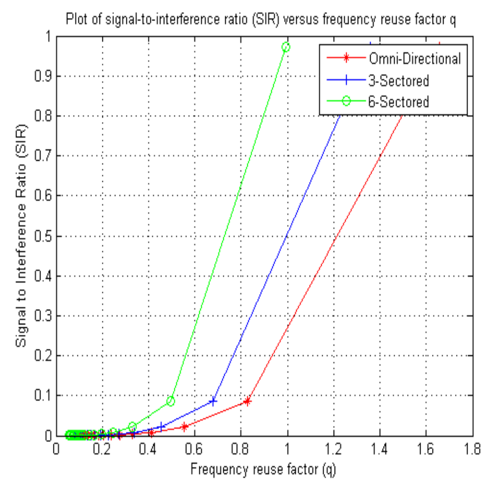


Figure 4: Plots showing SIR versus frequency reuse factor (q) for 360^0, 120^0 and 60^0 antennas beamwidths.

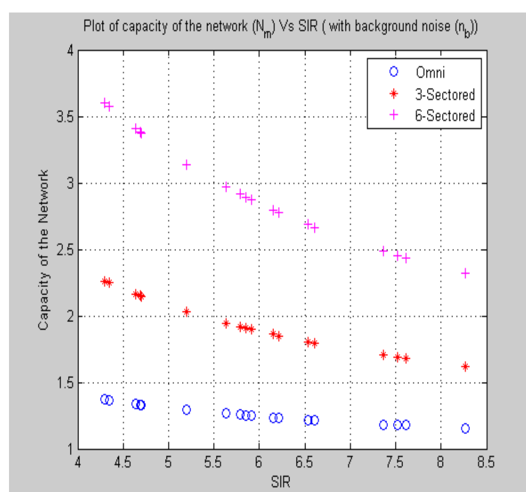


Figure 5: Plot of the network Capacity Vs the SIR for various sectored cell with back-ground noise

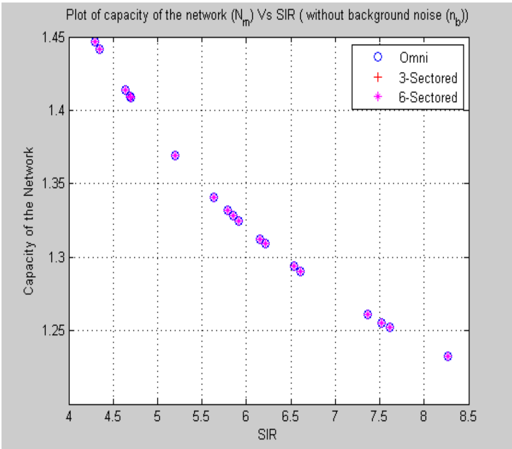


Figure 6: Plot of network Capacity Vs SIR for 6 sectored antenna without background noise.

5.0 Conclusion

Enhancement of cellular capacity being one of the cardinal objectives of any network operator has always taken the fore front in the analysis of network system in recent times. Hence the sectorization technique embarked upon in this work has complimented the efforts of other authors in finding the lasting solution to the seemingly unending problem of network congestion in Nigeria. Therefore the results obtained in this work has shown that with the deployment of 6-sectored cell technique, the signal-to-interference ratio has been improved drastically which translates into the reduction in the number of interfering mobile stations and base stations in CDMA wireless network. The reduction in the number of interference gives access to more mobiles users thereby increasing the capacity of the network. A slight improvement is attained when the background noise is reduced to the barest minimum since it cannot be removed completely. It can therefore be inferred that hexa-sectoral (6-sectored) cellular system is used in place of the three sectored system to combat the problem of network congestion and instability.

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