ENHANCING WCDMA TRAFFIC CAPACITY USING ADAPTIVE SECTORIZATION

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ABSTRACT
Quality of service (QoS) is a key performance indicator (KPI) that is used in determining the efficiency of telecommunication services rendered to end users. Accessibility, connection quality and retainability are major factors used in evaluating quality of service of a network provider. For consumers, it is expected that maximum satisfaction is to be derived from any services paid for. This maximum satisfaction has now become a difficult task to achieve in the Global System for Mobile communication (GSM) industry. Congestion in network channels contributes greatly to QoS of any network which the provider needs good resource management. One of the major problems affecting the capacity of Wideband Code Division Multiple Access (WCDMA) is interference. WCDMA cellular mobile systems has widespread acceptance particularly in regional centers where there are large geographical areas to cover. However, temporal changes of user density due to formation of congregated population centers (called hot spots) can seriously undermine the system design goals in terms of quality of service and system capacity. This paper presents focuses on reducing co-channel interference problems with the application of adaptive sectorization which increases the capacity of WCDMA by reducing interference through increase in number of cell sectors. This is achieved through modification of the number of antennas to be used in an array at a base station and determination of amount of energy leaked between users as well as the radiation pattern for the three mobile devices with a measure of the interference between them. Result shows a desirable reduction in the amplitude of the bars off the diagonal when more antennas are used and how the beams in the radiation patterns are also narrower. From set value of the experiment cell radius, R = 1km, Reverse Link (SIR_{th}) = -13.6dB, Number of Sector N = 12, the antenna array study from the base station (BS) increase, changes the beam pattern at different orientations Angle, with an increment of energy used as the angle tends to 90^o in SIR with angle θ ranging from 30^o,60^o,to 90^o with a significant reduction of SIR when the number is increased to 25, SIR were -15.19, -13.91and -13.30 for 30^o,60^o,to 90^o respectively. At the expense of the path shadow loss, the difference between the set values appreciate by 0.02dB at N= 10 instead of the set value N = 12. It is found that in all situations the adaptive sectorization brings an overall improvement to system capacity and this is particularly significant when the user concentration in hot spots is substantially larger than that of the rest of the cell.

Keywords: Interference Reduction, Antenna Array, Beam Switching, WCDMA Capacity.

1.0 INTRODUCTION

GSM mobile communication is one of the most explosive developments ever in the telecommunication industry. GSM takes the lead in wireless digital technology in the world and is the preferred technology for cellular services in most of the world emerging economies. GSM offers improved telephony services and functionality from a single network and provides full duplex data traffic to any device fitted with GSM capability at a rate of 9600bps using the time division multiple access (TDMA) communications scheme (Amaefule, 2003).

Mobile phones are an integral part of the society helping to reorganized how individual and business thrives, thereby creating jobs and transfer of technology. Nigerians is not left out is this technology development, with then NITEL leading the race (Osunade and Oyesanya, 2016). Also, during its launching in 2001, the core objective was to provide effective telecommunication services that will support good speech quality, spectral efficiency and minimized crosstalk, call blocks, among others. Hence the deployment into the Nigerian market was universally embraced and found to be relatively efficient at inception. With time, operators in the industry experienced an unprecedented growth in customer base. According to Matthews and Adetiba (2016), this explosive growth in the subscriber base on one hand brought huge revenue to both the operators and government through tax and license fee but on the other hand caused frequent call drop, poor network coverage, and unsatisfactory customer care support, among others. As a result, customer's dissatisfaction manifested with increasing complains against the networks.

Congestion is a problem all GSM service providers are facing and trying to solve. It is a situation that arises when the number of calls emanating or terminating from a particular network is more than the capacity the network is able to cater for at a particular time. In a bid to satisfy their teeming subscribers, GSM operators tend to cover the whole country when the capacity of their network cannot support such (Onianwa et al, 2003). When the demand for resources exceeds the available capacity, the result is call signals queuing on the transmission channel. This is the situation when blocking occurs and no free path can be provided for an offered call. Consequently, the rate of transfer of voice signals is reduced or quality of signals received become distorted or both. At worst, the calls will not connect at all. The problem of network congestion is a network managerial issue that affects the quality of service (QoS) rendered by a network, apart from the fact that over utilization of a node in a network can lead to resources' short span or malfunction (Newton and Arockiam, 2011).

2.0 WCDMA CAPACITY MODEL

The capacity of WCDMA system is a vital parameter in Universal Mobile Telecommunication System Networks and is determined by signal to noise ratio or mostly said Eb/No (Bit energy to effective noise power spectral density) and by the processing gain of the system. The processing gain is 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.

The expression for capacity i.e. the number of user in a cell in WCDMA system, then energy per bit can be written as (Newton and Arockiam, 2011):

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

$$\frac{E_B}{N_O} = \frac{P_s}{R_b N_O} \qquad (2)$$

where E_b= P_s= R_b = N_O. $N_O$is noise power spectral density and can be defined as interference power per unit spreading bandwidth and is given as:

$$N_O = \frac{P_I}{W} \qquad (3)$$

$$\frac{E_B}{N_O} = \frac{P_s}{P_I}.\frac{W}{R_b} = \frac{P_s}{P_I}P_G \qquad (4)$$

P as the processing gain, and if signal power of all users is the same and spreading sequence of all users has same rate then the equation for capacity in terms of number of users is given as:

$$\frac{P_I}{P_S} = (K-1) \quad (5)$$

$$(K-1) = \frac{P_G}{E_b/N_O} \quad (6)$$

$$(K) = 1 + \frac{P_G}{E_b/N_O} \quad (7)$$

K= number of users accessing the network at same frequency simultaneously and each user has its own PN code sequence.

P_s= the signal power, W = the bandwidth of spreading (PN) code sequence, R_b = the data bit rate; E_b= the energy per bit, N_O = noise power spectral density.

The basic capacity equation which determines the number of users in a WCDMA cells then depends on the processing gain 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.

The loading factor $L.F$ is given as:

$$L.F = \frac{K'}{1+\frac{P_G}{E_b/N_O}} \quad (8)$$

Where K is the number of users in a particular cell after loading from other cells. Generally, the loading factor is the percentage of capacity K and from this capacity$K$, a practical cell capacity Kafter loading in a WCDMA cell can be calculated:

$$K' = K * L.F\% \quad (9)$$

The loading factor increases in percentage while the number of active users in a particular cell decreases. Mathematically, the effect of loading on the capacity of WCDMA system is also given as:

$$K = 1 + \frac{P_G}{E_b/N_O}\left(\frac{1}{1+L.F}\right) \quad (10)$$

2.1 Interference

Interference is an important factor that limits the capacity of WCDMA systems. Interference in a WCDMA cell can be from the same cell, from the neighboring cell i.e. during handoffs and can be due to thermal noise of the cell. In order to calculate the capacity of WCDMA systems in the presence of these interferences, it is necessary to first calculate the noise rise. The noise rise (NR) is defined as the ratio of total wideband power to the thermal noise power P received at base station during uplink. The noise rise (NR) is given as:

$$NR = \frac{P_{Total}}{P_o} = \frac{P_o+P_{others}+P_{own}}{P_o} \quad (11)$$

On introducing the other-to-own cell interference ratio/factor, the NR can be written as

$$NR = \frac{P_{Total}}{P_o} = \frac{P_o+P_{own}(1+i)}{P_o} \quad (12)$$

The relation between noise rise (NR) and uplink loading μ is given as;

$$\mu_{UL} = \frac{1}{1-NR} \quad (13)$$

The uplink loading means number of users accessing the WCDMA cell base station and the users may be from the same cell or from the surrounding cells,

$$K = (1 + \frac{P_G}{E_b/N_O})\mu_{UL} \quad (14)$$

This is the Voice Activity Factor **(**also known as service activity factor) and means continuous use of some service in a cell. Monitoring of voice/data activity in a cell is an important technique to reduce interference or to increase the capacity as each transmitter is switched-off during the period of no activity and these periods can be used for other data flow without losing the QoS.

The relation between activity factor and cell capacity K is then given as:

$$K = \left(1 + \frac{P_G}{E_b/N_O}\right) * \frac{1}{v} \quad (15)$$

In Wideband Code Division Multiple Access cellular systems, the capacity is always affected by interference and reducing this interference leads to capacity improvement. The interference that a user faces consists of background noise and the signals generated by other users in the system. Therefore, user distribution in a cell is a crucial factor in estimating the capacity with the power control mechanisms employed in WCDMA systems. The methods adopted include power control, voice activity, antenna tilting, sectorization, etc.

Stations *BSo* and neighbor base station BS_1, and θ be the direction in which the MS (mobile station) is located with respect to the line joining the two base stations;

$$r_o = \sqrt{r^2 + d^2 - 2rd\cos\theta} \quad (16)$$

If N users in the interfering cell are uniformly distributed in the cell, then the user density in the cell ρ is;

$$\rho = \frac{2N}{\sqrt[3]{3R^2}} \quad (17)$$

Interference power received at the home cell base station, *BSo* due to users in the interfering cell can be expressed as;

$$I_{inter} = \int_0^{\pi} d\theta \int_0^{\pi} \left(\frac{2N}{3\sqrt{3R^2}}\right) \times S\left(\frac{r}{r_0}\right)^n 10^{(\gamma_o - \gamma)/10} r\theta dR \quad (18)$$

and the signal interference ratio *SIR* is;

$$SIR = \frac{S}{S(N-1) + 2S\int_o^{\pi} d\theta \int_o^{\gamma} \left(\frac{r}{r_0}\right)^n 10^{\frac{\gamma_O - \gamma}{10}} \left(\frac{2N}{3\sqrt{3R^2}}\right) rdr + \frac{n}{s}} \quad (19)$$

If *N* is the number of users in the home cell (sector), and *S* is the signal power received at every BS, the *SIR* at the home cell (sector) BS is given by,

$$SIR = \frac{S}{(N-1)S + I_{C,O}M} = \frac{1}{(N-1) + \frac{M}{S} I_{C,O}} \quad (20)$$

When the lognormal shadowing effect is incorporated using Longley-Rice model, the SIR at the home cell (sector) BS is given as;

$$SIR_{shad} = \frac{1}{(N-1) + \frac{M}{S} I_{c,o} 10^{\gamma/10}} \quad (21)$$

where γ is the standard deviation of a Gaussian random variable representing the lognormal shadowing, and the amount of shadowing is taken as 8dB (Longley-Rice model for urban area).

3.0 ESTIMATION OF WCDMA CAPACITY

When an MS chooses to access a certain sector's BS, the sector's BS will check whether the *SIR* prevailing there is greater than the minimum (threshold) value required. If the SIR is less than the threshold, the MS is blocked. This threshold value, SIR_{th} is;

$$\left(\frac{S}{I}\right) = \left(\left(\frac{E_b}{W}\right) / \left(\frac{N}{R_b}\right)\right) = \frac{Signal\ to\ noise\ power}{processing\ gain\ of\ the\ system} \tag{22}$$

At the rate of 1.2288 Mcps and signal to noise power ratio (E_b/N_o) of 7.4dB, the SIR_{th} (threshold) can be calculated:

$$\left(\frac{S}{I}\right)_{threshoild} = \left(\frac{E_b}{W}\right) / \left(\frac{N}{R_b}\right) \tag{23}$$

$$\left(\frac{S}{I}\right)_{threshoild} = \frac{10^{0.740}}{\left(\frac{1.2288 \times 10^6}{9.6 \times 10^3}\right)} = \frac{5.495}{128} = 0.0429$$

In decibel,

$$10log10\ 0.0429 = 13.6dB$$

The user signal which represents a mobile station coming to a receiver is affected by inter-cell and intra-cell interference which limits the available bandwidth. In order to improve the capacity of the WCDMA network as the number of users increases in a hot spot, a mechanism which compares the produced total interference with a set threshold is developed. Whenever the threshold is exceeded, the antenna switch radiates beam width to cover the increased traffic.

The main beam of an antenna array consisting of several equally spaced elements points in a direction θs to the array normal when the phase difference between adjacent elements is given by,

$$\beta = k\ d\ sin\ \theta s \tag{24}$$

where $k = 2/\lambda$, (λ is the free space wave length) and *d* is the spacing between adjacent elements. Thus, by varying the phase difference β, the beam can be steered through various directions. However, it is to be noted that for an element spacing of about half wavelength, beam steering is restricted to about ± 60^0 to avoid grating lobes.

Since the Array Factor of a linear array of *N* elements is given by the radiation pattern of a single element of the array, the resultant Antenna array is:

$$AF(\theta) = \sum_{n=0}^{N-1} Exp\left[\left(j.n(kd \sin\theta + \beta)\right)\right] \tag{25}$$

$$AF(\theta) = \sum_{n=0}^{N-1} Exp\left[\left(j.n(kd\sin\theta + sin\ (\theta s)\ )\right)\right] \quad (26)$$

where $0^0 \leq \theta \leq 360^0$ and $\theta_s = 45^0 15^0 - 15^0 - 45^0$

Pattern *AP (θ)* is found by pattern multiplication (that is, as the product of A(θ) and AF (θ).

$$AP\ (\theta) \;=\; A(\theta)\ AF(\theta) \quad (27)$$

By varying the element spacing d and/or the phase difference β between element excitations, the array factor and the resultant array pattern is varied to adjust to traffic demand.

4.0 RESULTS & ANALYSIS

4.1 Statistical Determination of Signal-to-Interference Ratio (SIR)

The SIR of the Hot Spot is calculated using equation (26),

$$SIR_{shad} = \frac{1}{(N-1)+\frac{M}{S}I_{c,o}10^{\gamma/10}} \quad (28)$$

It is assumed that a specific value for M is the number of MS in nearby cell and S is mobile signal power. However, $I_{(r,\theta)}$ depend on the distance of the MS location in near-by cell. Using random values to represent the position, r of the mobile station to the home cell, let r = 0.8, θ = (30^0, 60^0, 90^0); and
d = 2km.

$$r_o = \sqrt{r^2 + d^2 - 2rd\cos\theta} = 1.37km \quad (29)$$

$$SIR_{shad} = \frac{1}{(N-1)+\frac{M}{S}I_{c,o}10^{\gamma/10}} = 11.14db \quad (30)$$

$$I_{inter} = \int_0^{\pi} d\theta \int_0^{\pi} \left(\frac{2N}{3\sqrt{3R^2}}\right) \times S\left(\frac{r}{r_0}\right)^n 10^{(\gamma_o-\gamma)/10} r\theta dR \quad (31)$$

$$I(r, r_o)inter = S\left[\frac{10^{\gamma}/10}{r^n}\right]\left[\frac{\gamma^n}{10^{\gamma}/10}\right] = S\left(\frac{r}{r_o}\right)^n 10^{(\gamma_o-\gamma)/10} \quad (32)$$

4.2 Adaptive Beam Switching

When the SIR_{th} is reached the radiated beam is switched on. A four elements array antenna is used to switch from 30^0 to 120^0 sector in regard to traffic demand,

$$AF(\theta) = \sum_{n=0}^{N-1} Exp\left[\left(j.n(kd\sin\theta + sin\ (\theta s)\ )\right)\right] \quad (33)$$

where $0^0 \leq \theta \leq 360^0$ and θs = (45^0, 15^0, -15^0, -45^0), N = 4 is the number of elements, k is a constant with value 2/λ, d = λ/2 is the spacing between elements, λ is the free space wavelength of the users from one sector to another. The adaptive sectorization allows sector beam widths to be approximately 30^0, 60^0,90^0,120^0,150^0,180^0, 210^0 degree switched beams can adjust the sector size to include either fully or partially an area of high user density, that is, Hotspot (HS). By using adaptive beam switching, the traffic have been shifted from heavily loaded HS sectors to sectors that are underutilized as shown in figure 1.

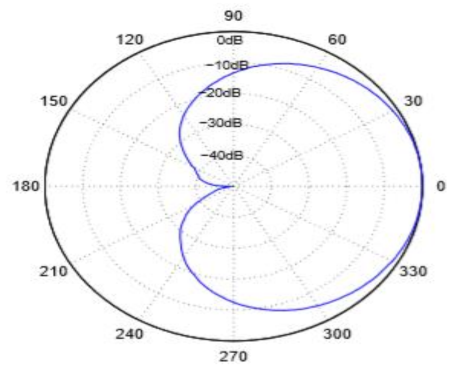

Figure 1: Switched Beam Pattern

For antenna array beam ($\theta=60^0$), the resultant antenna pattern (θ) is found by pattern multiplication (that is, it is the product of the AF (θ) and the pattern of a single element of the pattern of a single element of the array, AP (θ) = A (θ)XAF(θ).

The possibility of using adaptive sectorization as a means of reducing interference in sectors where it appears crucial in a bid to increase the overall capacity of the system was studied. It was found that the adaptive sectorization could be easily complemented using finite antenna beam switching, and for that practical array antennas could be employed. The capacity improvement obtainable with adaptive sectorization (in the presence of hotspots) is a function of user density in the hotspot in comparison to the user density in the rest of the cell.

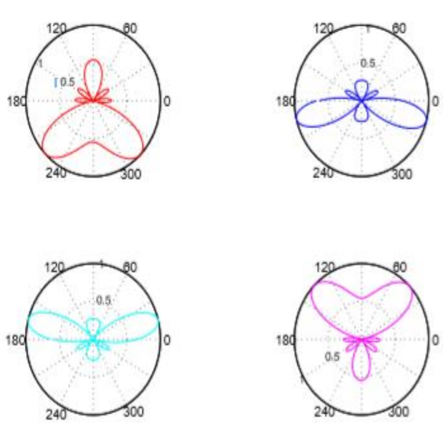

Figure 2: Array factor (clock wise from top left for $\theta s= -45^0, -15^0, 15^0$ and 45^0)

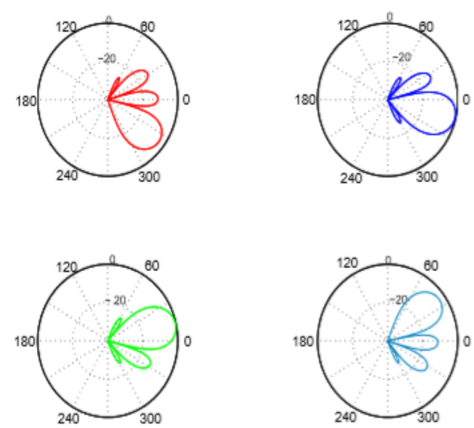

Figure 3: Resultant radiation pattern of practical array of 4 elements (clock wise from top left for $\theta s = -45^0, -15^0, 15^0$, and 45^0).

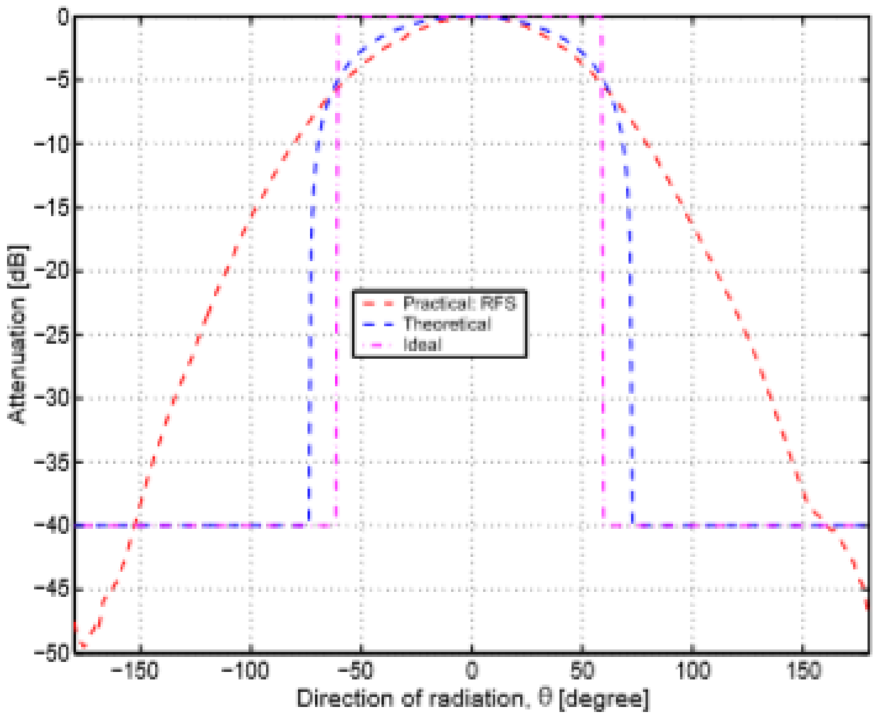

Figure 4: Radiation patterns for Ideal, Theoretical, and Practical cases

The modification the number of antennas to be used in the array at a base station compliments the amount of energy leaked between users and the radiation pattern for the three mobile devices and a measure of the interference between them. It is desirable to reduce the amplitude of the bars off the diagonal when more antennas are used (figures 2 and 3). It is also clear how the beams in the radiation patterns are also narrower. From set value of the experiment Cell radius, R, 1km, Reverse Link SIR_{th}-13.6 dB, Number of Sector N, 12. The antennas array study from base station, MS, increase changes the beam pattern at different orientations Angle, with an increment of energy used as the angle tends to 90^o in SIR with angle θ ranging from 30^o,60^o,to 90^o with a significant reduction of SIR when the number increase to 25, for SIR -15.19, -13.91 and -13.30 for 30^o,60^o to 90^o respectively in expense of the path shadow loss (figure 4). With the results the study shows that this improvement is significant particularly when the user density in the hot spot is an order of magnitude higher than that of the rest of the coverage area.

CONCLUSION

Reducing co-channel interference problem with the application of adaptive sectorization brings about modification in the number of antennas to be used in the array at a base station while considering the amount of energy leaked between users and the radiation pattern for three-way mobile devices and a measure of the interference between them. It is desirable to reduce the amplitude of the bars off the diagonal when more antennas are used. It is also clear how the beams in the radiation patterns are also narrower. The antennas array from base station, MS and changes in the beam pattern at different orientations Angle, with an increment of energy used as the angle tends to 90^o in SIR with angle θ ranging from 30^o,60^o to 90^o with a significant reduction of SIR when the number increases to 25. Adaptive sectorization is therefore effective in improving WCDMA network capacity especially when the user concentration in the hot spots.

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