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Development of Enhanced Dynamic Cell Sectorization Scheme for Improved WCDMA Network Capacity

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Abstract
Wideband Code Division Multiple Access (WCDMA) technology has provided a great multiple user interfaces to third generation (3G) wireless network mobile users. The existing cell sectoring scheme with directional (sector) antenna deployment lacks the capacity to mitigate the problem of Multiple Access Interference (MAI), interference from adjacent or nearby cell, and sudden increase in number of users that tend to exhaust the system capacity. Empirical measurements were taken from a third generation (3G) wireless network situated in Enugu metropolis South East Nigeria to determine the basic network configurations and the channel capacity of the existing sites. An Enhanced Dynamic Cell Sectoring (EDCS) model was also developed to improve on the multi-user system capacity. The measured data was deployed in the developed models using a three twin-beam sector antenna concepts to demonstrate how the new scheme added to capacity of the network. The model was simulated using matlab and the result obtained proved that replacing directional antennas with twin-beam sector antenna, the WCDMA capacity increase per sector would be of the ratio of 1:2, with decrease in sector overlap of 3.69%, thereby providing double capacity increase with less handover when compared with the existing cell sectoring scheme.

Keywords: Network Capacity, Multiple Access Interference (MAI), Wideband Code Division Multiple Access (WCDMA), twin-beam sector antenna, Enhanced Dynamic Cell Sectorization (EDCS).

1. Introduction

Wideband Code Division Multiple Access (WCDMA) technology usage was found more prominent in third generation (3G) wireless communication network. The technology acts as an interface for mobile users accessing the network simultaneously. In South East Nigeria, a Mobile Telecommunication Network (MTN) uses WCDMA technology in providing wireless communication services to its subscribers at EN0618 Base Transceiver Station (BTS) Enugu, Enugu State. The BTS uses cell sectoring scheme with the deployment of directional (sector) antenna which lacks capacity to mitigate the problem of Multiple Access Interference (MAI), interference from adjacent or nearby cell, and sudden increase in number of users that tend to exhaust the WCDMA system capacity.

Due to high cost of deployment of fourth generation (4G) network which was based on Orthogonal Frequency Division Multiple Access (OFDMA) technology, led to the development of new strategies that help the existing structure to improving on the system capacity. An Enhanced Dynamic Cell Sectoring (EDCS) Model was developed using twin-beam sector antenna concepts to improve on the WCDMA network capacity. The developed scheme was a better improvement with high increase in cell capacity when compared with the existing cell sectoring scheme. This was because the concept of twin-beam sector antenna used in the modelling dynamically repartitions a sectorized network into two equal sizes without deploying extra antennas thereby reducing interference by 1/6 for

120-degrees sector. With the adjustment of either the processing gain or other parameters in the analytical model, and use of the twin-sector antenna, the network provided greater traffic and coverage.

1.1 Review of Related Literatures

Boor-Oyibo, (2011) investigated the performance of antennas for mobile base station applications and techniques for improving the coverage and capacity within a base station cell. A novel smart antenna system incorporating an array of slant $\pm 45^{\circ}$ dual-polarized stacked patch elements of four columns wide excited by a novel multi-beam forming and beam shaping network were designed, simulated and implemented. The result indicated that sector capacity could be dynamically tailored to user demand profiles by the selection of the appropriate beam pattern provided by the novel smart antenna which in turn improved the system capacity of the cellular systems.

Mohan and Ravichandra, (2012) studied the interference that was produced by different factors such as thermal noise, intra cell traffic in adjacent cells in cellular system and how to control it. The work developed an Interference Revocation Technique in WCDMA systems using cell resizing approach. The approach classified Access Point (AP) into three types; as normal, saturated and corporate based on its Signal to Noise Ratio (SNR). The saturated cell triggers the process of cell resizing. This approach balanced the number of user in each cell and thereby cancels the interference completely. The technique equally increased the average throughput of each cell considerably

Ohaname, et al., (2012) researched about CDMA system and provided for appropriate way of enhancing the cellular capacity with the enhanced cell capacity that would go a long way in giving more mobile users access to network by using available static resource spectrum (channels). The cell sectoring technique deployed in the design utilized the directional antenna system to decrease the number of interfering users so that co-channel interference which is major factor in CDMA system was drastically reduced for optimum channel usage. Directional antenna deployed in this technique possess frequent handover as in the case of 30^{o}, 60^{o} and 90^{o} sector antenna system and less handover with 120^{o} sector antenna system.

Sohrab, et al. (2013) analyzed the performance of CDMA scheme in telecommunication system by using cell splitting technique to divide a large macro cell into micro or pico or femto cells. The authors calculated the processing gain, number of users requesting for service within each type of cell, user- transmitted in-band signal power to achieve desired Signal to Noise Ratio, probability that a call attempt fails and also compared the results by simulating the developed models using simulation software. The result showed that the scheme was good but the researcher failed to show whether the system was implemented in real time. The cost of building a new base station as in the case of this technique requires high cost, and more handover.

Sheu, Lyu and Lyu (2014), investigated the cell sectorization and power management scheme for Multiple Input Multiple Output (MIMO) systems. The investigation revealed that both the signal strength and interference quality greatly depend on the layout of cell sectorization. The results found that Diamond Shaped Frequency Reuse (DSFR) was better than the Triangular Shaped Frequency Reuse (TSFR) in the consideration of minimizing the interference of MIMO transmission.

Elechi, (2014) worked on an improved voice/data traffic performance using an SINR based on call admission control on the mobile to base station link , and a Large Range Dependent (LRD) variables was carried out. The result showed significant performance improvement in both data and voice traffic of mean delay as well as Erlang capability using Signal-to-Interference-plus-Noise Ratio (SINR) based admission control. The result also showed that the number of subscriber's voice/data that can be supported by the trunk during the busy hour for a specified blocking probability is 2% to 3%.

Mekonnen, (2016), evaluated the performance of smart antenna systems and its viability for deployment in the major 3G networks of Ethiotelecom. The performance of adaptive smart antenna using Constant Modulus Algorithm (CMA) and Least Mean Square (LMS) Algorithm was investigated which enhanced the overall mobile communication system capacity through suppressing the signal. A business case analysis for the conventional antenna and smart antenna based telecom system was studied in a comparative manner in which the result indicated that deployed smart antenna base station in the major 3G in Addis Ababa was feasible i.e. a range increased, capacity increased, number of base station reduced, Capital expenditure (CAPEX) and Operational Expenditure (OPEX) reduction help in recuperating the capital invested in the infrastructure with the deployment of smart antennas.

Haslett, (2017) in a paper titled ''The Capacity Crunch-Is the Revolution About to Begin?'' critically reviewed possible route to take to increase network capabilities in Long Term Evolution (LTE) cellular system. The paper found that active antenna could have a huge part to play in meeting the data demands of subscribers in the future, especially when deployed alongside LTE. Deploying active antenna system eliminated the need for costly and inefficient coaxial based systems. Almost all aspect of mobile radio base stations has improved as a result of the deployment of active antenna systems. The only component for which the performance gets worse is the duplexer. They have become worse, by necessity, smaller, but this has been accompanied by dramatic increase in loss. The author has addressed loss with the development of the (xCubeTM) -a small, cool running, low loss, high performance filter. This active antenna delivered those 65% capacity improvement that operators desperately needed.

After reviewing several literatures, the following research gaps were identified in different schemes deployed in improving WCDMA system capacity.

- Frequent Handoff associated with cell splitting scheme,
- Limited areas of application in the application of microcell zone ,
- False locking with shadowing and wide angular spread associated with smart antenna scheme, and
- Higher number of antenna required in the deployment of cell sectoring scheme.

The developed enhanced dynamic cell sectorization scheme improves the WCDMA system capacity with the concept of twin-sector antenna. The scheme if used with three-twin sector antenna yields six sectors instead of three sectors as the case of conventional cell sectoring scheme. This in-turns reduces the cost of antenna deployment as six antenna would have been required in the conventional six sector network, more users would be accommodated which reduces Signal to Interference ratio (SNR) , there would be reduction in handover and improvement on the overall coverage of the wireless network system.

2.0 Material and methods

This research dealt with the development of Enhanced Dynamic Cell Sectorization (EDCS) model for improved capacity of WCDMA network. In order to develop this model, series of measurements were carried out using existing 3G-EN0618 Wideband-CDMA (WCDMA) networks belonging to MTN Nigeria in urban city of Enugu, South East. Sweep test was conducted to determine the type of sectorization in use, current capacity of the network and the type of antenna in use while PL4 file data was collected to note the configurations of the base station. The essence of using an existing WCDMA network as an experimental testbed was to be able to verify the performance of the existing mobile network in Nigeria with a bid to improve on its performance. Using the level of performance obtained from the field tests, this work utilized the empirical data collectedto improve the capacity of the wireless network.

More so, the formulation and calculation of the maximum capacity in WCDMA cellular networks was done by modifying the existing capacity equation of WCDMA network using the concept of sectorization. A capacity enhancement expression was also presented using twin-beam antenna concept. The performance evaluation was done using MATLAB simulator. The evaluation of the Quality of Service (QoS) and performance was done through a programming simulation to analyse the relationship between Signal to Noise Ratio (SNR) and the antenna radiation pattern. Another simulation process was done to compare the increase in capacity, and enhanced performance of the network in the case of single cell traffic and multi cell traffic cases.

2.1 Sweep Test Results

The figure 1 below shows that the 3G wireless network located in Enugu with the code EN0618 operates with three sectors 120-degrees cell sectorization scheme. Each 120-degree sector has different signal strength; sector A has 110 user per sector, B with 323 user per sector and C with 475 user per sector. These show that the wireless system has a varying capacity and sector C with the highest number of user per sector was due to the peculiarity of that area. The BTS was quite dynamic in that whenever there’s increase in mobile users more than the capacity at a particular sector, the system can be reconfigured by adjusting the processing gain and the antenna. The adjustment would require the presence of the Wireless Service Provider (WSP) technical personnel at the BTS.

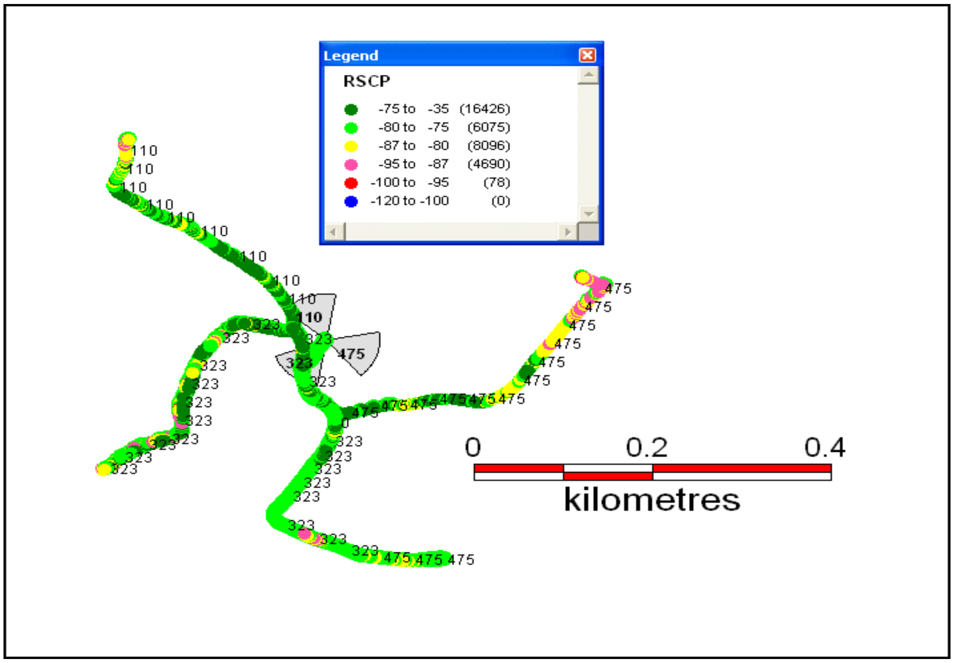

Figure 1: Received signal level from EN0618

2.1.1 PL4 File

The PL4 file is the data stored inside the wireless network system at the base transceiver station where the basic configurations of every system are obtained. Part of the WCDMA basic configurations at 3G-EN0618 MTN located near Park Lane Hospital Enugu is as shown in Table 1 below.

Table 1: PL4 File Obtained

Frequency	2300MHz
Sectorization factor	3
Energy per Bit (Eb/No)	2dB
Voice activity factor	0.375
Over All Processing Gain	226dB
Bit-to-Energy Ratio (BER)	7dB
Signal Power (Ps)	40dB
Thermal noise	-
Antenna height	30m

2.2 System Modelling

2.2.1 Enhanced dynamic cell sectorization (EDCS) model

A six-sector site application splits each of the original 120-degree coverage areas into two sectors, each served by a separate narrow beam antenna with a nominal azimuth beam-width of 60 degrees and above. If properly done, the model reduces the overlap interference by 1/6 for 120-degrees sector, pilot pollution and soft hand-off areas; all of this contribute to more efficient spectrum reuse and increase capacity.

The capacity and performance enhancements gained by implementing higher order sectorization are often undermined by the real cost of implementation. By definition, transitioning from a three- to a six-sector design doubles the number of antennas that must be purchased and increases many of the associated costs, including packaging, transportation and installation.

The Enhanced Dynamic Cell Sectorization scheme incorporates a “twin-sector antenna that alters the cost/benefit playing field for six-sector deployment. The scheme uses three-twin beam antennas to achieve higher-order sectorization without additional antennas. That is to say twin-sector antenna yields six sectors without deploying six sector antennas as the case of conventional six sector concepts using cell sectoring; this would drastically reduce the cost of antenna deployment. A cell partitioned into 120-degrees (3sectors) provides 60 to 65-degrees azimuth with beam-width of $\pm$ 45-degrees dual polarizations produces six (6) sectors as shown in figure 2 below. The technology effectively removes the major cost and a time barrier associated with six-sector deployment and provides a capacity-generating solution that wireless service providers can deploy immediately. Figure 2 below shows architecture of a twin-sector antenna system.

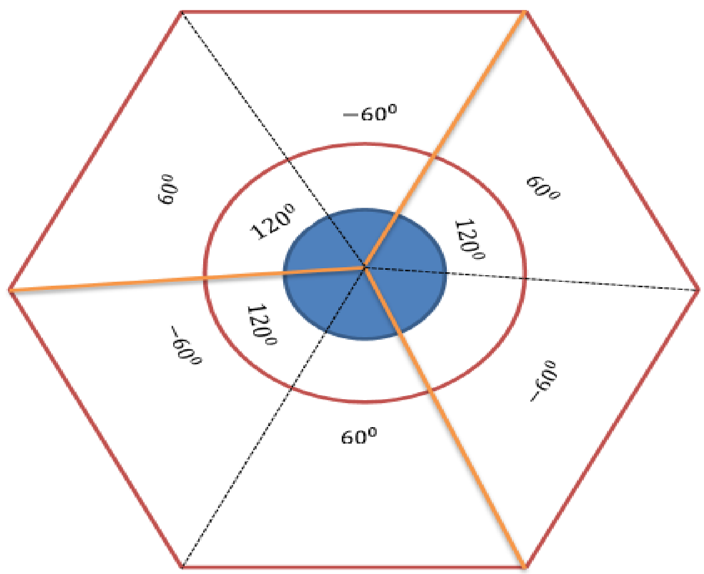

Figure 2: Architecture of three-twin sector antenna.

The twin-sector antenna provides a theoretical doubling of the sector capacity. Each antenna produces two separates narrow azimuth beam whose positions are directed at +60 and -60 degrees of the antenna bore sites.

(Ayyappan and Kumar, 2010) Description of any wireless network capacity without the mention of the Shannon’s law seems incomplete. Shannon’s law may refer statement defining the theoretical maximum rate at which error-free digits can be transmitted over a bandwidth-limited channel in the noise presence. According to Shannon’s Law, increasing capacity in a given bandwidth requires Wireless Service Providers (WSP) to improve the signal-to-noise ratio and/or increase frequency reuse. WCDMA is an interface limited system and therefore the capacity of the system is linearly proportional to any reduction in the interference.

The capacity of WCDMA system is an important parameter in Universal Mobile Telecommunication System Networks. The capacity of WCDMA system is basically determined by signal to noise ratio or mostly said E_b/N_o (Bit energy to effective noise power spectral density) and by the processing gain of the system. The processing gain is defined as the ratio of the spreading bandwidth of the system to the data bit rate for the selected application i.e. voice, data & multimedia etc. The interference is already included in noise power spectral density and can be self-interference, co-channel interference and multi-access interference.

Now in order to derive the expression for capacity i.e. the number of user in a cell of WCDMA system, it is assumed that there are K number of users accessing the network at same frequency simultaneously and each user has its own PN code sequence. Now if P_s is the signal power, W is the bandwidth of spreading (PN) code sequence, R_b is the data bit rate; E_b is the energy per bit, N_o is noise power spectral density, then energy per bit can be written as

$$E_b = \frac{P_s}{R_b} \quad (1)$$

And the SNR (E_b/N_o) is given as

$$E_b/N_o = \frac{P_s}{N_o . R_b} \quad (2)$$

But N_o is noise power spectral density and it's defined as the interference power per unit spreading bandwidth, it is given as

$$N_o = P_I/W \quad (3)$$

Combining Eq. (2) and Eq. (3) together

$$E_b/N_o = \frac{P_s}{\frac{P_I}{W} . R_b} = \frac{P_s}{P_I} . \frac{W}{R_b} \quad (4)$$

The processing gain (P_G) is defined as the ratio of the spreading bandwidth of the system to the data bit rate for the selected application, and it is given as W/R_b . Therefore Eq. (4) becomes

$$E_b/N_o = \frac{P_s}{P_I} . P_G \quad (5)$$

Taking the thermal noise (n) into account and assuming that the signal power of all users is the same and the spreading sequence of all users has the same rate, then the equation for capacity in terms of number of users is given as (Ayyappan and Kumar, 2010)

$$\frac{P_I}{P_s} = (K - 1) \quad (6)$$

But from Eq. (5) it follows that

$$\frac{P_I}{P_s} = \frac{P_G}{E_b/N_o} \quad (7)$$

Substituting Eq. (6) into Eq. (7), then

$$(K - 1) = \frac{P_G}{E_b/N_o} - (n/P_S)$$

$$K = 1 + \frac{P_G}{E_b/N_o} - (n/P_S) \quad (8)$$

Equation (8) was the basic capacity equation which determines the number of users in a WCDMA cell. This equation completely depends upon the processing gain P_G and E_b/N_o ratio. The capacity of a WCDMA system can be increased or decreased by adjusting the value of processing gain P_G and E_b/N_o. Beside these adjustments, there are some other factors that also affect the capacity of WCDMA network. This equation was used to determine the cell capacity of a site operating with directional antenna.

The capacity of a WCDMA system can be increased by cell sectorization as it reduces the intra-cell interference. Since the capacity is directly affected by the interference, less interference yield a higher system capacity. With uniform traffic distribution, the capacity of cellular system with sectorization is increased by a factor equal to the number of sectors because the interference is effectively reduced by the same factor.

The first sectorized systems replaced standard 360-degree Omni-directional antennas with three or more separate directional antennas. The most commonly deployed configuration uses three antennas, each with a nominal azimuth beamwidth of 120-degrees and above. While the antennas within a sectorized cell share a common base transceiver station (BTS), each is managed and operated independently with its own power level, frequencies and channels. The use of three directional sector antennas versus one Omni-directional antenna substantially reduces co-channel cell interference and triples the opportunity for frequency reuse. As a result, WSPs realize significant gains in capacity. While considering the various factors like voice activity factor and interference that affect the capacity of cell in a wireless network, the standard equation for a single cell WCDMA capacity using sectorization scheme was given as;

$$K_d = 1 + \frac{1}{\alpha}\left(\frac{P_G}{E_b/N_o}\right) - \frac{n}{P_S\ x\ \alpha}; 0 < \alpha < 1 \quad (9)$$

Where α voice activity factor expresses the percentage of time during which voice is present on the channel
Introducing sectorization factor (λ), which expresses the number of partitioning of the cell, traffic capacity of the network would be;

$$K_d = \lambda\left\{1 + \frac{1}{\alpha}\left(\frac{P_G}{E_b/N_o}\right) - \frac{n}{P_S\ x\ \alpha}\right\}, \quad 0<\alpha<1 \quad (10)$$

With the varying processing gain at the EN0618 BTS, consider the use of a twin-beam sector antenna which doubles the cell capacity of each sector, the new cell capacity (K_t) of WCDMA system equations becomes;

$$K_t = 2K_d \quad (11)$$

Taking into considerations of the various parameters for the multi-user system capacity design model, the varying processing gain of the various sectors could be determined using the figure 1 and Table 1 above.
For a single cell WCDMA system using directional/sectorial antenna, the varying processing gain of the individual sectors can be determined using Eq. (10);

$$K_d = \lambda\left\{1 + \frac{1}{\alpha}\left(\frac{P_G}{E_b/N_o}\right) - \frac{n}{P_S\ x\ \alpha}\right\}, \quad 0<\alpha<1$$

From Fig.1, K_d for Sector A= 110 users, sector B= 323 users and Sector C = 475 users

Therefore,

Processing Gain, P_{G_1} for Sector A can be determined by substituting the values;

$$110 = \left\{1 + \frac{1}{0.375}\left(\frac{P_{G_1}}{2}\right) - 0\right\}$$

$$110 = \left\{1 + 2.667\left(\frac{P_{G_1}}{2}\right)\right\}$$

$$110 = 1 + 2.667\left(\frac{P_{G_1}}{2}\right)$$

$$P_{G_1} = \frac{218}{2.667} = 82dB$$

Processing Gain for Sector B denoted by P_{G_2}

$$323 = \left\{1 + \frac{1}{0.375}\left(\frac{P_{G_2}}{2}\right) - 0\right\}$$

$$323 = \left\{1 + 2.667\left(\frac{P_{G_2}}{2}\right)\right\}$$

$$323 = 1 + 2.667\left(\frac{P_{G_2}}{2}\right)$$

$$P_{G_2} = \frac{644}{2.667} = 241dB$$

Processing Gain for Sector C denoted by P_{G_3}

$$475 = \left\{1 + \frac{1}{0.375}\left(\frac{P_3}{2}\right) - 0\right\}$$

$$475 = \left\{1 + 2.667\left(\frac{P_{G_3}}{2}\right)\right\}$$

$$475 = 1 + 2.667\left(\frac{P_{G_3}}{2}\right)$$

$$P_{G_3} = \frac{948}{2.667} = 355dB$$

Since the developed model repartitions the existing sector into two, with each providing the equal capacity, the varying processing gain was identical to each of the twin-sector. Hence, the principle of dynamism were based on the ability of the designed antenna to split a sectored site into two equal sizes and on parameters of the model which at any time could be varied just like the existing sites with different sectors possessing varying processing gain. The cell capacity of the new model provides double capacity in each twin-sector as shown in Table 2 below.

This Eq. (11) could be used to determine the traffic capacity of a single cell CDMA network when deploying twin-sector antenna system.

Table 2: Calculated number of users of single cell EN0618 WCDMA system for a varying processing gain using sectorization formula

Twin Sector A		Twin Sector B		Twin Sector C	
Sector A1	Sector A2	Sector B1	Sector B2	Sector C1	Sector C2
110	110	323	323	646	646

2.2.2 Simulation of the EDCS model using simulink environment

The performance evaluation was done using Matlab R2008a as the simulation platform. The Matlab codes were developed using the parameters of the experimental testbed to evaluate the performance of the twin-beam antenna concept. The main goals were to increase network capacity and decrease mobile user's interference of the wideband code division multiple access system. The simulation parameters were given in Table 3.

Table 3: Simulation Parameter from the measured results

Parameter	Value
Voice activity factor α	0.375
Processing Gain P_G	226
Sectorization factor λ	6
Transmitted power P_t	44.77dBm
Frequency F	2300MHz
Cell size	400m radius
Antenna gain	2dB
Inter-cell interference	0.1
Shadow fading	6dB
Base station antenna height	30m
Bit-to–Energy Ratio (BER)	7dB
Energy per bit to noise ratio(Eb / N_o)	2dB

3.0 Results and Discussions

The enhanced dynamic cell sectorization scheme was implemented in this work using the modified single cell WCDMA network capacity equation (11) developed using the concept of twin beam antenna, where a six sector sectorization scheme was implemented by using just three twin-beam sector antenna concept. This work ran simulations for the targeted sites (EN0618) in order to quantify the expected gains when switching from the existing traditional three-sector configuration to six-sector using three-twin-beam antennas. The following results were got from the simulations.

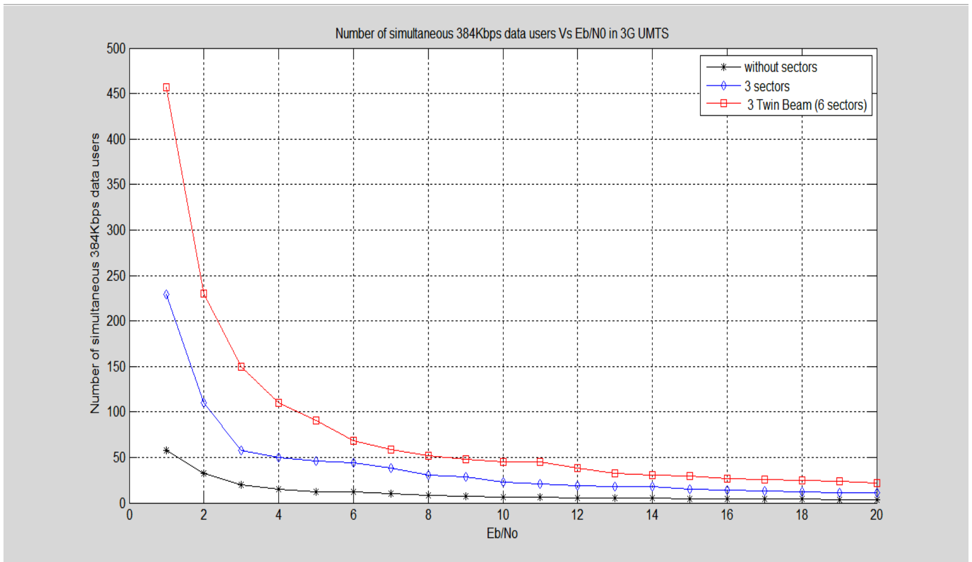

Figure 3: Number of simultaneous 384kbps data users Vs the Eb/No in 3G UMTS cell

Figure 3 shows that E_b/N_o was improved as a result of the reduction in interference due to increase in number of sectors without necessarily increasing the signal power; which allowed more users to access the network. Therefore, the number of mobile users was shown to have increased as the E_b/N_o was improved upon.

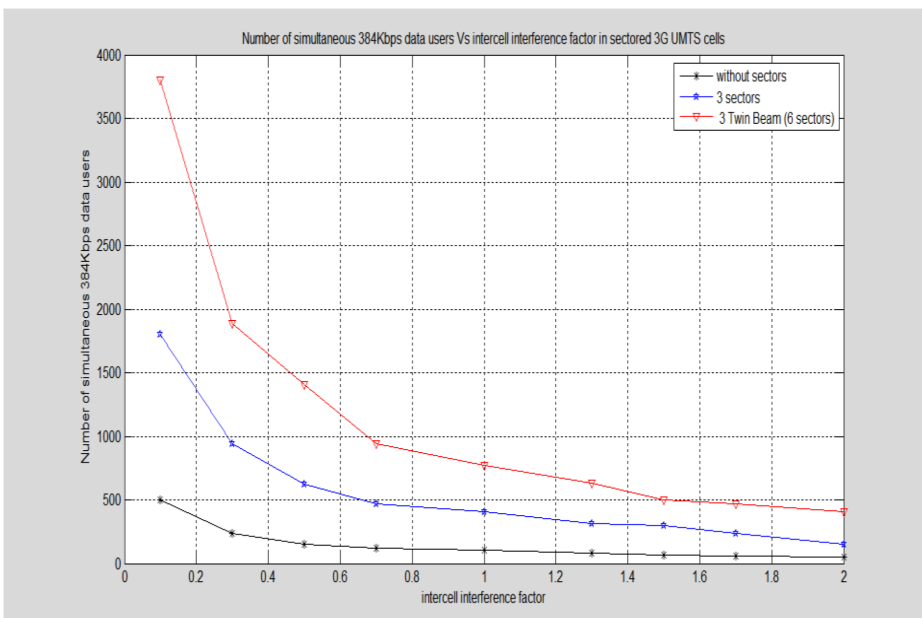

Figure 4: System capacity Vs inter-cell interference factor in the sectored 3G UMTS cell

It should be observed from figure 4 that there was an improvement in the inter-cell interference with sectorization, which then increased the number of users in the system. This is due to the fact that, as the beam-width decreases, the interfering users from other sectors are reduced thereby enhancing the capacity of the network.

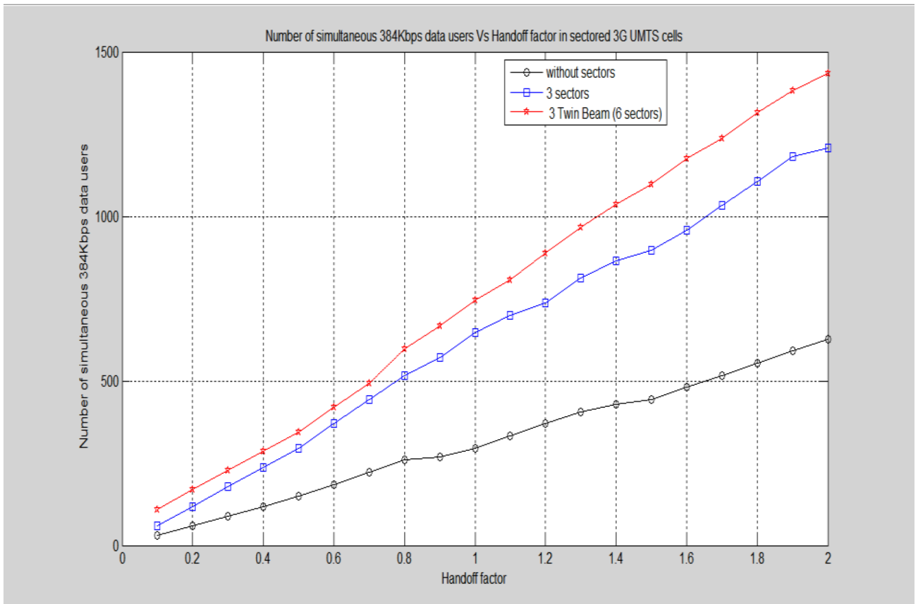

Figure 5: Number of simultaneous 384 kbps data users Vs Handoff Factor in the sectored 3G UMTS cells

Figure 5 show that for increasing handover factor and changing value of sectorization as given in the measured data of EN0618, the number of users that will access the network increases for the modelled 3G UMTS sectored cells as against the non-sectored cell (case of Omni-directional antenna). This indicated the ability of the Twin-Beam antenna to reduce the soft hand-off areas within a given sector. Once the percentage of soft hand-off areas between the left and right beams are averaged, the total sector showed a 3.69% decrease in sector overlap. Equally, figure6 shows that by changing the value of sectorization and reducing the voice activity factor, the number of simultaneous users in the cell was increased.

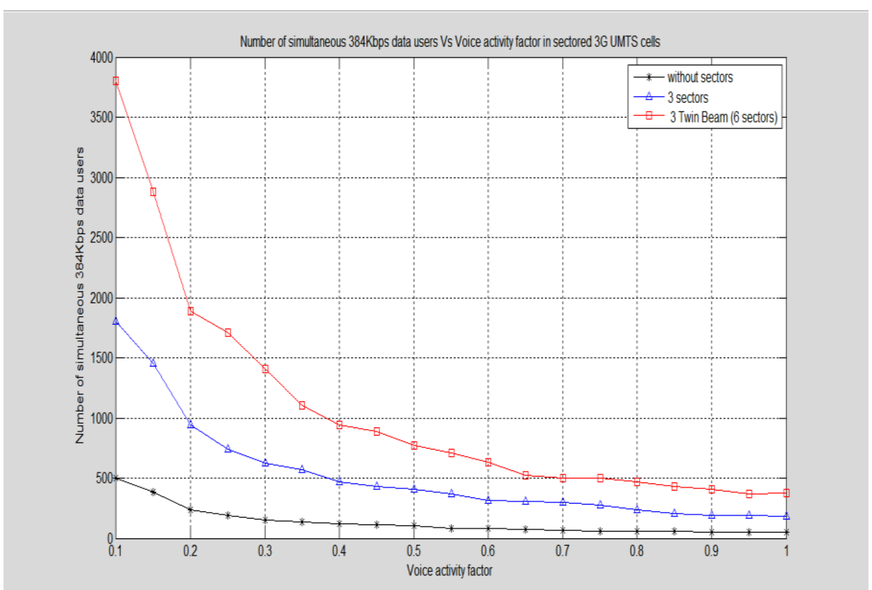

Figure 6: Number of users Vs Voice activity factor in the sectored cell

4.0. Conclusion

Obviously, creating increased capacity and keeping ahead of the high data are both means to a greater end: increasing quality of service (QoS). Increasing capacity using traditional methods of cell densification and the addition of antennas was expensive and time consuming. This research work has shown that the twin-beam sector-splitting solution was a fast and proven approach to quickly add capacity at most critical sites. Twin Beam enables WSPs to significantly increase capacity without substantially increasing costs. At the same time, it can improve throughput, allowing customers to take advantage of faster data speeds provided in the network. The results obtained in this work have shown that with the deployment of twin-beam sector splitting technique also known as Enhanced Dynamic Cell Sectorization (EDCS), EN0618 would have double cell capacity increase with 3.69% decrease in sector overlap. With this scheme, 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 WCDMA wireless network. The reduction in the number of interference gives access to more mobiles users thereby increasing the capacity of the network.

5.0 Recommendation

From the research result obtained in this work, it is recommended that the developed dynamic cell sectorization scheme be deployed in the existing telecommunication infrastructure to improve QoS thereby increasing the subscribers' satisfaction.

Acknowledgements

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