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A Certain Investigations on the Performance Issues of Smart Antennas for Cellular Mobile Communications

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***Abstract* - Adaptive antenna arrays are being developed to cope with the high capacity requirement of the 3G/4G wireless cellular communications systems. As adaptive antenna arrays focus narrow high gain beams towards the desired users and nulls towards the unwanted interferers, both coverage and capacity of the network can be improved. Radiation pattern of the array antennas depends on Geometric configurations, relative displacement between array elements, excitation amplitude and phase of individual elements and relative pattern of individual elements. The capacity of a Wireless network depends on the size of the antenna array, the beam pattern used and the speed with which the beam-former and Direction of Arrival estimator. The development of adaptive antenna includes the design of array antenna and optimizing the array antenna parameters such as directivity and half power beamwidth. We aimed to develop new array configurations with narrow beam pattern and to propose a suitable array configuration for capacity improvement in cellular mobile networks. In this paper, as an initial work, we have analyzed various types of existing primary array configurations such as linear, planar and circular arrays of isotropic sensors using array factor approach with the beamsteering capabilities using MATLAB simulations. From the simulation results it is clear that the circular and concentric circular arrays outperforms than other configurations.**

I. INTRODUCTION

The demand for Wireless Mobile Communication services are growing at an explosive rate, with the anticipation that communication to a mobile device anywhere on the globe at all times will be available in the near future. An array works on the premise that the desired signal and unwanted co-channel interferences arrive from different directions. The

beamforming and adaptive antenna arrays are very efficient capacity enhancement techniques. They have been proposed to reduce multipath fading of the desired signal and to suppress the co-channel interference. These antenna arrays have the function of optimizing the radiation pattern according to the environment. To cope with interference, smart antennas or adaptive array processing may be utilized to shape the antenna radiation pattern in such a way to enhance the desired signals and null the effect of the interfering signals.

II. SMART ANTENNAS

The need of the hour is the improved efficiency in beam formation, steering, power consumption, reduced co-channel interference, and QoS. Smart antenna promises to provide solution to the above mentioned problems [2]. With the Mobile Technology marching towards 3G / 4G there is more emphasis to reduce the bottleneck and to provide high data rate and good quality of service which can be accomplished with the help of smart antennas

III. ARRAY FACTOR

Array Factor is the mathematical representation of the radiation pattern of a particular configuration. Array factor is determined with the help of Maxwell's equations. As antenna operates in VHF and UHF, the electric and magnetic fields are governed by Maxwell's equations [1]. Every array has its own array factor. The uniqueness is because the array factor calculation takes in to account the effect of phase shift variation and geometry in which the elements are placed. Pattern Multiplication concept is one of the method to obtain the radiation pattern of array antennas, which involves multiplication of the unit pattern with the group pattern. Unit pattern is obtained by placing the single element or an array at the origin of the co-ordinate system and by evaluating its field at a point in the far field region. Group pattern is evaluated by replacing all the elements by hypothetic isotropic sensors and finding the radiation pattern.

IV. MICROSTRIP PATCH ARRAY

A patch antenna is a narrowband, wide-beam antenna fabricated by etching the antenna element pattern in metal trace bonded to an insulating dielectric substrate with a continuous metal layer bonded to the opposite side of the substrate which forms a ground plane. Because such antennas have a very low profile, are mechanically rugged and can be conformable, they are often mounted on the exterior of aircraft and spacecraft, or are incorporated into mobile radio communications devices. Electric field equations of single rectangular microstrip patch is given by [1]

$$E_{\varphi}^{t} = j k_0 W V_0 e^{-jk_0 r} / \pi r \, * \left\{ \frac{\sin\left(k_0 h * \frac{\cos\varphi}{2}\right)}{k_0 h * \frac{\cos\varphi}{2}} \right\} \cos\left(k_0 L_e * \frac{\sin\varphi}{2}\right) \qquad \text{-- 1}$$

V. LINEAR ARRAY

This array includes N-elements arranged in z-direction. Assuming that all elements have identical amplitudes but each succeeding element has a β progressive phase lead current excitation relative to the preceding one. An array of identical elements all of identical magnitude and each with a progressive phase are referred to as a uniform array.

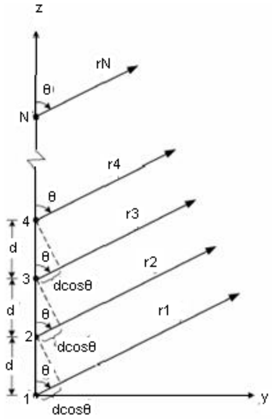

Fig.1 Linear array

The array factor is given by

$$AF = 1 + e^{+j(kd\cos\theta+\beta)} + e^{+j2(kd\cos\theta+\beta)} + e^{+j3(kd\cos\theta+\beta)} + \dots + e^{+j(N-1)(kd\cos\theta+\beta)} \quad \text{--2}$$

$$AF = \sum_{n=1}^{N} e^{+j(n-1)(kd\cos\theta+\beta)} \quad \text{-- 3}$$

This can be written as

$$AF = \sum_{n=1}^{N} e^{+j(n-1)\psi} \quad \text{-- 4}$$

Where $\Psi = k\ d\cos\theta + \beta$
The maximum radiation occurs at
$\psi = 0$ hence $\beta = -\ k\ d\cos\theta$

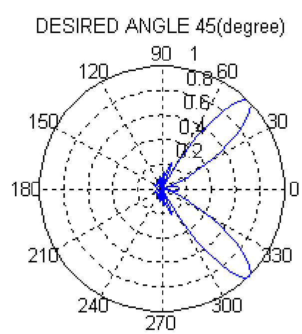

Fig.1.1 Radiation pattern of 16-element ULA with 45°

VI.PLANAR ARRAY

In addition to placing elements along a line, individual radiators can be positioned along a rectangular grid to form a rectangular or planar array. Planar arrays provide additional variables which can be used to control and shape the pattern of the array.
Planar arrays are more versatile and can provide more symmetrical patterns with lower side lobes. In addition, they can be used to scan the main beam of the antenna towards any point in space.

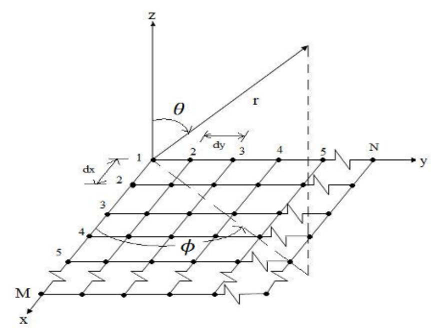

Fig.2 Planar Array

If m elements are placed along x-direction and n elements are placed along y-direction with spacing of d_x and d_y respectively. The array factor of planar array is given by

$$AF = S_{xm} * S_{yn}$$

Where

$$S_{xm} = \sum_{m=1}^{M} I_m * e^{j(m-1)(k*d*\sin(\theta)*\cos(\phi)+\alpha_x)} \quad \text{-- 5}$$

$$S_{yn} = \sum_{n=1}^{N} I_n * e^{j(n-1)(k*d*\sin(\theta)*\sin(\phi)+\alpha_y)} \quad \text{-- 6}$$

The normalised form of array factor is given by

$$AF(\theta,\phi) = \left\{\frac{1}{M}\frac{\sin\left(\frac{M}{2}\psi_x\right)}{\sin\left(\frac{\psi_x}{2}\right)}\right\}\left\{\frac{1}{N}\frac{\sin\left(\frac{N}{2}\psi_y\right)}{\sin\left(\frac{\psi_y}{2}\right)}\right\} \quad \text{-- 7}$$

where

$$\psi_x = k*d_x*\sin(\theta)*\cos(\phi)+\alpha_x$$
$$\psi_y = k*d_y*\sin(\theta)*\sin(\phi)+\alpha_x$$

To avoid grating lobes in the x-z and y-z planes, the spacing between elements in the x- and y- directions, respectively, must be less than λ ($d_x < \lambda$ and $d_y < \lambda$). For a rectangular array, the major lobes and grating lobes of S_{xn} and S_{yn} are located at

$$kd_x\sin\theta\cos\phi + \alpha_x = \pm 2m\pi \qquad m = 0, 1, 2...$$
$$kd_y\sin\theta\sin\phi + \alpha_y = \pm 2n\pi \qquad n = 0, 1, 2...$$

If it is desired to have a main beam directed along $\theta = \theta_0$ and $\phi = \phi_0$,the progressive phase shift between the elements in the x and y directions must be equal to

$$\alpha_x = -kd_x \sin\theta_0 \cos\phi_0$$
$$\alpha_y = -kd_y \sin\theta_0 \sin\phi_0$$

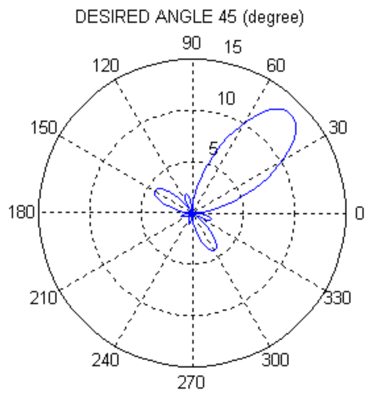

Fig.2.1 Radiation pattern of 4*4 uniform planar array with 45°dx=dy=λ/2,

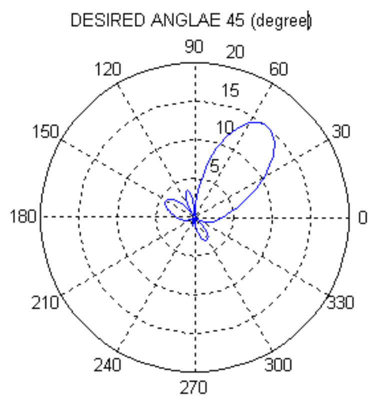

Fig.3.1 Radiation pattern of 4*4 non-uniform planar array with 45° dx= λ/2;dy=λ/4

VII.CIRCULAR ARRAY

The circular array, in which the elements are placed in a circular ring, is an array configuration of very practical interest. If N isotropic elements are equally spaced on the XY plane along a circular ring of the radius a.

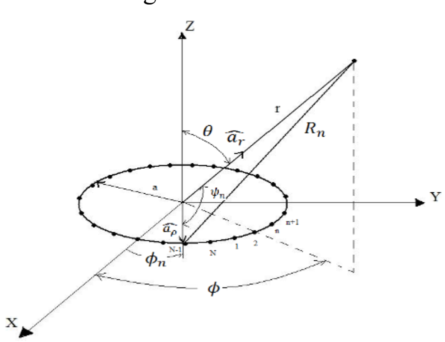

Fig.3 Circular Array

The normalised field of the array can be written as

$$E_n(r,\theta,\phi) = \sum_{n=1}^{N} a_n \frac{e^{-jkR_n}}{R_n} \qquad \text{-- 8}$$

Where R_n is the distance from the nth element to the observation point.

$$R_n = (r^2 + a^2 - 2ar\cos\psi)^{1/2}$$

When $R_n \approx r$ then

$$E_n(r,\theta,\phi) = \frac{e^{-jkr}}{r} \sum_{n=1}^{N} a_n e^{jka\sin\theta\cos(\phi-\phi_n)} \qquad \text{-- 9}$$

where

$a_n =$ excitation coefficients of nth element

$\phi_n = 2\pi \frac{n}{N}$ = angular position of the nth element on x-y plane.

In general

$$E_n(r,\theta,\phi) = \frac{e^{-jkr}}{r} [AF(\theta,\phi)] \qquad \text{-- 10}$$

where

$$AF(\theta,\phi) = \sum_{n=1}^{N} I_n e^{j[ka\sin\theta\cos(\phi-\phi_n)+\alpha_n]} \qquad \text{-- 11}$$

The above equation represents the array factor of a circular array of N equally spaced elements. To direct the peak of the main beam in the (θ_o, ϕ_o) direction, the phase excitation of the nth element can be chosen to be

$\alpha_n = -ka\sin\theta_o \cos(\phi_o - \phi_n)$

The array factor can be simplified as

$$AF(\theta,\phi) = \sum_{n=1}^{N} I_n e^{jk\rho_o(\cos\phi_n - \xi)}$$

where

$$\rho_o = a[(\sin\theta\cos\phi - \sin\theta_o\cos\phi_o)^2 + (\sin\theta\sin\phi - \sin\theta_o\sin\phi_o)^2]^{1/2}$$

$$\xi = \tan^{-1}\left[\frac{\sin\theta\sin\phi - \sin\theta_o\sin\phi_o}{\sin\theta\cos\phi - \sin\theta_o\cos\phi_o}\right]$$

For uniform amplitude excitation of each element $(I_n = I_o)$, the array factor can be written as

$$AF(\theta,\phi) = NI_o \sum_{n=1}^{N} J_{mN}(k\rho_o) e^{jmN(\pi/2-\xi)} \qquad \text{-- 12}$$

Where $J_{mN}(x)$ is the Bessel function of the first kind. The part of the array factor associated with zero order Bessel function $J_0(k\rho_o)$ is called the *principal term* and the remaining terms are noted as the *residuals*. For a circular array with large number of elements, the term $J_0(k\rho_o)$ alone can be used to approximate the two dimensional principal plane patterns. The remaining terms can be neglected.

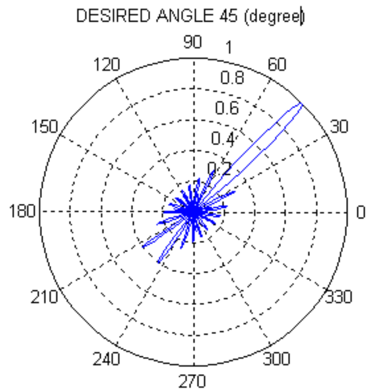

Fig.4.1.Radiation pattern of circular array with 45°

VII.CONCENTRIC CIRCLES

The concentric circular array, in which the elements are placed in a concentric circular fashion, is an array configuration of very practical interest. Here the number of elements in each concentric circle decides the beam width and number of side lobes in the radiation pattern.

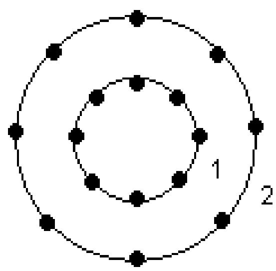

Fig.4. Concentric Circular Array-16 elements

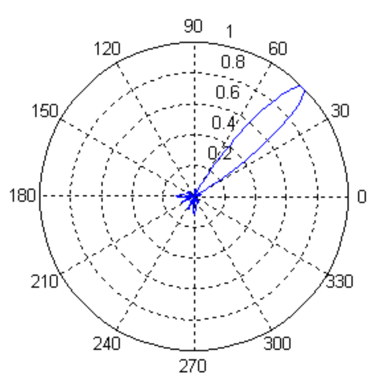

Fig.5.1.Radiation pattern of circular array with 45°

IX.MODIFIED CONCENTRIC CIRCULAR ARRAY

The array factor of concentric circles is obtained by pattern multiplication concept.

$$AF(\theta,\phi) = N I_0 \sum_{m=1}^{N} J_{mN}(k\rho_a)\, e^{jmN(\pi/2-\phi)}$$

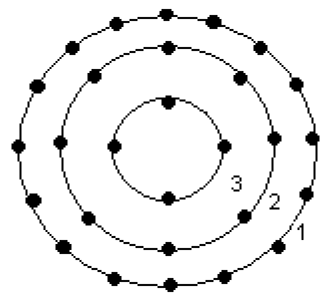

Fig.5 Modified Concentric Circular Array

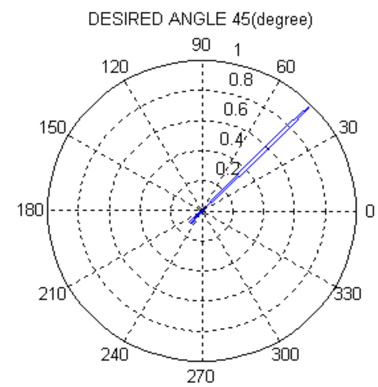

Fig.5.1.Radiation pattern of modified concentric circular array with 45°

X.RESULTS AND DISCUSSIONS

The number of elements considered for simulation environment is 16.

TABLE 1.1

COMPARISON OF VARIOUS ARRAY CONFIGURATIONS WITH DESIRED ANGLE 45°

ARRAY CONFIGURATIONS	**HPBW (degree)**
LINEAR	21.6
RECTANGULAR-uniform spacing	86.4
RECTANGULAR- non uniform spacing	169.2
CIRCULAR	5.729
CONCENTRIC CIRCLES	12.602

TABLE 2.1.

COMPARISON OF VARIOUS ARRAY CONFIGURATIONS WITH DESIRED ANGLE 60°

ARRAY CONFIGURATIONS	**HPBW (degree)**
LINEAR	14.4
RECTANGULAR-uniform spacing	79.2
RECTANGULAR- non uniform spacing	169.2
CIRCULAR	5.729
CONCENTRIC CIRCLES	12.602

TABLE 3.1

COMPARISON OF VARIOUS CIRCULAR ARRAY CONFIGURATIONS WITH DESIRED ANGLE 60° AND 45°

ARRAY CONFIGURATIONS	**HPBW (degree)**
CIRCULAR	5.729
MODIFIED CONCENTRIC CIRCULAR	2.291

Referring to the above tables the circular array offers very narrow beamwidth that remains constant even when the main lobe is steered at different angles. From table 3.1 as the number of elements in the concentric circular configuration increases, the beamwidth reduces considerably.

XI.CONCLUSIONS AND FUTURE WORK

We have analyzed various types of primary array configurations such as linear, planar and circular arrays of isotropic sensors using array factor approach with the beam steering capabilities using MATLAB simulations. Simulation results proved that the number of elements in the concentric circular array increases, beamwidth reduces than other configurations. A narrow beam pattern leads to the substantial improvement in the capacity of the cellular mobile network. Hence we propose modified concentric circular array configuration may be the suitable one for cellular mobile communication base station antenna. In future the above analysis to be carried out for microstrip arrays for all the configurations and these arrays will be designed by using IE3D (Integrated Electromagnetic 3 Dimensional simulation and optimization) software.

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