Evaluation Of Circular Array Antenna For Mobile Base Station To Increase Reverse-Link Capacity

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ABSTRACT

Circular phase array antenna has wide application in Mobile communication system for object to increase system capacity through reduction of co-channel interference caused by a single cell adjacent cell. These improvements in system capacity depend mainly on the antenna beam pattern and directivity and the process is a kind of spatial filtering, known by Space Division Multiple Axes (SDMA). In this paper a theoretical calculation and MAT-LAB simulation was performed to evaluate beam pattern and antenna directivity considering different design parameters such as number of radiator element, circle radius, excitation current distribution, and beam scanning. This paper show also through MAT-LAB calculation that by adopting such circular array antenna in Mobile Base Station, leads to improve the reverse-link capacity for a typical Direct Sequence Code Division Multiple Access (DS-CDMA) cellular mobile communication system.

Key Word: Uniform Circular Array (UCA) antenna, Directivity, DS-CDMA Capacity, SDMA, Mobile cellular.

1. INTRODUCTION

The circular array antennas can be used in many fields such as radar systems, mobile systems and navigation systems. The circular array antennas are usually adopted because their radiation patterns are symmetric.

The circular array can be seen as an elementary building block of conformal array antenna with rotational symmetry. A circular phase array antenna means, an array of radiators distributed with equal spacing along the periphery of a circle ring of radius 'R' as shown in Fig.1. Circular array has several advantages over other schemes such as good scanning performance in the whole plane. They also have the advantage that the mutual coupling is symmetric and the size of the array is comparatively small [1].

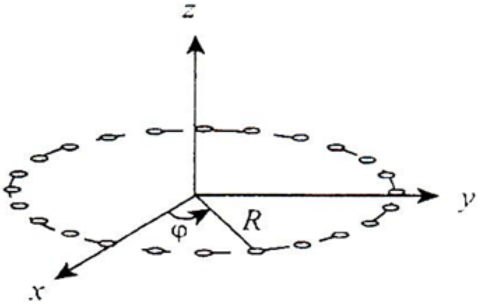


Fig.1.Uniform circular array

A Uniform Circular Array (UCA) antennas with uniformly space radiation elements and with equal amplitude and phase excitation have long been used for the purpose of obtaining good omnidirectional pattern. In the plane of the array (usually the horizontal plane). Later application includes phases-steered directional beams and array with several simultaneous beams, including broadband circular array [1] [2] [3].

In the last few years, the demand for mobile communication services has increased tremendously. However, there is no proportionate increase in the spectrum allocated. As a result, there is an urgent need for new techniques to improve spectrum utilization by maximizing the number of users with the same available spectrum.

In traditional cellular systems the base station, having no information on the position of mobile units, is forced to radiate the signal in all direction to cover the entire area of the cell. This entails both a waste of power and the transmission, in the directions where there are no mobile terminates to reach, of a signal which will be seen as interfering for co-channel cells, i.e. those cells using the same group of radio channels. Analogously, in reception, the antenna picks up signals coming from all direction, including noise and interference [4].

These considerations have led to the development of the Space Division Multiple Access (SDMA) technique. In SDMA number of users share the same available resources and are distinguished only in the spatial dimension which is based on deriving and exploiting information on the spatial position of mobile terminals. In particular, the radiation pattern of the base station, both in transmission and receptions is adapted to each different user so as to obtain, the highest gain in the direction of the mobile user. Simultaneously, radiation nulls shall be positioned in the direction of interfering mobile units. The behavior is just defined "Interference nulling" this lead to increased system capacity [4] [5].

In addition to the opportunity to increase system capacity, the SDMA technique has additional characteristics making its introduction in a mobile radio system advantageous. In particular, it is possible to exploit the higher receive gain offered by an antenna array with respect to an omnidirectional case, to allow mobile units to transmit at reduced power, and therefore lower consumption [4].

One promising technique is to use circular phase antenna arrays at the Base Station (BS) for spatial filtering of signals [6]. Another promising technique for better frequency utilization in 3G/4G systems is Code-Division Multiple Access (CDMA). All CDMA based systems capacity is essentially limited by multiple access interference (MAI). The use of an antenna array, in the reverse link, at the base station serves to enhance the performance and increase capacity (number of user per cell) of a cellular CDMA system, particularly in environments where multi path is a limiting factor as shown in Fig.2. Such an array provides a unique transmitter receive spatial channel for every user in the cell hence reducing the interference caused by users within the same cell and neighboring cells [5].

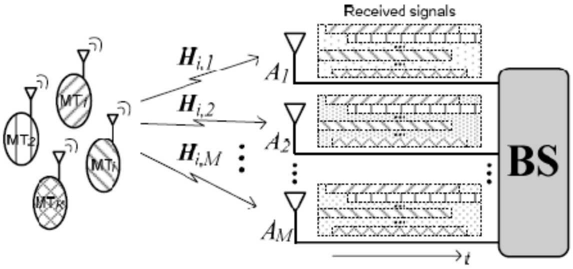


Fig.2. Asynchronous uplink SDM-CDMA-Single Cell transmission model

In this paper, the use of adaptive uniform circular array (UCA) antenna at base station for cellular CDMA using Space Division Multiplexing (SDM) technology is studied. Radiation patterns of circular array antenna arrays were analyzed and plotted and directivity was computed for different antenna parameters and compared in view of applications in CDMA mobile system using Space Division Multiplexing (SDM) technology.

It presents a performance evaluation (BER) for a single and multi cell CDMA network with an antenna array at the base-station for use in mobile to base-station (reverse link or uplink). It considers the effects of, Rayleigh fading channel, multiple access interference, number of interfering cells and thermal noise, and show that by using an antenna array at the base-station, in receive, so it will increase the system capacity for several fold.

2. Uniform Circular Array Antenna

The circular array, in which the elements are placed in a circular ring, is an array configuration of very practical interest. In uniform circular array, N elements are placed in a circular ring of radius 'R'. The spacing between the elements is proportional to wave length λ as shown in Fig.3. Using circular array the beam scanning of 360° can be obtained without change in antenna design parameters [3].

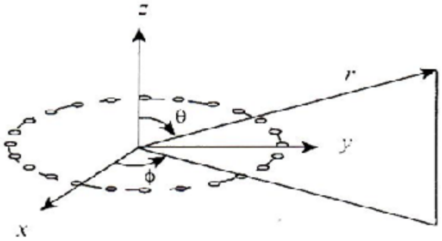


Fig.3. Far- field coordinates for uniform circular array.

The radiation pattern of 16 and 24 element UCA is obtained by the array factor approach as a polar and 3D plot as shown in Fig.4 and Fig.5 bellow, it is evident that by increasing the number of elements, directivity (D) will increase.

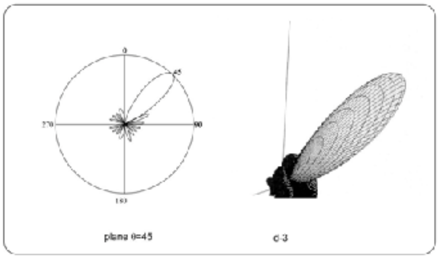


Fig.4. Radiation pattern of UCA antenna N=16, θo=45 ,Φo=90

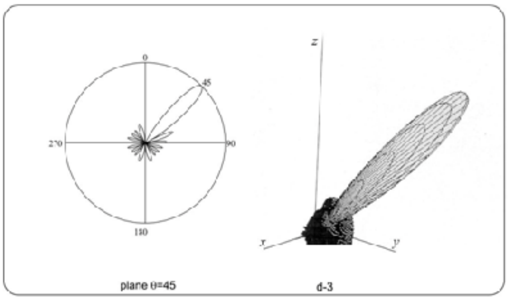


Fig.5. Radiation pattern of UCA antenna N=24, θo=45 ,Φo=90

The radiation pattern of a circular array antenna with N isotropic elements spaced on a circular ring of radius R (Fig.3) , is given by equation(1) [8]:

$$F(\theta,\Phi) = \sum_{n=1}^{N} I_n e^{j\beta R\{\sin\theta\cos(\Phi-\Phi n) - \sin\theta o \cos(\Phi o-\Phi n)\}} \qquad (1)$$

Where

$\beta = 2\pi/\lambda$ constant phase shift.

R= radius of the circle (ring), in wave length (λ).

$\Phi n = n\,\Delta\Phi$ = azimuth location of each element on the circle.

$(\theta o,\Phi o)$= is the direction of the maximum beam scanning.

I_n= is the amplitude of the excitation current.

In general the directivity (D) of the radiation pattern beam F (θ, Φ) is giving by equation (2):

$$D(\theta_o,\emptyset_o) = \frac{4\pi}{\int_0^{2\pi}\int_0^{\pi} |F(\theta,\emptyset)|^2 \sin\theta \, d\theta \, d\emptyset} \qquad (2)$$

3. Parameters effecting beamforming

For the design of circular array one has to adequately choose the number of antennas in the array (N), their position on the circle (inter element spacing d) and the circle radius(R). Also, the control function of the complex weighting coefficients (beam forming factor W) should be specified in order to obtain the desired radiation pattern with a suitable resolution. These parameters were reflected directly on the antenna directivity (D) and on the communication system capacity, which represents the number of user per cell (K) for a mobile system.

The Beam width is inversely related to spacing between the antenna elements. We obtain a narrow beam width when the antenna spacing is large, however it is required that the spacing be less than *λ/ 2* where λ is the wavelength of the radiated frequency, else we get spurious beams apart from the required ones. Number of antennas elements also effect the beam width inversely, more the elements, less the beam width. Additionally we have a reduction in side lobes amplitudes, with more antenna elements [9] [10].

4. Performance of a SDMA-CDMA system in absence of fading effect

For interference limited asynchronous reverse channel CDMA over non faded additive white Gaussian channel (AWGN) channel, operating with perfect power control with no interference from adjacent cells and with omnidirectional antennas used at the base stations, the average bit error rate (BER), P_b, for a user can be found from the Gaussian approximation [11].

$$P_b = Q\left(\sqrt{\frac{3N}{K-1}}\right) \qquad (3)$$

Where K is the number of users in a cell and N is the spreading factor. $Q(x)$ is the standard Q-function.

To illustrate how directive antennas can improve the reverse link in a single-cell CDMA system, consider Fig.6, which illustrates three possible base station antenna configuration.

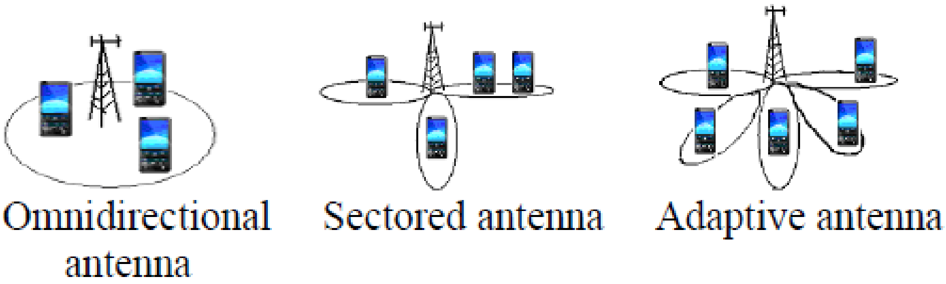


Fig. 6. Base Station Antenna Configurations

The omnidirectional receiver antenna will detect signals from all users in the system, and thus will receive the greatest amount of noise. The sectored antenna will divide the received noise into a smaller value and will increase the number of user (capacity) in the CDMA system. The adaptive antenna will be used to simultaneously steer energy jn the direction of many users at once, so it provides a spot beam for each user, and it is this implementation which is the most powerful form of SDMA [12] [13].

Assume that a beam pattern $F(\emptyset)$ in equation (1), is formed such that the pattern has maximum gain in the direction of the desired user. Such a directive pattern can be formed at the base station using an N-element circular array antenna. The pattern, $F(\emptyset)$ can be steered through 360° in the horizontal ($\emptyset$) plane such that the desired user is always in the main beam of the pattern. It is assumed that K users in the single-cell CDMA system are uniformly distributed throughout a two-dimensional cell (in the horizontal plane, $\theta = \pi/2$), and the base station antenna is capable of simultaneously providing such a pattern for all users in the cell. On the reverse link, the power received from the desired mobile signals is P_{ro} . The powers of the signal incident at the base station antenna from K-1 interfering users are given by $P_{r,i}$ for i = 1, ……k -1. The average total interference power, I, seen by a single desired user, (measured in the received signal at the array port of the base station antenna array, which is steered to the user 0), is given by:

$$I = E\left\{\sum_{i=1}^{K-1} F(\emptyset i) P_{r,i}\right\} \qquad (4)$$

Where $\emptyset_i$ is the direction of the ith user in the horizontal plane, measured in the x-axis, and E is the expectation operator. No interference from adjacent cells contributes to total received interference in equation (4) [11].

Assuming perfect power control is applied such that the power incident at the base station antenna from each user is the same, then $P_{r,i} = P_c$ for each of the *K* users, base station antenna pattern has no variation in the θ direction and the users are independently and identically distributed throughout the cell. The average bit error rate for user 0 can thus be given by [4]:

$$P_b = Q\left(\sqrt{\frac{3DN}{K-1}}\right) \qquad (5)$$

Where *D* is the directivity of the antenna, given by *Max*(F(ϕ_i)). In typical cellular installations, *D* ranges between 3 dB to 10 dB [4].

Equation (5) is useful in showing that the probability of error for a SDM-CDMA system is related to the beam pattern of a receiver, and there it is immediately apparent that the gain of the antenna directly contributes to the performance of a CDMA system. A considerable improvement that is achieved by using a high directivity adaptive circular array antenna at the base station.

5. Performance of SDMA-CDMA system over fading channel and adjacent cells interference

Fig.7 shows a desired signal and interference signals from mobiles within cells and outer cells for both omnidirectional Beams and directional beams. Clearly, directional beams reduce the interference power and boast the signal to interference-plus-noise ratio [14] [15].

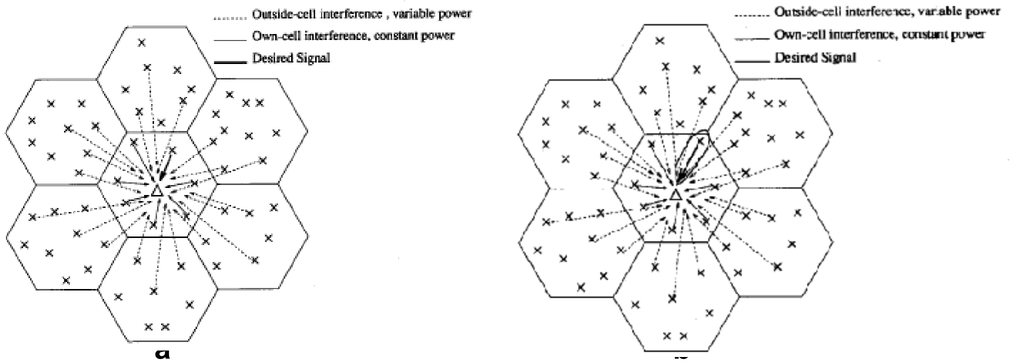


Fig.7 Multi cell interference in the reverse link.

a- Omnidirectional, b- Directional beams.

For CDMA operating in an Frequency selective Rayleigh Fading and Additive White Gaussian Noise (AWGN) channel, with perfect power control with interference from adjacent cells which equipped by a conventional correlated- type receiver at the base station and with SDMA technique by using

adaptive array antennas at the base station, the average Bit Error Rate(BER), *Pe* be found from the Standard Gaussian Approximation as [12] [11].

$$P_e' = \frac{1}{2} - \frac{1}{2\sqrt{1 + \frac{N_0}{2E_b} + \frac{2}{3DN_c}\left[(1+\frac{M_c}{5})LK - 1\right]}} \qquad (6)$$

Where

E_b/N_0 = Signal to Noise (AWGN) ratio.

N_c= Processing gain of the CDMA system.

M_c = Number of interfering cells.

L = Number of channel multi paths.

K = Number of user per cell.

6. SIMULATION AND RESULTS

A MATLAB program was used to plot the radiation patterns of a UCA antenna depending on equation (1) in the polar plan and as 3-D plot as shown in figure 8, considering as an application a reverse link SDMA-CDMA mobile system with transmitted frequency of 1.9 GHz [16]. For this application the simulation results show that the antenna diameter (2R) is suitable as a mechanical dimension to be mounted on the mobile base station .

When looking at the polar plot, the spot beams covering the whole direction of the whole user's cell. To be able to form K separated spot beams at the base station with the required directivity D for each beam and pointed at each of the K users within the cell of interest, it needs to estimate the array response vector, or the spatial signature, of the desired user mobile. Using this estimate of the array response vector, it can form a beam towards each mobile and this can be achieved by beamforming techniques (switched beamforming or adaptive beamforming).

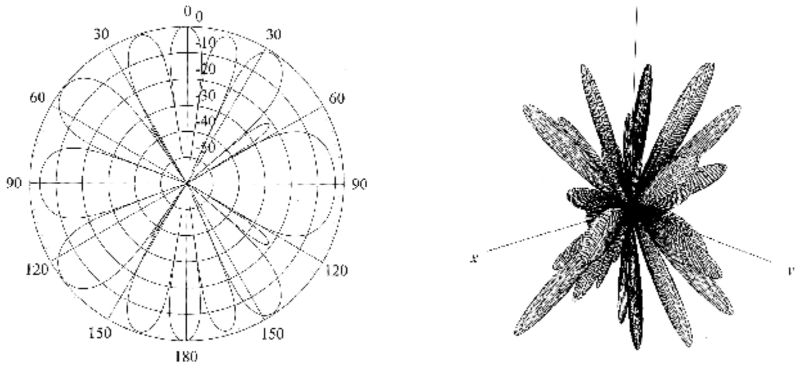


Fig.8 Radiation patterns of single ring antenna

$R=2\lambda$, $\theta_o=45$, $\emptyset_o=60$, $N=8$.

There are mainly two approaches for beamforming: switched beamforming and Adaptive beamforming. Switched beamforming is a simpler approach where the direction of arrival (DOA) of the signal is detected and corresponding beam is formed in that direction by multiplying pre-computed complex vector (adding phase shift and scaling) called array factor (AF). When the user moves out of the beam, the next beam takes over (switching). In practice, the data from antennas is stored and multiplied with different AF to obtain many beams and processing the data concurrently, thus increasing the capacity by SDMA. Adaptive beamforming is more complex, but more efficient, where the radiation pattern is constructed dynamically such that interferers are blocked by placing nulls and beam is formed in the direction of users. By using fully adaptive antenna array, the beam can be constantly steered in the direction of the user as it moves. Here DOA is computed more frequently, followed by computation of AF i.e. complex weight for each antenna and the beam pattern formed by its multiplication with data at antenna array. Block diagram of adaptive beamforming is shown in Fig.9 [9] [7] [3].

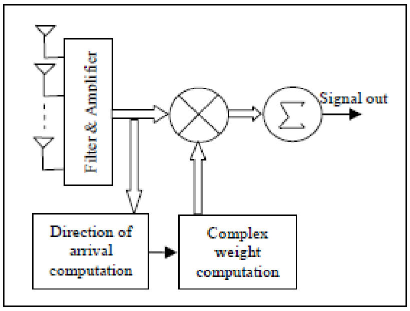
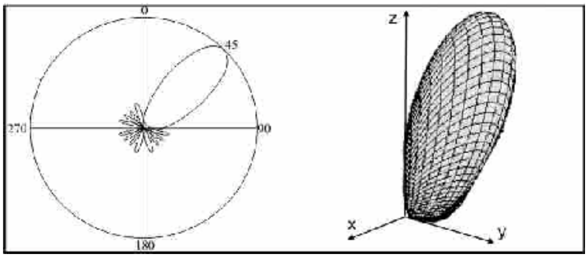
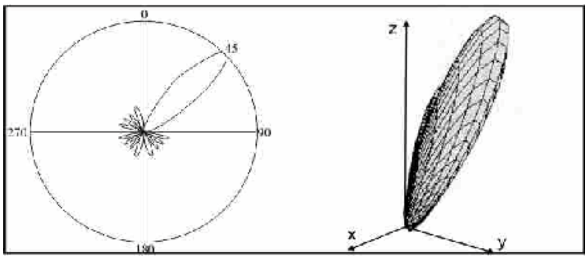


Fig.9. Adaptive beam forming

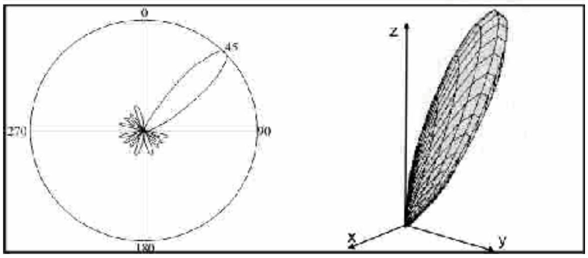
For evaluation purposes of the directivity value (D) in equation (5) and equation (6), a directive pattern in the direction of the desired user for the UCA antenna was evaluated using MATLAB calculation and the required directivity (D) was calculated depending on such patterns. The resultant pattern for different value of D is shown in Fig.10 bellow.



a- N=10, R=1λ, θ_o=45, ϕ_o=60, D=5dB



b- N=16, R=2λ, θ_o=45, ϕ_o=60, D=8dB



c- N=20, R=2λ, θ_o=45, ϕ_o=60, D=10dB

Fig.10. Directive Radiation pattern for UCA antenna.

A MATLAB program was used to plot the BER based on equation (5). In Fig.11 for a single cell interference and NC=64, the average bit error (BER) verses K was plotted at Nc=64 for a conventional CDMA system using Omnidirectional antenna and for SDMA system using adaptive circular array antenna (UCA) with different antenna directivity (5dB, 8dB and 10dB). System design parameters and system capacity (K) is given by table 1 evaluated at BER=10^{-3}.

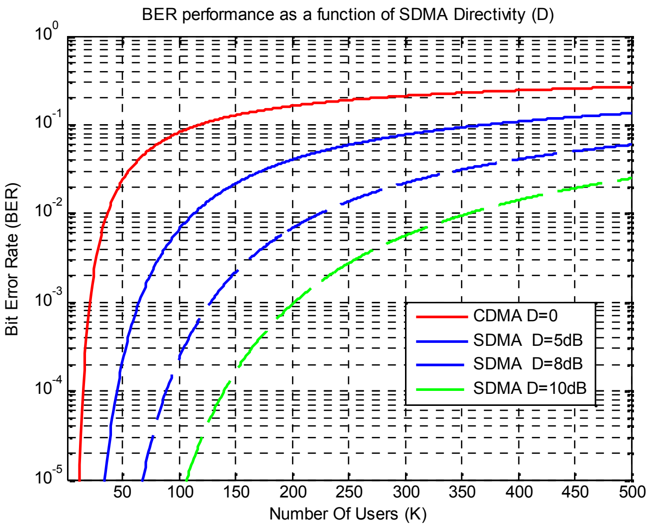


Fig. 11. Average BER verses number of users per cell (k).

Table.1. Design parameters for mobile communication at

f=1.9 GHz and single cell interference

Antenna	BER	D(dB)	R(Cm)	N	Mc	K
Omni	10^{-3}	0	-	1	1	22
UCA	10^{-3}	5	15.7	10	1	64
UCA	10^{-3}	8	31.4	16	1	128
UCA	10^{-3}	10	31.4	20	1	200

From the above results, it is clear that using circular array antenna, leads to improve system capacity considerably compared with the case of Omnidirectional antenna. At BER of 10^{-3}, the number of users are 22 for omnidirectional antenna against 64 users , 128 users and 200 users for UCA antenna with directivity of 5dB , 8dB and 10dB respectively.

Figures (12-14), shows the BER verses K according to equation(6) at Nc=64, L=6, and Eb/No=20dB, for different numbers of interfering cells (Mc) for the case of CDMA and SDMA-CDMA with antenna directivity equal to 5dB , 8dB and 10dB respectively. System design parameters and system capacity (K) is given by table 2 and table 3 evaluated at BER=10^{-1} .

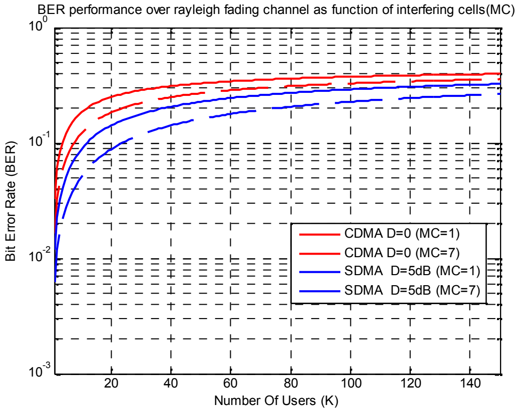


Fig.12 BER verses number of users per cell (k) for D=5dB.

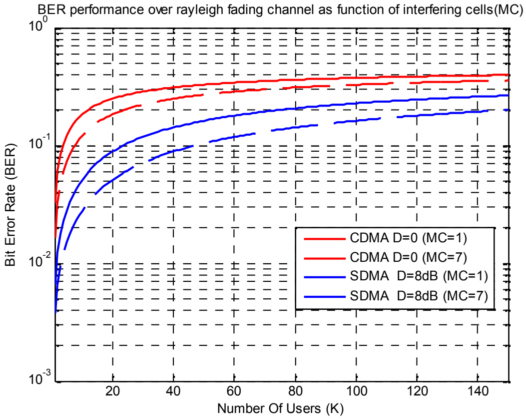


Fig.13 BER verses number of users per cell (k) for D=8dB.

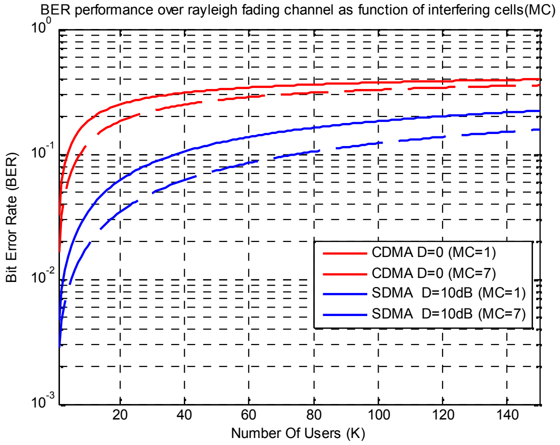


Fig.14 BER verses number of users per cell (k) for D=10dB.

Table.2. Design parameters for mobile communication at

f=1.9 GHz, Mc=1, and fading

Antenna	BER	D(dB)	R(Cm)	N	Mc	K
Omni	10^{-1}	0	-	1	1	8
UCA	10^{-1}	5	15.7	10	1	24
UCA	10^{-1}	8	31.4	16	1	48
UCA	10^{-1}	10	31.4	20	1	75

Table.3. Design parameters for mobile communication at

f=1.9 GHz, Mc=7, and fading

Antenna	BER	D(dB)	R(Cm)	N	Mc	K
Omni	10^{-1}	0	-	1	7	4
UCA	10^{-1}	5	15.7	10	7	11
UCA	10^{-1}	8	31.4	16	7	23
UCA	10^{-1}	10	31.4	20	7	36

At BER of 10^{-1} and Mc=1, the number of users are 4 for omnidirectional antenna (CDMA system) against 11 users , 23 and 36 users for UCA antenna (SDMA system) with directivity of 5dB , 8dB and 10dB respectively.

At BER of 10^{-1} and Mc=7, the number of users are 4 for omnidirectional antenna (CDMA system) against 11 users , 23 and 35 users for UCA antenna (SDMA system) with directivity of 5dB , 8dB and 10dB respectively.

Figures(15-16) shows the BER as a function of Eb/No for different numbers of users per cell (K) and for different numbers of the interfering cells (Mc) at Nc=64, L=6.

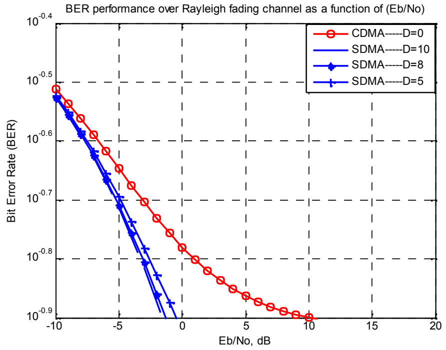


Fig. 15 BER as a function of signal to noise ratio

(Eb/No) K=10,Mc=1.

At low number of user per cell (K=10) , Fig.15 and figure 16 show that the SDMA system still not affected by the adjacent cells and fading interferences since there is a continuous curve decaying with Eb/No, while the CDMA system was considerably affected.

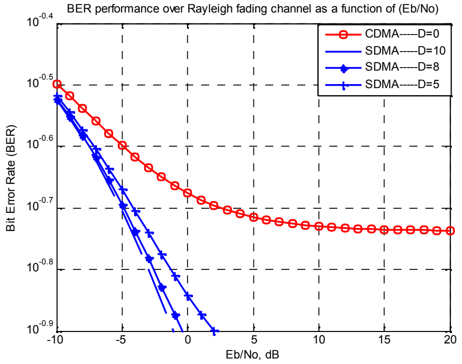


Fig. 16 BER as a function of signal to noise ratio (Eb/No)

K=10, Mc=7

7. CONCLUSION

The radiation patterns of the uniform circular array (UCA) antenna was evaluated for different antenna parameters for purposes of obtaining a directive multi spot beams to be used in the base station of SDMA-CDMA mobile system for the reverse link (up link) transmission to improve system capacity. Different antenna directivities was considered (5dB, 8dB, and 10dB) and a suitable design parameters was chosen so as to obtain a UCA antenna with suitable mechanical dimensions (R) to be mounted on the base station.

The BER of SDMA and CDMA was compared considering frequency Selective multipath Rayleigh Fading Channel and adjacent cells interference. The BER is found for a conventional CDMA System, and the another set of curves is found for SDMA System.

At BER of 10^{-3} and single cell system (Mc=1), the number of users are 22 for CDMA against 64 ,128, and 200 user for SDMA System with directivity of 5dB , 8dB and 10dB respectively. At BER of 10^{-1} , multi cell (Mc=7) and fading channel, the number of users are 4 for conventional CDMA system against 11, 23, and 36 users for SDMA system with directivity of 5dB , 8dB and 10dB respectively. This increase in the number of users illustrates the promise SDMA offers for improving capacity in mobile communication system.

At low number of user per cell, the SDMA system still not affected by the adjacent cells and fading interferences while the CDMA system was considerably affected.

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تقييم الهوائي الحلقي ذو المصفوفة الطورية في المحطة الموقعية للهاتف النقال لزيادة السعة العكسية

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المستخلص:

يعتبر الهوائي الحلقي ذو المصفوفة الطورية من الهوائيات ذات التطبيقات الواسعة في مجال اتصالات الهاتف النقال بهدف زيادة سعة المنظومة من خلال تقليل تداخل القناة المتلازم المتأتي من خلية واحدة ومن الخلايا المجاورة وتعتمد هذة التحسينات في السعة بشكل اساسي على شكل نموذج شعاع الهوائي وعلى اتجاهيته وأن هذة العملية تمثل ترشيحا حيزيا ,يعرف بتقنية تقسيم الحيز متعدد المنافذ.

تم في هذا البحث بلورة نتائج نظرية مع محاكات برمجية لتحليل نموذج شعاع الهوائي واتجاهيته بأعتماد معاملات تصميمية مختلفة متمثله بأعداد المشعات وقطر الحلقة وتوزيع التيار التحفيزي ومسح شعاع الهوائي.

يبين هذا البحث ايضا وباعتماد الحسابات البرمجيه, بأن اعتماد الهوائي الحلقي ذو المصفوفة الطورية في المحطة الموقعية للهاتف النقال يقود الى تحسين سعة القناة العكسية لمنظومة تقسيم الشفره متعدد المنافذ المعتمدة في نظام التراسل الخلوي للهاتف النقال.