A Novelistic Approach for Rapid Beam Forming in Smart Antennas for Wireless Applications using Smart-Fractal concepts and New Algorithm

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***Abstract*— Smart antennas offer a broad range of ways to improve wireless system performance. It provides enhanced coverage through range extension, hole filling and better building penetration. Smart antennas use an array of low gain antenna elements which are connected by a network. Fractal concepts are used in antenna arrays recently. The important properties of fractal arrays are frequency independent multi-band characteristics, schemes for realizing low side lobe designs, systematic approaches to thinning and the ability to develop rapid beam forming algorithms. In this paper, an attempt has been made to apply assignment of usage time and location tag algorithm for smart antennas combined with the fractal concepts to reduce the computational complexity and enhance resource allocation for rapid beam forming algorithms.**

***Keywords* — Smart antennas, Beam forming, Fractal concepts, Assignment of usage time algorithm**

I. Introduction

SMART antennas are MIMO arrays that emphasizes on the signal-of-interest and minimizes the interfering signals by adjusting or adapting its own beam pattern. This is done by varying the relative phases of the respective signals feeding the antennas in such a way that the effective radiation pattern of the array is reinforced in the desired direction and suppressed in undesired directions to model any desired radiation pattern. Smart antenna techniques are used notably in signal processing, RADAR, radio astronomy, and cellular systems like W-CDMA and UMTS. The smart antenna concept can be used in optical antenna technology also to produce rapid beam scanning. Spatial time multiplexing techniques and space time block code techniques also widely use smart antennas. UWB communication also makes use of smart antennas with proper bandwidth allocated to it.

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II. Fractal Concepts

A fractal is a recursively generated object having a fractional dimension. Many objects, including antennas, can be designed using the recursive nature of a fractal. The important properties of fractal arrays are frequency independent multi band characteristic schemes for realizing low-side lobe designs, systematic approaches to thinning, and the ability to develop rapid beam-forming algorithms by exploiting the recursive nature of fractals. These arrays have fractional dimensions that are found from generating sub array used to recursively create the fractal array.

The term fractal, meaning *broken* or *irregular fragments*, was originally coined by Mandelbrot [1] to describe a family of complex shapes that possess an inherent self-similarity in their geometrical structure. Since the pioneering work of Mandelbrot and others, a wide variety of applications for fractals has been found in many branches of science and engineering. One such area is fractal electrodynamics, in which fractal geometry is combined with electromagnetic theory for the purpose of investigation of new class of radiation, propagation, and scattering problems. One of the most promising areas of fractal electrodynamics research is in its applications to antenna theory and design. We refer to this new and rapidly growing field of research as fractal antenna engineering. There are primarily two active areas of research in fractal antenna engineering: study of fractal-shaped antenna elements, and, the use of fractals in antenna arrays.

The first application of fractals to the field of antenna theory was reported by Kim and Jaggard [2]. They introduced a methodology for designing low-side lobe arrays that is based on the theory of random fractals. Lakhtakia *et al.* [3] demonstrated that the diffracted field of a self-similar fractal screen also exhibits self-similarity. The fact that self-scaling arrays can produce fractal radiation patterns was first established and the work was later extended to the case of concentric ring arrays by Liang *et al*. [4]. Applications of fractal concepts to the design of multi-band Koch arrays, as well as to low-side lobe Cantor arrays, are discussed by Puente Baliarda *et al*. [5]. Other types of fractal array configurations are discussed by Douglas H. Werner *et al*. [6].

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A rich class of fractal arrays exists that can be formed recursively through the repetitive application of a generating sub array. A generating sub array is a small array at scale one ($P = 1$) where P is the scale factor, is used to construct larger arrays at higher scales ($\text{i.e.} P > 1$). In many cases, the generating sub array has elements that are turned on and off in a certain pattern. A set formula for copying, scaling, and translation of the generating sub array is then followed in order to produce the fractal array. Hence, fractal arrays that are created in this manner will be composed of a sequence of self-similar sub arrays. In other words, they may be conveniently thought of as arrays of arrays [6].

The array factor for a fractal array of this type may be expressed in the general form :

$$AF_P(\psi) = \prod_{i=1}^{P} \hat{G}A(\delta^{i-1}\psi) \tag{1.1}$$

where $GA(\psi)$ represents the array factor associated with the generating sub array. The parameter δ is a scale or expansion factor that governs how large the array grows with each recursive application of the generating sub array. The expression for the fractal array factor given in equation (1.1) is simply the product of scaled versions of a generating sub array factor. Therefore, we may regard equation (1.1) as representing a formal statement of the pattern multiplication theorem for fractal arrays. Applications of this specialized pattern-multiplication theorem to the analysis and development of rapid beam forming algorithms will be considered in the following sections.

III. Smart Antennas : Beam-forming

There is an ever-increasing demand on mobile wireless operators to provide voice and high-speed data services. At the same time, these operators want to support more users per base station to reduce overall network costs and make the services affordable to subscribers. As a result, wireless systems that enable higher data rates and higher capacities are a pressing need. Unfortunately, because of the availability of broadcast spectrum is limited, attempts to increase traffic within a fixed bandwidth create more interference in the system and degrade the signal quality.

In particular, when Omni-directional antennas [Figure 1(a)] are used at the base station, the transmission/reception of each user's signal becomes a source of interference to other users located in the same cell, making the overall system interference limited. An effective way to reduce this type of interference is to split up the cell into multiple sectors and use sectorized antennas, as shown in Figure 1(b).

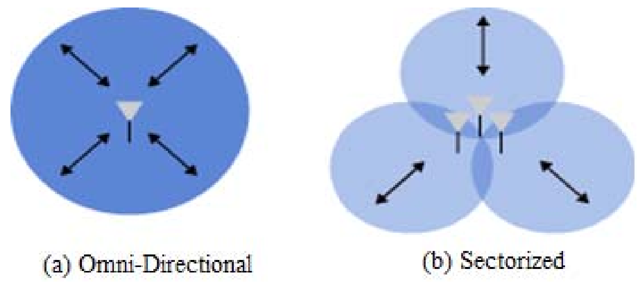

Fig. 1. Non Smart Antennas System

Smart antenna technology offers a significantly improved solution to reduce interference levels and improve the system capacity. With this technology, each user's signal is transmitted and received by the base station only in the direction of that particular user. This drastically reduces the overall interference in the system. A smart antenna system, as shown in Figure 2 and 3, consists of an array of antennas that together direct different transmission/reception beams towards each user in the system. This method of transmission and reception is called beam forming and is made possible through smart (advanced) signal processing at the baseband.

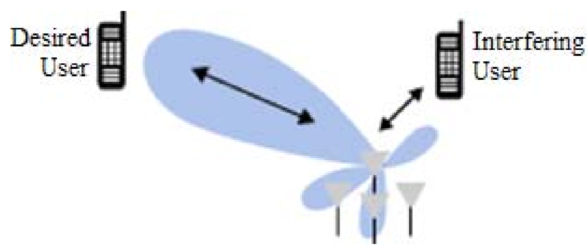

Fig. 2. Smart Antenna System - Beam forming

In beam forming, each user's signal is multiplied with complex weights that adjust the magnitude and phase of the signal to and from each antenna. This causes the output from the array of antennas to form a transmit/receive beam in the desired direction and minimizes the intensities in other directions.

If the complex weights are selected from a library of weights that form beams in specific, predetermined directions, the process is called switched beam forming. Here, the base station basically switches between the different beams based on the received signal strength measurements. On the other hand, if the weights are computed and adaptively updated in real time, the process is called adaptive beam forming. Through adaptive beam forming, the base station can form narrower beams towards the desired user and nulls towards interfering users, considerably improving the signal-to-interference-plus-noise ratio.

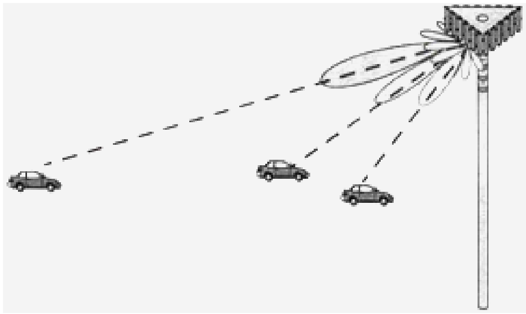

Fig. 3. Separate beam for each user

IV. Fractal Algorithm

One of the more intriguing attributes of fractal arrays is the possibility for developing algorithms, based on the compact product representation of equation (1.1), which are capable of performing extremely rapid pattern computations. For example consider a linear array of isotropic elements, uniformly spaced and a distance d apart along the z axis. The array factor corresponding to this linear array may be expressed in the form :

$$AF(\psi) = I_o + 2\sum_{n=1}^{N} I_n \cos\{n\psi\} \qquad (1.2)$$

for odd number of elements and,

$$AF(\psi) = 2\sum_{n=1}^{N} I_n \cos\left\{\left(n-\frac{1}{2}\right)\psi\right\} \qquad (1.2)$$

for even number of elements where n is the total number of elements.

$$N = \left(\frac{n-1}{2}\right) \qquad (1.4)$$

$$\psi = kd\{\cos\theta - \cos\theta_o\} \qquad (1.5)$$

$$k = \frac{2\pi}{\lambda} \qquad (1.6)$$

The directivity for fractal array antenna is given by :

$$D_P(u) = \frac{\hat{A}F_P^2\left(\frac{\pi}{2}u\right)}{\frac{1}{2}\int_{-1}^{1}\hat{A}F_P^2\left(\frac{\pi}{2}u\right)du} \qquad (1.7)$$

where,

$$\psi = \frac{\pi}{2}u \qquad (1.8)$$

and,

$$u = \cos\theta \qquad (1.9)$$

These arrays become fractal-like when appropriate elements are turned off or removed, such that

$I_n = 1$, if element n is turned ON, &
$I_n = 0$, if element n is turned OFF.

Hence, fractal arrays produced by following this procedure belong to a special category of thinned arrays. If the above equations are used to calculate the array factor for an odd number of elements, then N cosine functions must be evaluated and N additions performed, for each angle. One of the simplest schemes for constructing a fractal linear array follows the recipe for the Cantor set. Cantor linear arrays were first proposed and studied in [5] for their great potential use in the design of low-side lobe arrays.

The basic triadic Cantor array may be created by starting with a three- element generating sub-array, and then applying it repeatedly over P scales of growth. The generating sub-array in this case has three uniformly spaced elements, with the center element turned off or removed, i.e., 101. The triadic Cantor array is generated recursively by replacing 1 by 101 and 0 by 000 at each stage of the construction. For example, at the second stage of construction ($P = 2$), the array pattern would look like :

1 0 1 0 0 0 1 0 1

In this fashion the different stages of fractal pattern is grown. Starting with the basic stage whatever value we assume for the basic stage the value will be substituted for each stage and the antenna array grows in size rapidly. The same case can be applied for planar construction also. Current research and investigations on three dimensional fractal arrays is in progress to refine and tailor the pattern of the required beam. Research is also in progress on non-linear arrays with non uniform amplitude and un equal spacing arrays to get the radiation pattern of desired extent.

At the third stage ($P = 3$) , we would have :

1 0 1 0 0 0 1 0 1 0 0 0 0 0 0 0 0 0 1 0 1 0 0 0 1 0 1

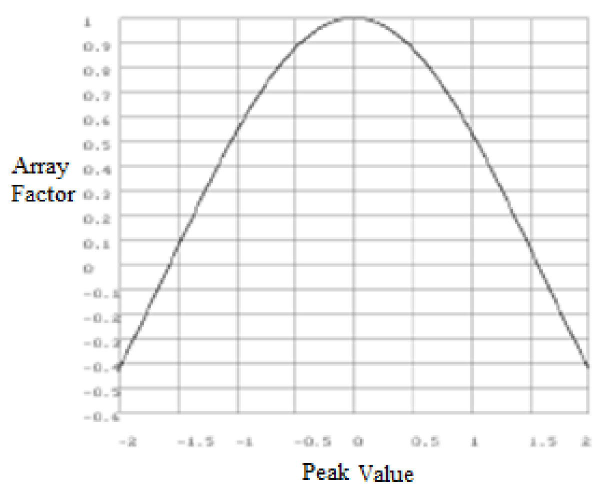

Fig. 4: Fractal array pattern for $P = 1$; $\delta = 3$.

The array factor of the three-element generating subarray with the representation 101 is :

$$GA(\psi) = 2\cos\{\psi\} \qquad (1.10)$$

which may be derived from Array factor equation by setting $N = 1, I_o = 0 \;\&\; I_1 = 1$. Substituting this equation into equation (1.1) and choosing an expansion factor of 3, results in an expression for the Cantor array factor given by :

$$\hat{A}F_P(\psi) = \prod_{i=1}^{P} \hat{G}A(3^{i-1}\psi) = \prod_{i=1}^{P} \cos\{3^{i-1}\psi\} \qquad (1.11)$$

where the hat notation indicates that the quantities have been normalized. The array factor plot and the directivity plot for different values of P and δ are shown in Figures 4 to 9.

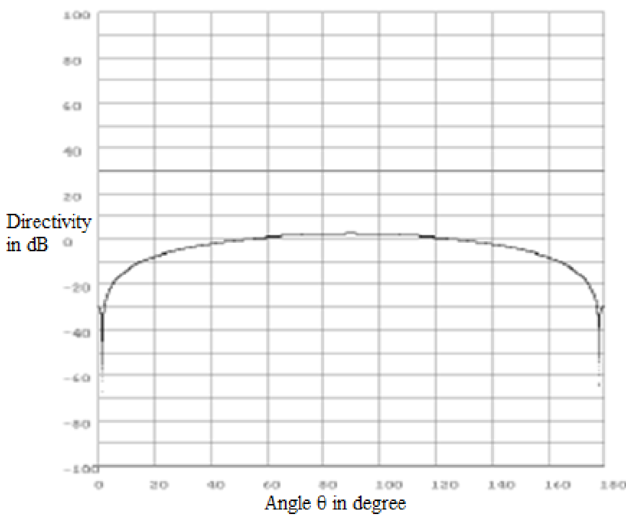

Fig. 5: Directivity pattern for $P = 1$; $\delta = 3$.

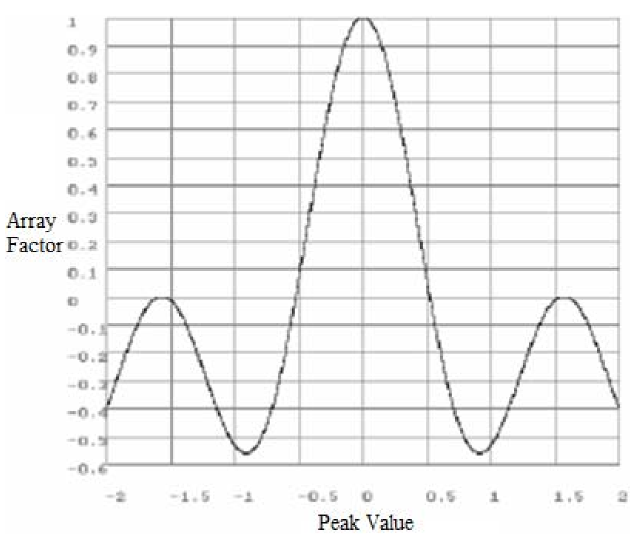

Fig. 6: Fractal array pattern for $P = 2$; $\delta = 3$.

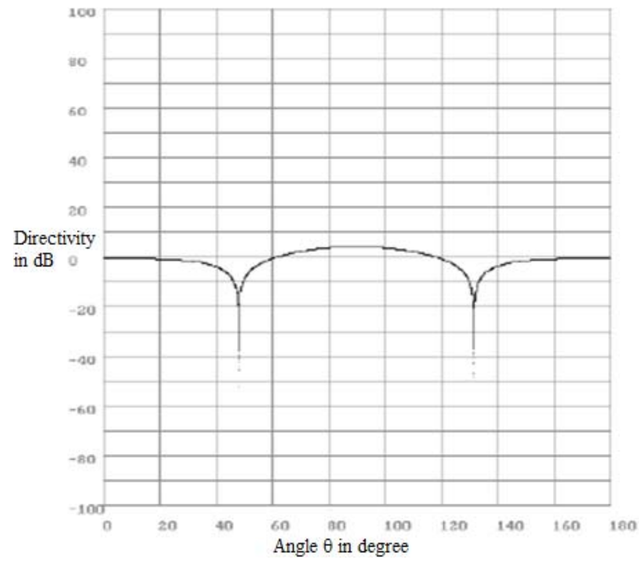

Fig. 7: Directivity pattern for $P = 2$; $\delta = 3$.

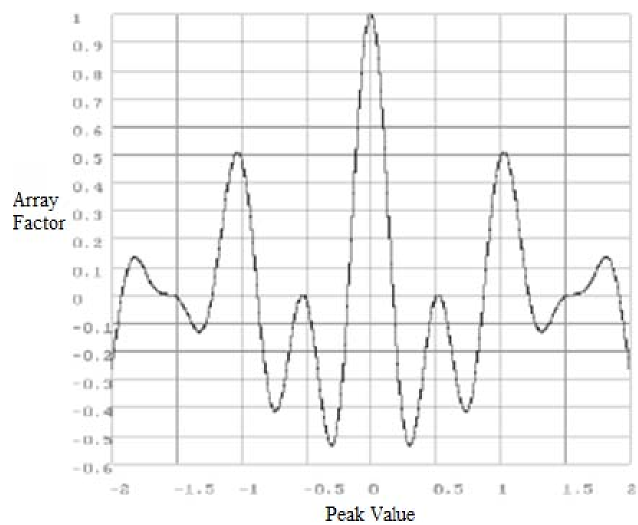

Fig. 8: Fractal array pattern for $P = 3$; $\delta = 3$.

As both values increases the plot shows improvement in characteristics, the directivity increases and the pattern becomes narrower. Another fantastic advantage is the equation (1.11) only requires P cosine–function evaluations and P-1 multiplication. In the case of an 81 element triadic cantor array, the fractal array factor is at least $N/_P = 40/_4 = 10$ times faster to calculate than the conventional discrete Fourier transform. The multiband characteristics of linear fractal array is discussed in [3] and [4]. The same procedure can be applied for the Sierpinski carpet arrays for developing efficient algorithms which can be used in planar smart antennas. The multiband characteristics of Sierpinski carpet array is discussed in [5]. More about fractal arrays are discussed in [6].

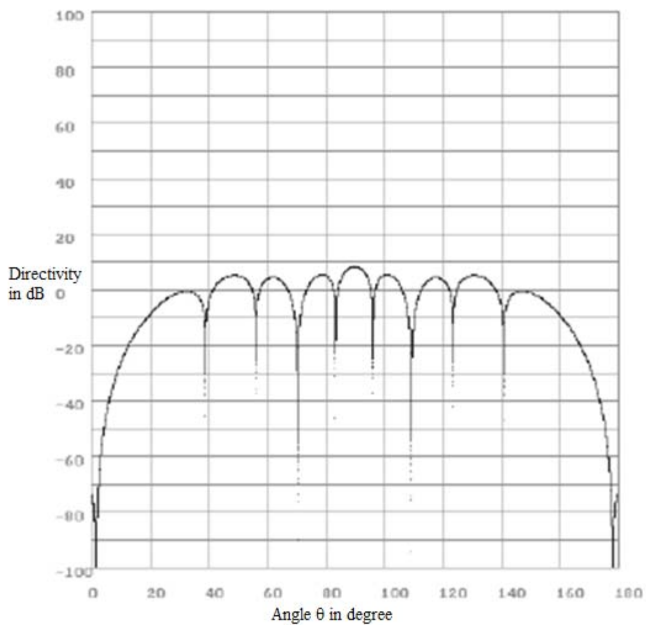

Fig. 9: Directivity pattern for $P = 3$; $\delta = 3$.

Table 1 shows the increase in speed factor as the values of P and δ varies. As the value of P and δ increases the speed factor increases enormously. For example, with for $P = 4$ & $\delta = 7$ the fractal array factor is 300 times faster to calculate than the conventional case. This property can be utilized in smart antennas to produce rabid beam forming algorithms.

	P=1	P=2	P=3	P=4	P=5
δ=3	1	2	4	10	24
δ=5	2	6	20	78	312
δ=7	3	12	57	300	1680
δ=9	4	20	121	820	5904

Table 1: Tabulation of the variation of P and δ.

V. Assignment Of Usage Time And Location Tag Algorithm

After studying the advantages of fractal concepts over the development of rapid beam forming algorithms in smart antennas and some new algorithms [8] , now we can extend the concept to another new algorithm technique called assignment of usage time and location tag algorithm.. Let us consider the same case of four users. Assume that the initial two proposed algorithms are applied and the system is working in efficient mode. We will simply call this as efficient mode as far as our case is considered. This can be considered as algorithm over algorithms to increase the effectiveness of the system. Now let us introduce the parameters called delta which refers to the effective usage time of each user and sigma which refers to the location tag of each user. Assume that we have some mechanisms to know the probability of usage duration of each user and we got the location tag by global positioning systems. Note that we have already optimized the system with respect to user speed and having introduced a new technique called scan antenna technology, now this additional parameters can still enhance the system speed effectively. From the smart antenna side there is a considerable amount of time is needed for the development of each new beam. With these two parameters delta and sigma, now there are four possible cases for each user if we take only two variables into account i.e. long and short duration user and fast and slow moving user. A user can be in long duration and slow moving, long duration and fast moving, short duration and slow moving and finally short duration and fast moving as show in Table 2.

Sl No.	User	Usage time	Location tag	Computation and Resource allocation
1	A	Long duration	Slow moving	Very less
2	B	Long duration	Fast moving	Less
3	C	Short duration	Slow moving	Medium
4	D	Short duration	Fast moving	High

Table 2: Look-up table.

From the Look-up table it can be easily concluded that user A can be considered as stationary user since he is in long duration and slow moving. The term smart can be removed from user A antennas and can be allotted a single wide coverage beam antenna. The computational complexity time and resource allocation will be nullified. User B can be given less priority for he is long duration though fast moving. The type of beam pattern can be recognized and stored in memory. User C is short duration and slow moving, a type of medium complexity can be allotted. And finally as User D is concerned, he is short duration and fast moving therefore more complexity is required for him. All this data can be observed for a long time basis and stored in memory so that the observation table can help in allocating the resources which speeds up the process of producing rapid beams. Coverage performance analysis is discussed in [7] by Badjian *et al*. and uses genetic algorithm technique. But the proposed one in this paper is a novelistic approach to reduce the computational complexity and properly allocate the resource so that rapid beam forming can be enhanced.

VI. CONCLUSION

In this paper a rapid beam forming algorithm for smart antennas is proposed using the concepts of fractal array and novel algorithms and further it is enhanced by using algorithm over algorithm called assignment of usage time and location tag technique. It is found that the proposed methods greatly reduces the time needed for calculating the array factor and the proposed new techniques still enhances the allocation of computational resources for the development of rapid beam. It also reduces the memory requirements to a greater extent.

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