Asian Journal of
Science, Technology, Engineering, and Art

e-ISSN: 3025-4507
p-ISSN: 3025-5287

Index: Harvard, Boston, Sydney University, Dimensions, Lens, Scilit, Semantic, Google, etc

https://doi.org/10.58578/AJSTEA.v3i4.6648

Enhancement of Quality of Service (QoS) through Improvement of WCDMA Capacity

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Article Info:

Submitted:	Revised:	Accepted:	Published:
Jun 22, 2025	Jul 16, 2025	Jul 28, 2025	Aug 3, 2025

Abstract

Achieving maximum customer satisfaction in the Global System for Mobile Communications (GSM) industry has become increasingly challenging due to heightened awareness of consumer rights, population growth, and economic expansion. A critical factor influencing service delivery is network congestion, which significantly impacts the Quality of Service (QoS), a key performance indicator (KPI) used to assess the efficiency of telecommunication services provided to end users. Core metrics for evaluating QoS include accessibility, voice connection quality, and retainability. While various studies have explored methods to mitigate congestion, interference remains a major constraint on the capacity of Wideband Code Division Multiple Access (WCDMA) systems, especially in regions where population density fluctuates, forming high-demand zones or "hot spots." This study investigates the application of adaptive sectorization as a strategy to reduce co-channel interference. The methodology involves modifying the number of antennas in the base station array, analyzing energy leakage between users, and examining the resulting radiation patterns for three mobile devices to measure inter-user interference. Results indicate that increasing the number of antennas narrows radiation beams and reduces off-diagonal interference levels. The findings demonstrate that adaptive sectorization consistently enhances system capacity, with particularly notable improvements in scenarios where user concentration in hot spots significantly exceeds that in surrounding areas.

Keywords: Adaptive Sectorization; Co-Channel Interference; WCDMA Capacity; Antenna Array; Quality of Service

INTRODUCTION

GSM mobile communication is one of the most explosive developments ever in the telecommunications 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 improves 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 thrive, thereby creating jobs and transfer of technology.

The great need for GSM services demand improved quality of service in the areas of mobility, capacity, expanded area coverage and improved features for the aim not to be defeated since it has come to stay as it is not luxury anymore but a necessity. Despite the good number of communication companies operating the celular technologies and services, subscribers'satisfaction and quality service delivery in some area is far below expectation. There have been series of complaints: call conversation echoes, drop calls, blocked calls, among others, from mobile subscribers. Some users even resort to the option of subscribing to more than one service provider just to maintain seamless connectivity, thereby losing a fortune to network operators (Moses and Imeh, 2012).

Over the last few years, the cellular network industry has been struggling to cope with the increasing data demands of new devices like smart phones and tablets (Adeosun et al., 2014). The majority of communication applications from mobile telephone conversations to credit card transactions assume the availability of a reliable network. However, such applications have not been able to fully take advantage of the higher transmission rates available from the new radio interfaces and the rapid performance/cost improvement of the wireless transmission technologies that connect the rest of the cellular network beyond radio links. A sound infrastructure in the telecommunication (telecom) sector is crucial for sustainable economic growth of a country. Nigeria as a developing economy leverages on the potentials of telecommunication to execute its business processes, (Nochiri et al., 2014).

Nigerians is not left out is this technology development, with then NITEL leading the race (Bukie *et al.*, 2017)). Also, during its launching in 2001, the core objective is to provide effective telecommunication services that will support good speech quality, spectral efficiency, and minimized crosstalk call blocks among others. Hence the deployment into Nigerian market was universally embraced and found to be relatively efficient at the inception. With time, operators in the industry experienced an unprecedented growth in customer base. According to Matthews & 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 is increasing and complains against the network are also increasing (Newton *et al.*, 2011).

Review of Related Works

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 that the network is able to cater for at a particular time. In a bid to satisfy their teeming subscribers, the GSM operators tend to cover the whole country when the capacity of their network cannot support such (Muzellec & Lambkin, 2006). When the demand for resources exceeds the available capacity, the result is call signals queuing on the transmission channel. This is the situation when the 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 (Monego et al., 2005, Akut & Sani, 2013). 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 malfunctioning Luk & Layton, (2002) and Alexander et al., (2013) defined quality as the degree to which a set of inherent characteristics fulfills requirements. In her words, Nnochiri (2015) states that excellent quality of service sustains customers'confidence and is essential for a competitive advantage. Moreover, operators are implementing new features in their networks even with limited network facilities without performing proper pre-trial, hence overloading the network (Joseph &Moses, 2015). Therefore congestion control is of utmost importance for the sustainability of the system and the development of a congestion control measures should be a good effort in the right direction (Aliyu et al.,2015, Ofomaja et al., 2013).

Factors That Could Lead to Congestion

A number of factors have been seen to lead to network congestion and some of these factors include;

I. Low WCDMA Traffic Capacity which can lead to congestion
II. Inadequate radio channels and infrastructure to support the vast number of subscribers on the network.
III. Redialing of subscribers when they experience blocking.
IV. Traffic built up during peak periods and at hot spots on the network
V. Marketing strategies and pricing schemes
VI. Use of the old equipment facilities instead of new ones
VII. Technical mechanisms along the transmission link such as inadequate dimensioning of the network particularly the switching system, End-to-End System connections

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

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

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

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. Now if signal power of all users is the same and spreading sequence of all users has same rate then the equation for capacity equation in terms of number of users is given as

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

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

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

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. This equation completely depends the processing gain and Eb/No 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

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

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

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

it is clear that as the loading factor increases in percentage, the number of active users in a particular cell decrease. Mathematically, the effect of loading on the capacity of WCDMA system is also given as

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

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 i.e. own cell interference own, other cell interference other and thermal noise or background noise of the cell Io, 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

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

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

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

The relation between noise rise (NR) and uplink loading µis given as

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

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.

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

Voice Activity Factor It is also called service activity factor. Service activity 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 Quality of Service (QoS).

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

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

In Wideband Code Division Multiple Access (WCDMA) 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 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 is located with respect to the line joining the two base stations

$$r_o = \sqrt{r^2 + d^2 - 2rd\cos\theta} \qquad (20)$$

If N users in the interfering cell are uniformly distributed in the cell, then the user density in the cell ρ(see appendix B) is

$$\rho = \frac{2N}{\sqrt[3]{3R^2}} \qquad (21)$$

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

$$I_{inter} = \int_0^{\pi} d\theta \int_0^{\pi} \left(\frac{2N}{3\sqrt{3R^2}}\right) \times S\left(\frac{r}{r_0}\right)^n 10^{(\gamma_o - \gamma)/10} r\theta dR \qquad (22)$$

$$SIR = \frac{S}{S(N-1)+2S\int_0^{\pi} d\theta \int_0^{\gamma}\left(\frac{r}{r_0}\right)^n 10^{\frac{\gamma_0-\gamma}{10}}\left(\frac{2N}{3\sqrt{3R^2}}\right) r dr+\frac{n}{S}} \quad (23)$$

If N is the number of users in the home cell (sector). And S is the signal power received at every BS, the S/I at the home cell (sector) BS is given by

$$SIR = \frac{S}{(N-1)S+I_{C,O}M} = \frac{1}{(N-1)+\frac{M}{S}I_{C,O}} \quad (24)$$

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

$$SIR_{shad} = \frac{1}{(N-1)+\frac{M}{S}I_{c,o}10^{\gamma/10}} \quad (25)$$

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

METHODOLOGY

System Design

The user signal which represents a mobile station coming to a receiver is affected by intercell and intracell interference which limits the available bandwidth. In order to improve the capacity of WCDMA 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 as shown in figure.1.

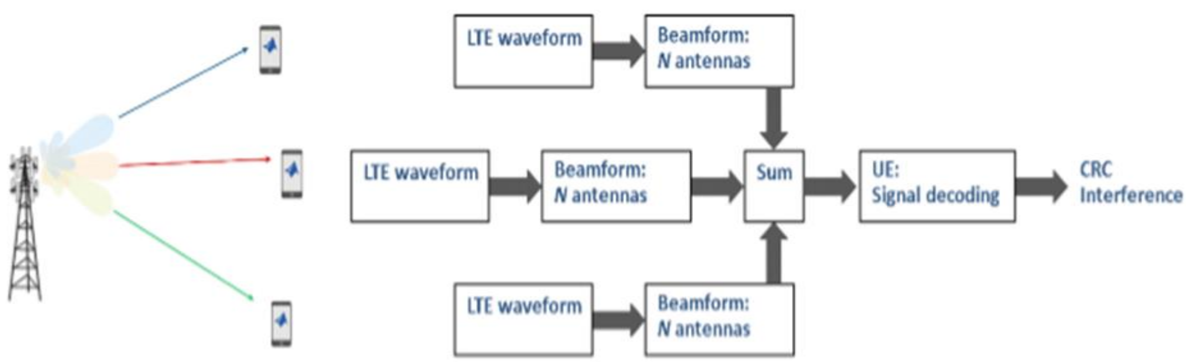


Figure.1: Antenna and Beam Forming

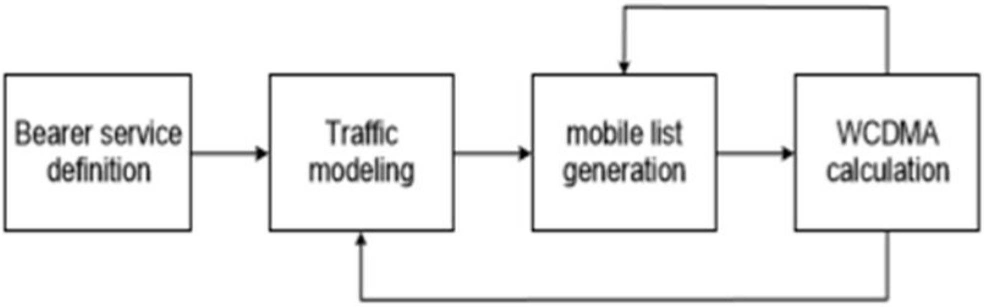


Figure. 2: WCDMA Calculation

Work Flow

Figure 3 shows the work flow adopted in this research. In the investigation of WCDMA system capacity, the number of users the system can support is evaluated using a computer simulation (MAT LAB 7.5) 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) valve required. If the SIR is less than the thresholds the MS is blocked. This threshold valve, SIR th is– 13.6 db

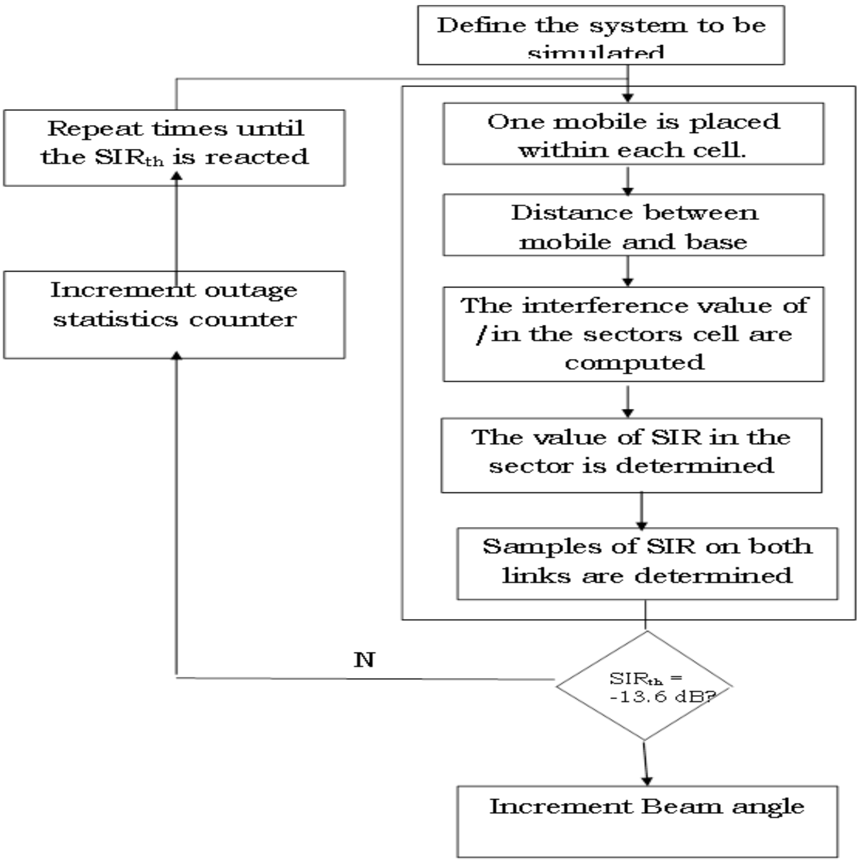


Figure 3.2 Flow Chart To Estimate The Sir And Outage In A WCDMA

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

$$\left(\frac{S}{I}\right) = \left(\left(\frac{E_b}{W}\right)/\left(\frac{N}{R_b}\right)\right) = \frac{\text{Signal to noise power}}{\text{processing gain of the system}} \qquad (26)$$

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

$$\left(\frac{S}{I}\right)_{threshoild} = \left(\frac{E_b}{W}\right)/\left(\frac{N}{R_b}\right) \qquad (27)$$

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

In decibel,

$$10log10\ 0.0429 = 13.6dB$$

The user signal which represents a mobile station coming to a receiver is affected by intercell and intracell interference which limits the available bandwidth. In order to improve the capacity of WCDMA 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 radiated 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

$$\beta = k\ d\ sin\ \theta s \qquad (28)$$

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 represents the radiation pattern of a single element of the array, the resultant Antenna

$$AF(\theta) = \sum_{n=0}^{N-1} Exp\left[\left(j.n(kd\sin\theta + \beta)\right)\right] \quad (29)$$

$$AF(\theta) = \sum_{n=0}^{N-1} Exp\left[\left(j.n(kd\sin\theta + sin\ (\theta s)\ )\right)\right] \quad (30)$$

Where

$$0^0 \leq \theta \leq 360^0$$

$$\theta_s = 45^0 15^0 - 15^0 - 45^0$$

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

$$AP\ (\theta)\ =\ A(\theta)\ AF(\theta) \quad (31)$$

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.

RESULTS AND DISCUSSION

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

The SIR of the Hot Spot is calculated using equation 26 as shown

$$SIR_{shad} = \frac{1}{(N-1) + \frac{M}{S} I_{c,o} 10^{\gamma}/_{10}} \quad (32)$$

For the purpose of this work, we assume a specific value for M which is the number of MS in nearby cell and S is mobile Signal power.

But $I_{(r,\theta)}$ depend on the distance of the MS location in near-by cell. For this work, we will use 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. d = 2km.

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

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

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

$$I(r, r_o)inter = S\left[\frac{10^{\gamma/10}}{r^n}\right]\left[\frac{\gamma^n}{10^{\gamma}/10}\right] = S\left(\frac{r}{r_o}\right)^n 10^{(\gamma_o-\gamma)/10} = 0.07$$

Adaptive beam switching

When the SIR_{th} is reached the radiated beam is switched

A four elements array antenna is used to switch from 30^0 to 120^0 sector in regard to traffic demand

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

Where $0^0 \leq \theta \leq 360^0$ and $\theta s = (45^0, 15^0, -15^0, -45^0)$, 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 the users from one sector to another. the adaptive sectorisation allows sector beam widths to be approximately 300, 600,900,1200,1500,1800,2100 degree switched beams can adjust the sector size to include either fuly or partially an area of high user density, that is, Hotspot (HS). By using adaptive beam switching the traffic h shifted from heavily loaded HS sectors to sectors that are underutilized.

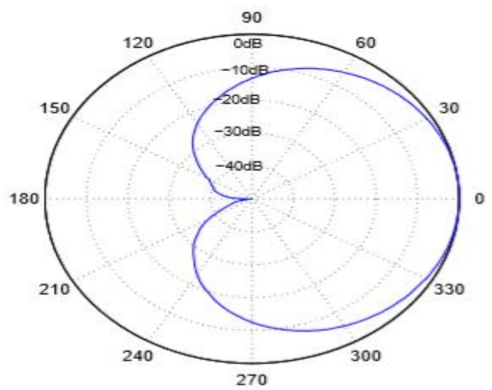


Figure:4

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)

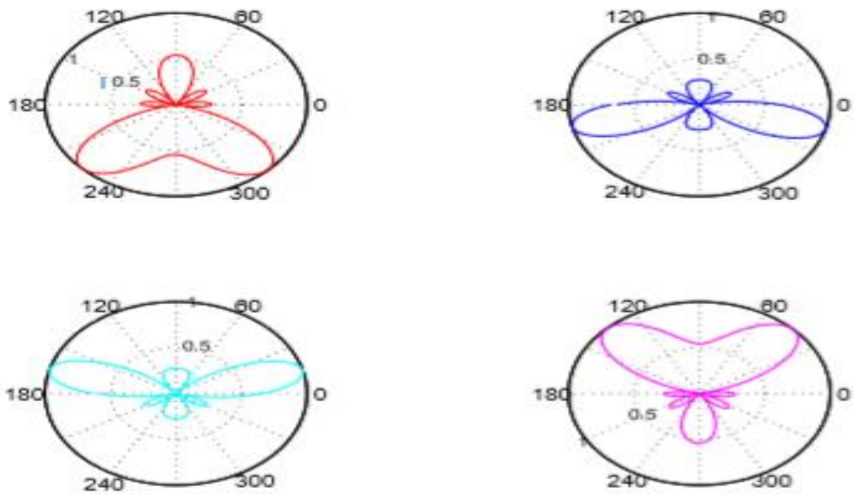


Figure:5

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

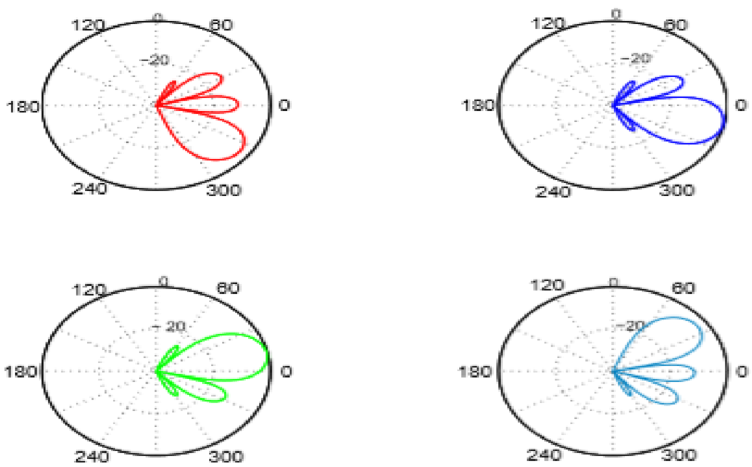
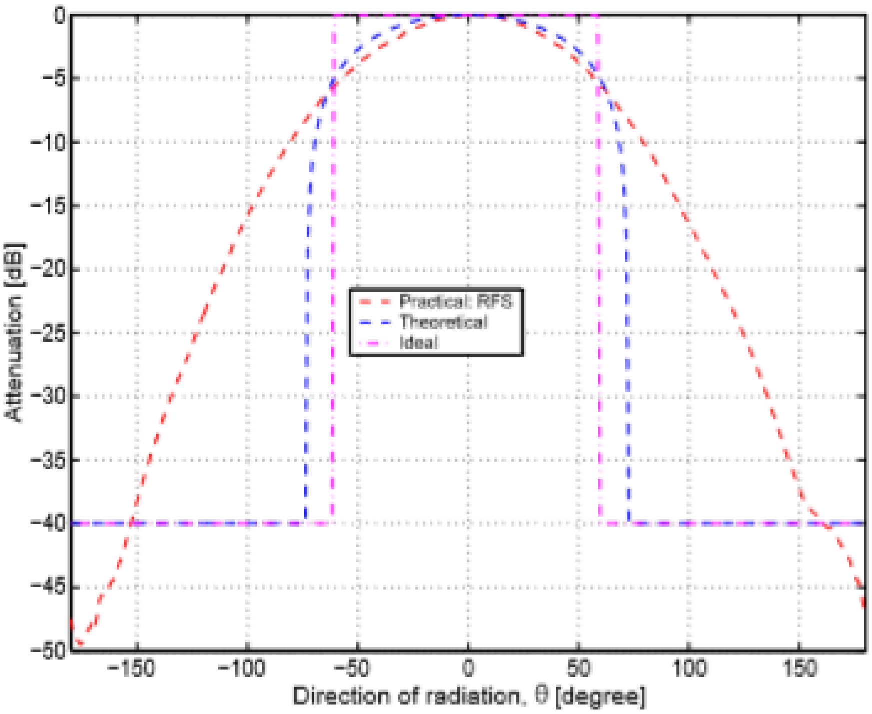


Figure:6

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)



Direction of radiation, θ [degree]

Figure:7. Radiation patterns for Ideal, Theoretical, and Practical cases

The possibility of using adaptive sectorisation 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 sectorisation could be easily complemented using finite antenna beam switching, and for that purpose practical array antennas could be employed. The capacity improvement obtainable with adaptive sectorisation (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. The modification the number of antennas to be used in the array at a base station while study 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. It is also clear how the beams in the radiation patterns are also narrower. From set value of the experiment Cell radius,R1km,Reverse Link SIR^{th}-13.6dB Number of Sector N, 12.The antennas aray study from base station,MS increase changes the beam parttern 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 of ioncrease to 25,SIR were-15.19,-13.91and-13.30 for 30^o,60^o,to 90^o respectively in expense of the path shadow loss. With the results the study shows that this improvement is significant particularly when the user density in hot spot is an order of magnitude higher than that of the rest of the coverage area.

The case of a perfect antenna serves as a reference to examine the system under ideal conditions and to compare it with the practical the sector coverage in this case is assumed to be uniform over the entire sector and these are not spillover of main lobe or occurrence of side lobes in the radiation pattern.Table 4.1 and fig 4.1 shows the SIR at the home sector BS as evaluated against the number of users in the home sector with different location and concentrations of hot spot and the angular position changes

Table 1 Regulation between SIR and MS position

Number of MS in	SIR	SIR	SIR
Home sector	ζr=o.8,θ=30	ζr=o.8,θ=60	ζr=o.8,θ=90
0	-11.14	-6.63	-1.4
1	-11.46	-7.48	-3.8
5	-12.55	-9.82	-8.06
10	-13.61	-11.64	-10.57
15	-14.47	-12.92	-12.57
20	-15.19	-13.91	-13.30
25	-15.80	-14.71	-14.22

Table 2 Relation between SIR and MS position

Number of MS in	SIR	SIR	SIR
Home sector	ζr=o.8,θ=60	ζr=0.9,θ=60	ζr=1R,θ=60
0	-6.62	-9.54	-11.14
1	-7.48	-10.0	-11.46
5	-9.82	-11.46	-12.55
10	-11.6	-12.79	-13.62
15	-12.96	-13.8	-14.47
20	-13.91	-14.62	-15.19
25	-14.71	-15.31	-15.80

CONCLUSION

Reducing co-channel interference problem by the application of adaptive sectorization brings about the modification the number of antennas to be used in the array at a base station while study amount of energy leaked between users and the radiation pattern for a 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. It is also clear how the beams in the radiation patterns are also narrower. From set value of the experiment Cell radius,R1km,Reverse Link SIRth-13.6dB Number of Sector N, 12.The antennas aray 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 of ioncrease to 25,SIR were-15.19,-13.91and-13.30 for 30^o,60^o,to 90^o respectively in expense of the path shadow loss.It is found that in all situations the adaptive victimization brings an overall improvement to system capacity and this is particularly significant when the user concentration in hot spots is substantially bigger than that of the rest of the cell.

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