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# Adaptive Antenna Capabilities InGSM Systems Performance Improvement

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## ABSTRACT

In this work, the major impairment regarding the coverage and capacity of GSM system have been explained. This paper presents the adaptive antenna array systems as a promise technology that have the ability to overcome the mobile communication performance limitations.

The major contribution of this paper is to estimate the coverage, the blockage probability, and capacity improvement during the use of adaptive antennas in GSM base stations. MATLAB 6.5, has been used for simulation and performance improvement evaluation of capacity and coverage in GSM system.

The results show that an adaptive antenna array of eight elements has a potential to reduce outage probability, and improve coverage extension by about 280% and capacity by 40%.

**Key words:** Coverage Area, Propagation Models, Blockage probability, spectral Efficiency, Cell Sectoring.

# إمكانيات الهوائي التكيفي في تحسين أداء أنظمة اتصالات GSM

## الخلاصة

تم في هذا العمل توضيح المشاكل الكبيرة لنظم اتصالات GSM المتعلقة بالتغطية والسعة. يقدم هذا البحث مصفوفة الهوائي التكيفي كتكنولوجيا واعدة لها القابلية على تلافي صعوبات أداء نظم الاتصالات المتنقلة.

إن الإسهام الأساسي لهذا البحث هو تخمين تحسين التغطية واحتمالية حجب المكالمات والسعة خلال استخدام مصفوفة الهوائيات التكيفية في محطات القاعدة لنظام الـ (GSM ). تم استخدام برنامج الماتلاب 6.5 في المحاكاة وحساب خواص السعة والتغطية لأنظمة الـ (GSM ).

بينت النتائج بان هوائي تكيفي من ثمانية عناصر يمكن أن يقلل من احتمالية فشل المكالمات ويمكن أن يزيد مساحة التغطية بنسبه 280% والسعة بمقدار 40%.

## INTRODUCTION

Conventional cellular base stations use either omnidirectional or sectored antennas to establish a connection between the base station and the mobile units moving in the covered cell or sector. This kind of signal transmission

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wastes a lot of energy as most of the power is radiated in other directions instead of toward the desired mobile unit. Besides, the broadcasting signal also causes undesired interference to other users, located within the cell or co-channel cells[1]. Furthermore, increasing the number of sectors increases the handoffs the mobile experiences while moving across the cell[2].

Wireless communication systems are limited in performance and capacity by three major impairments, multipath, delay spread, and co-channel interference. In view of explosive growth in the number of cellular subscribers, service providers are becoming concerned with the limited capacities of their existing networks[3]. This has led to the deployment of adaptive antenna systems. If a adaptive antenna would be used, and the user’s direction would be tracked, the antenna could radiate mainly in the direction of the active users, and a lot of unnecessary interference can be removed by placing a null in the direction of the jammer. This is the basic philosophy behind the use of adaptive antenna systems[4].

Adaptive antenna systems capability in beam-forming, and directing the antenna power in the direction of the desired user was discussed in [5]. The potentialsof adaptive antenna in capacity improvement and power reduction were discussed in details in [2], [6], and [7].

This paper mainly concentrates on use of adaptive antennas in Global System for Mobile Communication (GSM) to overcome the problem of limited channel bandwidth, and enhancing their performance.

This paper is structured in six sections. Adaptive antenna array concepts are described in section two. Section three provides a brief overview of propagation models used in assessing the potential of adaptive antennas in coverage extension, and presents two proposed approaches for coverage extension evaluation. The fourth section presents the capability of adaptive antenna array in beamforming and blockage probability reduction. Section five, discusses the capability of adaptive antenna to support greater capacities. The paper is concluded in the sixth section.

## ADAPTIVE ANTENNA SYSTEMS

Adaptive antenna system consists of a set of antenna elements distributed in a certain configuration, associated RF hardware, and a computer controller or that is called digital signal processor (DSP) [2].

The array with N number of antenna elements collects signals that containing both the desired signal and the interfering signals are down converted, sampled and digitized to generate the inputs ($x_1$, $x_2$… $x_N$).

An adaptive array controls its own pattern dynamically in response to the radio frequency environment, using feedback to vary the phase and/or amplitude of the exciting current at each element to optimize the received signal[6]. The phases and the amplitudes are adjusted through a complex weight vectors ($w_1$, $w_2$, $w_3$… $w_N$) and combined to generate the array output y(t) as shown in Figure 1[3].

$$y(t) = \sum_{m=1}^{N} x(t)\, w^H(t) \qquad ...(1)$$

Where

($w^H$) denotes the transposition of the complex conjugated vector.

Through appropriate selection of the weight set, the adaptive antenna can shape its pattern so as to maximize the power towards the desired direction, and to minimize the influence of the interfering mobile stations.

The array output is then compared with some reference signal u(t), to generate an error signal *e*(t), which is then adaptively minimized by an adaptive algorithm. The error signal, which is used to control the weights, is given as[4]:

$$e(t) = u(t) - x(t).w^H(t) \qquad ...(2)$$

There are many algorithms to determine and update the uplink weight vectors for performing beam forming on the received signals as well as the downlink weight vectors for performing beam forming on the transmitted signals[8].

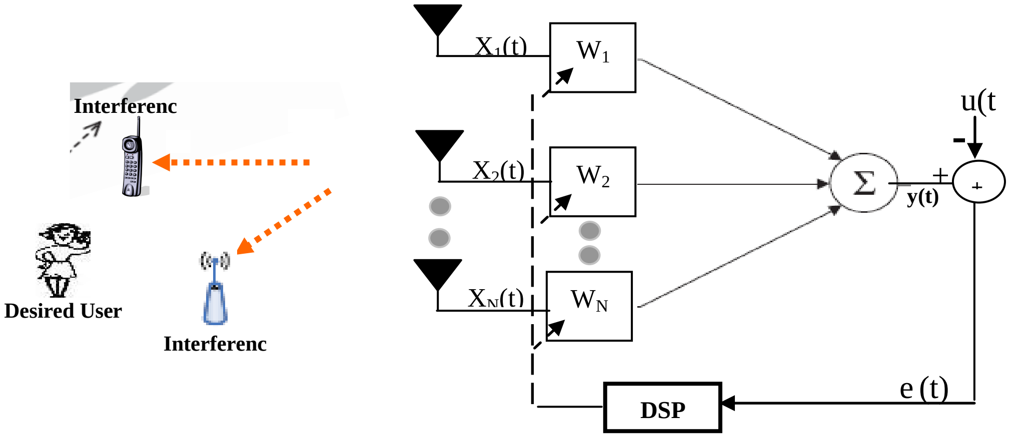

Figure (1). Adaptive Antenna System Construction

The desired signal received at each antenna element is phase shifted due to the weight coefficients, and the components from each branch are positively combined. As a result, the signal amplitude increases N times so the power of the desired signal increases $N^2$ times.The gain will be equal to N, and obtained gain in dB scale the obtained gain is[9]

$$(G)_{dB} = 10 \log (N) \qquad ...(3)$$

As an example, the application of an adaptive antenna of four elements results in 6.02 dB improvement in signal to noise (SNR) ratio.

## COVERAGE IMPROVEMENT STRATEGY

One of the wireless system design objectives is to provide coverage on the entire serving area with a minimum number of base stations. The coverage area, is the area in which communication between a mobile and the base station is possible. To obtain a reliable wireless system design, it is necessary to understand how signals propagate in the cell environment as radio propagation conditions limit the area which can be covered by a transmitter[10].

This paper presents two empirical propagation models; log distance model ( $d^n$) model, and Hata-Okumura model as they are active tools in propagation prediction and frequency planning of cellular mobile systems. The coverage extension obtained during the used of an adaptive antenna will be derived with the use of these two models.

## LOG - DISTANCE PATH LOSS ( $d^n$ ) MODEL

The $d^n$ path loss model is used to predict the pathloss or the power transfer between a transmitter and a receiver. It takes into account the decrease in energy density suffered by the electromagnetic wave due to spreading. The $d^n$ model predicts that the mean received power, $P_r$, and the mean path loss, $P_L$, measured in dB, at a any distance d from the transmitter can be given as[11]:

$$P_r(d) = P_r(d_o)\left(d_o / d\right)^n \qquad ...(4)$$

$$P_L(d) = P_L(d_o)\left(d / d_o\right)^n \qquad ...(5)$$

where

$P_r(d_o)$ is the mean received power in dB at a reference distance $d_o$ that is chosen to be in the far-field of the antenna, $P_L(d_o)$ is the mean path loss in dB at $d_o$, and n is the empirical quantity (path loss exponent value) .The path loss exponent value is between 2 (for free space), and 4 (for standard urban environments) as in urban areas,the signal arrives after reflection,diffraction,or in multipath [11] [12].

## HATA-OKUMURA MODEL

Hata-Okumura model can extrapolate predictions up to the 2GHz band in large cell coverage.In Hata -Okumura model, the following empirical formula is proposed tor estime the signal attenuation ($P_L$). For an urban area in the frequency range from 150 MHz to 2GHz and for the effective base station antenna height ($h_b$) between 30 and 200m[9] [11].

$$\left((P_L)_{dB}\right)_{urban} = 69.55 + 26.16 \log f - 13.83 \log(h_b) - a(h_m) + \left[(44.9 - 6.55 \log(h_b)\right] \log(d) \qquad ...(6)$$

Where

f is the frequency in MHz, $h_b$ is the effective base station antenna height, $h_m$ is the mobile antenna height, $a(h_m)$ is the correction factor for mobile unit antenna height (dB), and d is the communication range.

## DERIVATION OF COVERAGE EXTENSION

when a single omnidirectional antenna is used the maximum permissible pathloss $P_L(d)$ is achieved at the distance $d_1$ from the mobile base station. the additional gain provided with the application of adaptive array in base station will increase the median tolerable pathloss, and as a result it can be exploited for range extension to the distance $d_2$.

### Coverage Extension Derivation Using Log-Distance Propagation Model

$$P_L(d_2) = P_L(d_1)\,.\,G \quad \Rightarrow \quad P_L(d_o)\,(d_2 / d_o)^n = .\,P_L(d_o)\,(d_1 / d_o)^n\,.\,G$$

$$G = \left(\frac{d_2}{d_o}.\frac{d_o}{d_1}\right)^n = \left(\frac{d_2}{d_1}\right)^n .$$

$$G^{\frac{1}{n}} = (d_2 / d_1) = (R_{c2} / R_{c1}) = Range\ \ Extension\ Factor \qquad ...(7)$$

Where
$R_{c1}$ is the cell radius when a single omnidirectional antenna is used, while $R_{c2}$ is the cell radius during the use of an adaptive antenna array. As the gain of adaptive antenna is equal to (10 log N) in dB scale, it will equivalent to (N) which is the number of array elements in a dimensionless scale, therefore,

$$Range\ Extension\ Factor = \frac{R_{c2}}{R_{c1}} = N^{\frac{1}{n}} \qquad ...(8)$$

In general, the area covered by a hexagonal cell ($A_c$) can be determined by[13]:

$$A_c \approx \ \ 2.6\,(R_c)^2 \qquad ...(9)$$

Assuming that the cell area covered by a base station with a single antenna is $A_{c1}$, and the area covered by adaptive array is $A_{c2}$, the coverage extension will be

$$Coverage\ \ Extension\ Factor = \frac{A_{c2}}{A_{c1}} = \frac{2.6\ (R_{c2})^2}{2.6\ (R_{c1})^2} = \left(N^{\frac{1}{n}}\right)^2 = N^{\frac{2}{n}} \qquad ...(10)$$

In Figure 2, the range extension factor is plotted against the number of adaptive antenna array elements for different power exponent values(n). It can be noticed that the range extension increases as the number of array element is increased. Also, it can be seen that with small power exponents the range improvement is higher, i.e. the improvement will be higher in free space environment or Line-of-Sight (LOS) than urban environments. Eight antenna elements can result in 282% range extension at n=4, while it will be about 400% at n=3.

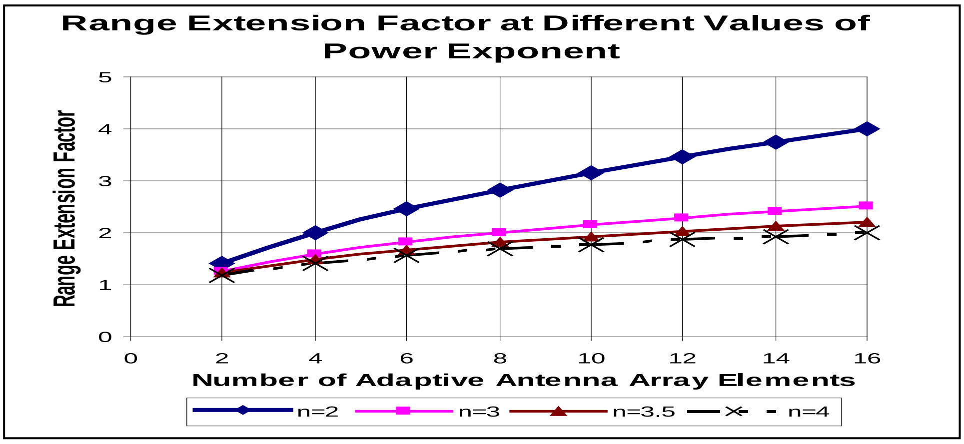

**Figure (2). Range Extension Using Log-Distance Model**

## Using Hata-Okumura Propagation Model

Hata-Okumura model can be used to predict the signal attenuation in GSM which is the most widely used mobile standard in many countries.

GSM can operate in two main frequency bands: one between 880MHz and 960MHz that is called (GSM-900), the other between 1710MHz and 1880MHz which is called (GSM-1800)[12]. Typical GSM propagation conditions (carrier frequency range, and base stations and mobile station antenna heights), the Hata- Okumura model can be written in the following forms:

For typical GSM-900, with a base station of 30-40 m height, the model can be deduced to

$$\left(P_L\right)_{dB} = 126.418 - a(h_m) + 35.224 \log(d) \qquad \mathit{for}\ h_b = 30\,m \qquad ...(11)$$

$$\left(P_L\right)_{dB} = 124.692 - a(h_m) + 34.406 \log(d) \qquad \mathit{for}\ h_b = 40\,m \qquad ...(12)$$

For typical GSM-1800, with a base station of 30-40 m height, the model can be deduced to

$$\left(P_L\right)_{dB} = 161.307 - a(h_m) + 35.224 \log(d) \qquad \mathit{for}\ h_b = 30\,m \qquad ...(13)$$

$$\left(P_L\right)_{dB} = 132.568 - a(h_m) + 34.406 \log(d) \qquad \mathit{for}\ h_b = 40\,m \qquad ...(14)$$

The maximum permissible attenuation level $P_L(d)$ during the use of adaptive array base station will be achieved at the distance $d_2$ that is more than the distance of the omindirectional antenna base station $d_1$ by the gain G, which is equal to the number of array elements (N). So, we can write,

$$P_L(d_2) = P_L(d_1) + G$$

Applying the case of GSM-900, with $h_b$ = 40 m, $h_m$ =1.5 m, yields;

$$124.692 - a(h_m) + 34.4 \log(d_2) \quad = \quad 124.692 - a(h_m) + 34.4 \log(d_1) + G$$

$$G = 34.4 \log(d_2) - 34.4 \log(d_1) \quad \Rightarrow \quad G = 34.4 \log_{10}(d_2 / d_1)$$

$$\log_{10}(d_2 / d_1) = G\ / 34.4 = 10 \log_{10}(N) / 34.3 = 0.29 \log_{10}(N) = \log_{10}(N)^{0.29}$$

$$\mathit{Range\ Multiplier} = (d_2 / d_1) = (R_{c2} / R_{c1}) = N^{0.29}$$

$$\mathit{Coverage\ Extension} = \frac{A_{c2}}{A_{c1}} = \frac{2.6\,(R_{c2})^2}{2.6\,(R_{c1})^2} = \left(N^{0.29}\right)^2 = N^{0.58} \qquad ...(15)$$

Applying the same method for other types of GSM, we can conclude that the use of adaptive antenna array of N antenna elements results in coverage extension between $N^{0.567}$ and $N^{0.58}$.

Figure 3, shows the coverage area extension against the number of adaptive array elements by using both log-distance model, and Hata-Okumura model.Table(1) shows that the use of adaptive antenna with eight elements can result in coverage extension between 282% (for n=4), to 334%. Due to the long range associated with adaptive, the number of base station can be reduced. The inverse of the coverage area extension represents the reduction factor in the base station number required to serve the same area. This implies that adaptive antennas can be deployed with less number of base stations.

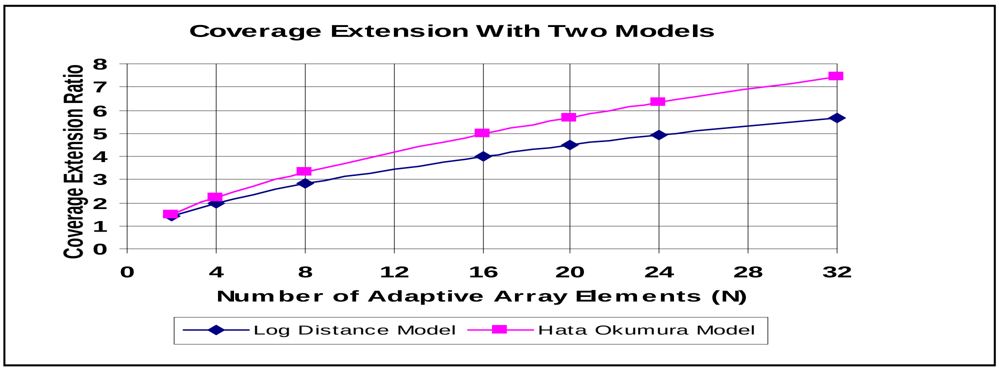

**Figure (3). Coverage Extension (Log-distance, Hata Models)**

**Table(1).Coverage Extension Using Adaptive Antenna Array**

| **Number of Array Element N** | **Log – Distance Model** | | **Hata – Okumura Model** |
|---|---|---|---|
| | **Power Exponent** | | |
| | **n=2** | **n=4** | |
| | **Range Extension%** | | **Range Extension%** |
| 2 | 200 | 141,4 | 149,4 |
| 4 | 400 | 200,0 | 223,4 |
| 6 | 600 | 244,9 | 282,7 |
| 8 | 800 | 282,4 | 334,0 |
| 10 | 1000 | 316,2 | 380,1 |
| 12 | 1200 | 346,4 | 422,5 |
| 14 | 1400 | 374,1 | 462,1 |
| 16 | 1600 | 400,0 | 499,3 |

## BEAMFORMING-BLOCKING PROBABILITY REDUCTION

In areas with interference, call drops are very frequent. The probability of failing to obtain satisfactory reception at the mobile unit in the presence of high levels of interference is referred to as outage or blockage probability. It is required to reduce the outage probability in systems with high quality of service (QoS) [8] [10].

In order to test the potential of adaptive antennas in outage probability reduction, a network with a specified frequency re-use pattern with uniformly distributed users in each hexagonal cell will be assumed.

For a cellular network with $N_c$ cells, each cell has C allocated channels, and A Erlangs traffic intensity, the actual traffic carried by each cell will be A (1-B), where B is the blocking probability, and the channel usage efficiency ( $\eta$ ) can be defined as [13] [14]:

$$\eta = \frac{A(1-B)}{C} \qquad ...(16)$$

Using Log-distance propagation model, the received signal power by a mobile unit from the wanted cell base station $p_r(w)$, and the interfering base station $p_r(i)$ that are shown in Figure 4, can be written as[11]:

$$P_r(w) = P_r(d_o)\,(d_o/d_w)^n \quad , \quad P_r(i) = P_r(d_o)\,(d_o/d_i)^n \qquad ...(17)$$

$$P_r(w)/P_r(i) = (d_i/d_w)^n \qquad ...(18)$$

Where

$d_w$ and $d_i$ are distances from the wanted (serving) cell and the interfering cell to the mobile unit, n is the power exponent value.

Assuming identical radiated powers and same signal propagation conditions in the serving cell, and interfering cell, the interference will occur when the wanted signal power $p_r(w)$ is less than or equal to the interfering signal power $p_r(i)$, and it is logical to compare the outage probability with the occurrence of interference, that occurs when $P_r(w) \le P_r(i)$.

When an omnidirectional antenna base station cell of C channels with η channel efficiency, the probability of channels activity in an interfering call can be determined by the required outage probability, that is given as[14]:

$$\Pr obability\ of\ P_r(w) \le P_r(i) = \frac{Number\ of\ active\ channels}{Number\ of\ cell\ channels} = \frac{\eta\, C}{C} = \eta \qquad ...(19)$$

When an adaptive antenna is considered, the number of active channels or beams will be equal to (η C/**m**) as the adaptive antenna is capable of forming **m** beams, with beam width of (2π/m), so the outage probability in the adaptive case becomes [14]:

$$\Pr obability\ of\ P_r(w) \le P_r(i) = \frac{\frac{\eta\, C}{m}}{C} = \frac{\eta}{m} \qquad ...(20)$$

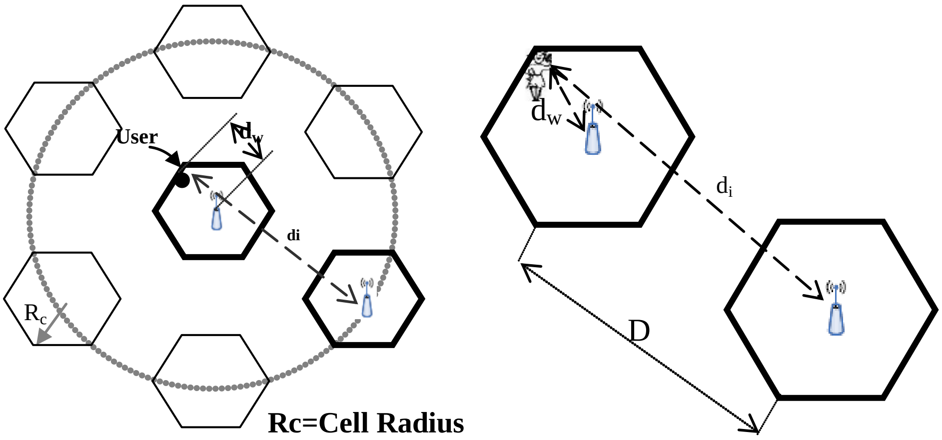

**Figure (4). Interfering Co-channel Cells**

Figure 5, shows the simulation results of omnidirectional , and adaptive antenna potentials in blocking probability reduction at different levels of network efficiency. The figure shows that at 50% network efficiency, the blocking probability can be reduced from 50% (with omnidirectional antenna base station) to 5% (with adaptive antenna of ten beams), and to 2% (with adaptive antenna of 25 beams). This implies that the blocking probability decreases as the number of adaptive beams increase, and the call drops will be very small.

In Figure 6, the adaptive antenna of eight anmtenna elements is simulated by using the Least Mean Square (LMS) Algorithm to check its potential in beamforming, and nulling the interference signals.

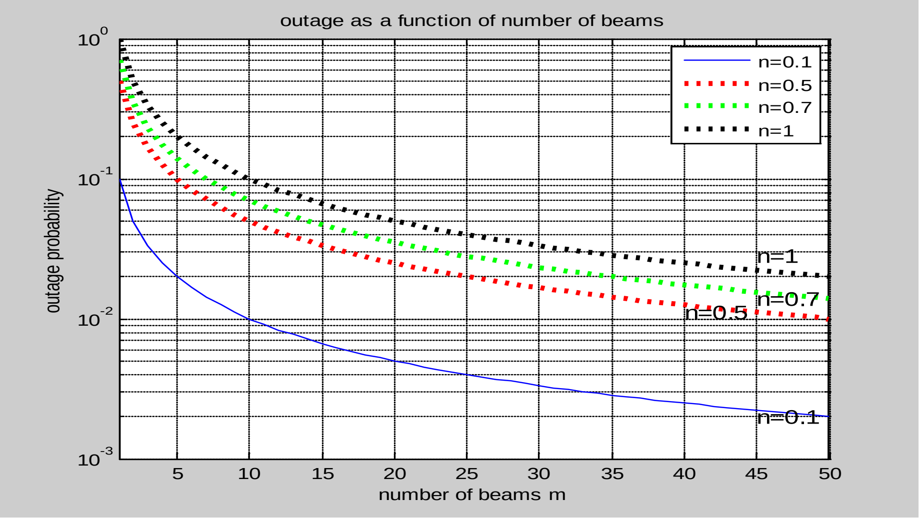

**Figure (5).Blocking Probability Using Adaptive Antenna**

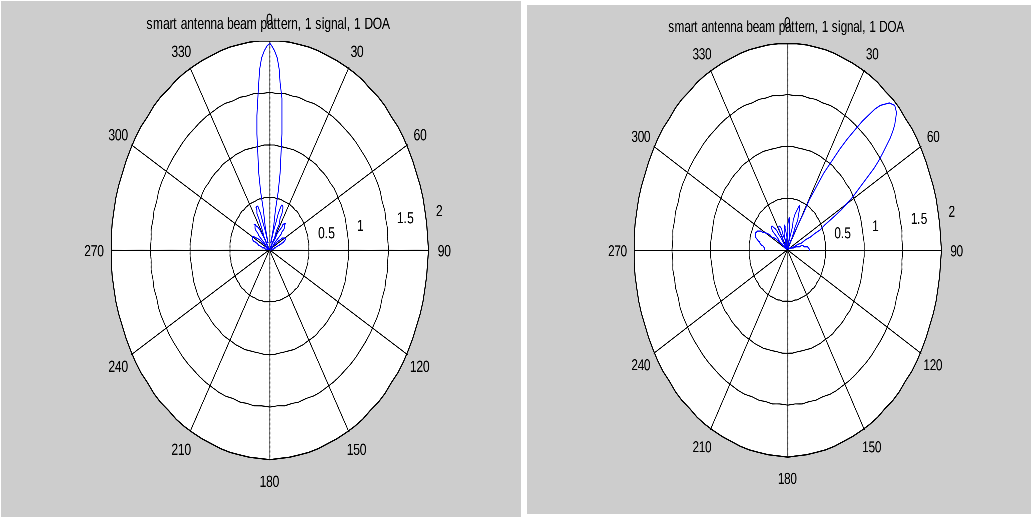

**Figure (6).Beamforming with Adaptive Antenna Array**

## CAPACITY IMPROVENENT

Adaptive antennas are now seen as a solution to the cellular network capacity problem, that is the main concern in dense urban areas[4].

The following analysis explains how adaptive antennas can support greater capacities. The minimum signal to interference ratio SIR worst case on the down link can be computed using the expression[8]:

$$(SIR)_{dB} = 10 \log_{10}\left(\frac{(\sqrt{3K})^n}{i_o}\right) \qquad ...(21)$$

where

n is the power exponent value, K is the cluster size, and $i_o$ is the number of interfering base stations in the first tire.

In Figure 7, the relation of the minimum required SIR with the cluster size is plotted for standard urban area (n=4). It can be noticed that an omnidirectional cellular system requires a cluster size of (K=7), while a three-sectored cellular network (120° per sector), requires a cluster size of(k= 4) and a six-sectored cells (60° per sector) requires a cluster size of 3 for a desired mean SIR of approximately 18 dB. For that reason, sectorization technique can be used to reduce co-channel interference and improves the mean SIR for a given cell reuse factor.

Since adaptive antenna base stations has fewer co-channel interferers, it is possible to reduce the cluster size. With the use of an adaptive antenna of eight elements which theoretically provides (9.02dB) of interference reduction, it is possible to plan adaptive network with a three frequency reuse (K=3) rather than with a seven frequency reuse (K=7). That is about 40% less spectrum than would be required in an omnidirectional network. Spectrum per cell increases with a tight frequency re-use pattern since the available bandwidth can be reused to a great extent. Hence, transition from K=7, to K=3, will result in more channels in each cell as the total available frequency band will be divided by 3 instead of 7.

This leads to an increase in the number of traffic channels per cell and an increase in the amount of traffic (Erlangs) capacity.

The spectral efficiency E, measured in channels/km$^2$/MHz, is expressed as[9]

$$E = \frac{(BW)_t - (BW)_{ch}}{(BW)_t \; K \; A_c} = \frac{1}{(BW)_{ch} \; K \; A_c} \qquad ...(22)$$

Where

$(BW)_t$ is the total bandwidth of the system available for voice channels (transmit or receive), in MHz, $(BW)_{ch}$ is the bandwidth per voice channel in MHz, K is the number of cells per cluster, and $A_c$ is the area per cell in square kilometers. Therefore, as adaptive antenna systems offered less number of cells in each cluster(K),and have the ability to reduce the channel bandwidth, it can contribute in spectral efficiency improvement.

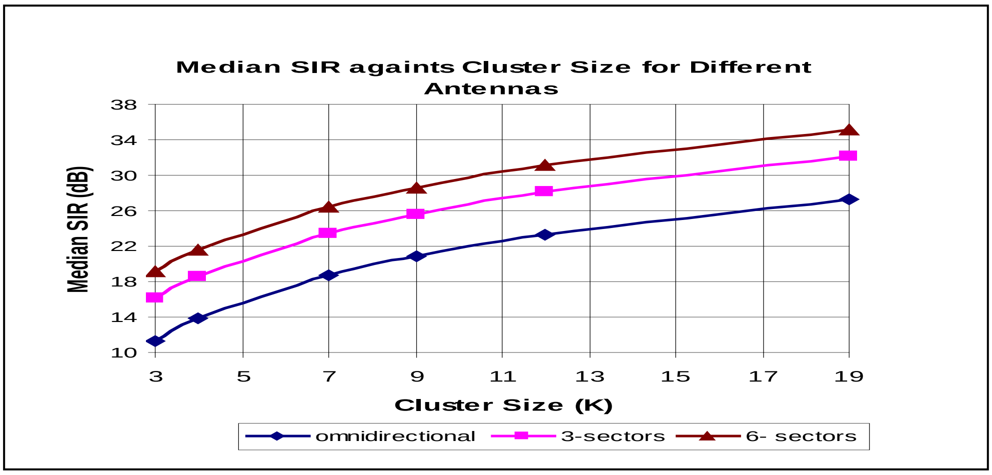

Figure (7).SIR with Cluster Size For Different Antennas

## CONCLUSIONS

This paper discussed adaptive antenna systems, and analyze their potentials in coverage and capacity improvement, outage and interference reduction in GSM cellular network. Simulation results show that adaptive antenna systems offers several advantages over conventional antennas. These include coverage extension by 280 % , when an adaptive antenna of eight elements is used in urban area base station. It has been noticed that gain obtained during using adaptive antenna of N elements leads to reduce mobile transmitted power by $N^{-1}$. Results presented show that using adaptive antenna yields in decreasing blockage probability of the system in presence of interference from 1 to 0.02.

## REFRENCES

[1]. Nguyen, Hung Tuan, "Multiple Antenna Systems for Mobile Terminals", A PHD Thesis, Engineering and Science Aalborg University, Denmark, 2005.

[2]. El Zooghby, Ahmed, "Potentials of Smart Antennas in CDMA Systems and Uplink Improvements", IEEE Antennas and Propagation Magazine, Volume 43, No. 5, October, 2001,pp 172-177.

[3]. Jain, RK, Katiyar, Sumit, and Agrawal, NK, "Smart Antenna for Cellular Mobile Communications ", International Journal of Electrical, Electronics, and Communication Engineering(IJEECE), Vol.1.No.9 , 2011, pp 530-541.

[4]. Gross, Frank B, "Smart Antennas for Wireless Communications", McGraw- Hill, First Edition,2005.

[5]. Ram, Shankar, " A study of Adaptive Beamforming Techniques Using Smart Antenna For Mobile Communications", A Master Degree Thesis, National Institute of Technology, 2007.

[6]. Jadhav, A.N, Mhalgi, and Khumane, " Wireless communication using Adaptive Smart Antenna System", International Journal of Engineering Research & Technology (IJERT), Vol.1.No.3 , 2012, pp 1-4.

[7]. Mubeen, S., Prasad,A.M, and Jhansi, R, "An Overview of Smart Antennas and Its Techniques Beamforming and diversity", International Journal of Computational Engineering (IJCER), Vol.2.No.3 , May-June, 2012, pp 732-736.

[8]. El Zooghby, Ahmed, "Smart Antenna Engineering", Artech House, INC., Norwood, MA, 2005.

[9]. Krzysztof, Wesolowski," Mobile Communication Systems", Jhone Willy and Sons Ltd, First Edition, 2002.

[10]. Seybold, John S., " Introduction to RF Propagation”, John Wiley & Sons, Inc., New Jersey , First Edition, 2005.

[11]. Rappaport, T. S., "Wireless Communications Principles and Practice", Prentice Hall, Upper Saddle River NJ, Second Edition, 2002.

[12]. Rappaport ,S. Theodore and Blankship, Keith." Propagation and Radio System Design Issues in Mobile Radio Systems, Virginia polytechnic Institute, 1997.

[13]. Garg ,Vijay K., " Wireless Communications and Networking", Morgan Kaufmann Publishers, USA, First Edition, 2007.

[14]. Rugamba, John, "Viability of Using Intelligent Smart Antenna Systems in GSM Cellular Networks in Africa", A Master Degree Thesis, Tshwane University of Technology, 2005.