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Optimization of SLL in Concentric Circular Antenna Array using DE/BBO

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***Abstract:** In this paper, optimization of sidelobe level (SLL) of concentric circular antenna array is done using Hybrid differential evolution with Biogeography based optimization (DE/BBO) method. The concentric circular antenna arrays (CCAA) are used in mobile and communication applications. The reduction of SLL is needed to ensure that energy going in unwanted directions is greatly reduced and noise received from unwanted directions is eliminated. A trade-off between SLL and beamwidth exists in conventional optimization methods. Using random stochastic techniques like GA, PSO, BBO etc., SLL can be reduced without any appreciable effect on beamwidth. The SLL of CCAA is optimized using DE/BBO, BBO, PSO and GA methods and the results obtained are compared.*

***Index terms:** Antenna arrays, Beamwidth, Optimization technique, Sidelobe level.*

I. INTRODUCTION

The Concentric circular antenna array (CCAA) is a planar antenna array in which antennas are arranged in a concentric circular array structure. This antenna array is used in radar, mobile communication applications. This arrangement has low mutual coupling loss compared to linear antenna array. The structure of CCAA is used to scan total 360^0 of the azimuthal plane. DE/BBO is a modern evolutionary optimization technique. The migration operator and mutation operator of BBO, DE are combined to form a new operator called hybrid migration operator in this technique. The Hybrid migration operator of DE/BBO has good exploration because of migration operator of BBO and good exploitation capabilities because of the mutation of DE. The goal of optimization is to reduce the sidelobe level of CCAA without appreciable effect on beamwidth using different random stochastic methods like DE/BBO, Biogeography based optimization (BBO), Particle swarm optimization (PSO) and Genetic algorithm (GA).

II. CONCENTRIC CIRCULAR ANTENNA ARRAY (CCAA)

In CCAA, the elements are organized in concentric circular array fashion.

The array factor of concentric circular antenna array with centre element is given by

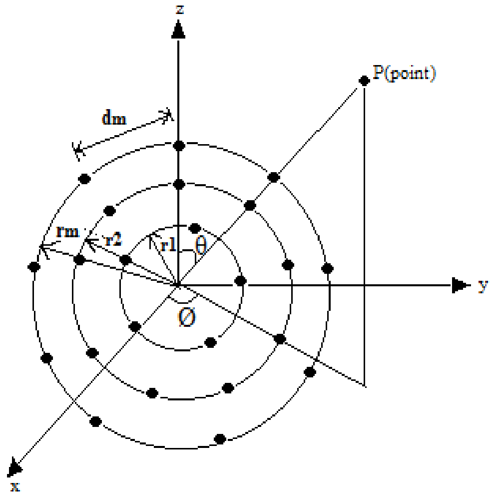

Fig. 1. Concentric circular antenna array

$$AF = \sum_{m=1}^{M} \sum_{n=1}^{N} I_{mn} e^{j(kr_m sin\theta(\cos(\emptyset-\emptyset_{mn})+\alpha_{mn})}$$

M = number of rings
G = Number of elements in first ring
Phase constant, $k = 2\pi/ \lambda$,
Wavelength of signal, $\lambda = 1$
I_{mn} = current excitation of m^{th} ring's n^{th} element
r_m = radius of m^{th} ring
d_m= spacing between elements in ring
N_m = Number of elements in m^{th} ring = $(2\pi r_m)/d_m$,
$\emptyset_{mn}$ represents angular position of n^{th} element of m^{th} ring,
$\emptyset_{mn} = 2\pi\ (n-1)/N_m$,
α_{mn} = residual phase,
Ø and θ represents azimuthal and zenith angle.

The spacing between the elements in a ring is taken as constant, d_m=0.5. The wavelength of signal is taken as $\lambda/2$. The number of elements in first ring is chosen. The number of elements increases by 6 for every ring. All the elements in a ring have same current amplitude excitation. The total number of current excitations is equal to total number of rings.

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III. OPTIMIZATION TECHNIQUES

A. Genetic Algorithm (GA)

GA is a population based algorithm inspired from Darwin's theory of evolution. The three main operators in GA are selection, crossover and mutation. The algorithm works with a hope that newer generation is better than older generation. In crossover operation the offspring have the characteristics of both the parents. The mutation occurs due to abrupt changes in genes. The mutation probability must be less than crossover probability. The random population is initialized. Using the genetic operators the population is modified continuously until stopping criteria is met and an optimal solution is obtained.

B. Particle Swarm Optimization (PSO)

PSO is the simplest optimization algorithm. This algorithm is inspired from food searching process of birds. The positions of the particles are initialized. The particle's velocities are calculated using personal best (pbest), global best (gbest), acceleration coefficients and inertial weight. The personal best is the optimal position of the particular particle achieved until that iteration. The global best is the best position attained among all the particles. The particle's positions are updated using the velocities. This process of updating the positions of particles are continued until an optimal solution is achieved. chi1, chi2 are acceleration constants. K is the inertial weight.

C.Biogeography based optimization (BBO)

BBO is an optimization algorithm inspired from of migration of species between islands based on their sustainability index. The sustainability index depends on factors like rainfall, moisture, soil, and temperature etc., of the island. The two operators in BBO are migration and mutation. The migration between the islands depends on immigration and emigration rates of islands. The information is shared between the islands in migration. BBO has good exploitation capability because of migration operator. The elitism is another important concept in which worst solutions of present iteration are replaced by best solutions of previous iteration. This helps to enhance the performance of optimization in BBO. The random solutions are initialized. The solutions are modified using migration and mutation operators until optimal solution is obtained.

D.Hybrid differential evolution with Biogeography based optimization (DE/BBO)

DE/BBO is an evolutionary based optimization technique which is emerged by the combination of migration in BBO and mutation and selection operators in DE (Differential Evolution) [5]. The DE has good exploration capability because of mutation operator. The mutation vector is attained by adding a vector to the difference of another two vectors. BBO has good exploitation capability because of migration operator. The information is shared between the vectors in migration. This helps in enhancing the performance of bad vectors. The combined operator of DE and BBO is called Hybrid migration operator. DE/BBO has good exploitation and exploration capabilities because of Hybrid migration operator. The vectors generated using hybrid migration operator is called offspring vectors (V). The selection of vectors is done based on fitness function. If the cost function of offspring vector greater than the cost function of parent vector (P) then replaces the parent vector with offspring vector else there will be no change in parent vector. The crossover probability (CR) is used for selection between migration and mutation operators and scaling factor (F) is used in improving the convergence.

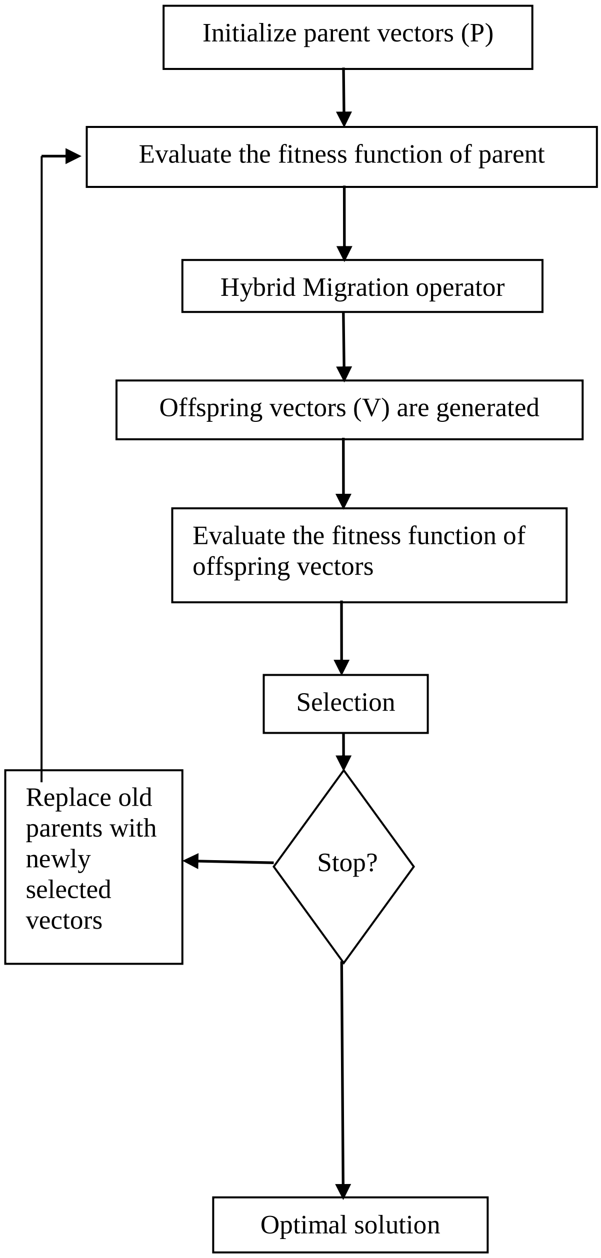

Fig. 2. Flowchart of DE/BBO

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IV. RESULTS AND DISCUSSIONS

In this paper, the optimization of SLL of CCAA is done using four random stochastic techniques GA, PSO, BBO, DE/BBO. The sidelobes are reduced without any appreciable effect on beamwidth. The current excitations of the antenna array are modified to attain the desired pattern.
The fitness function used for optimization of SLL in CCAA is,

Fitness = a * abs (SLL) + b * BW

In the above fitness function a, b are taken as 2 and 1 respectively. BW indicates beamwidth and abs ( ) means absolute value. The cost function increases with increase of iterations. MATLAB R2016a is used for simulation.
All the elements in a particular ring have same current excitation.

The parameters of GA are crossover probability is taken as 0.85; mutation probability is taken as 0.01.
The acceleration coefficients of PSO are taken as chi1 = 1.5, chi2 = 2 and inertial weight K = 1. The inertial weight is reduced with iteration with a damping ration of 0.99.
The immigration and emigration rates of the islands in BBO are calculated as follows:
Immigration rate, $\lambda_k = I_b\left[1 - \frac{k}{n}\right]$, Emigration rate, $\mu_k = E_b\left[\frac{k}{n}\right]$, I_b = maximum possible immigration rate, E_b = maximum possible emigration rate, $E_b = I_b = 1$, 'k' represents the k^{th} island and 'n' represents total number of islands. The mutation probability of BBO is taken as 0.04. Elitism constant is taken as 2.
In DE/BBO the scaling factor, F = 0.5 and crossover probability, CR is taken as 0.9.
For all four algorithms,
Number of iterations=100
Number of initial population =100
The results for two different CCAA of 12 rings with first ring containing 4 elements and 10 rings with first ring of 6 elements are tabulated and radiation patterns are shown respectively.

TABLE I

SLL and BW OF DIFFERENT CCAA (N = 12, G = 4)

Algorithm	SLL(dB)	Beamwidth
Fully populated	-17.5345	12^0
GA	-24.6168	13.4^0
PSO	-25.0024	13.4^0
BBO	-25.3474	13.4^0
DE/BBO	-26.2601	13.4^0

TABLE II

CURRENT EXCITATIONS OF CCAA

Algorithm	Current excitations
Fully populated	[1,1,1,1,1,1,1,1,1,1,1,1]
GA	[1.0000, 0.8616, 0.8816, 0.4196, 0.9497, 0.3293, 0.5222, 0.8329, 0.1164, 0.5120, 0.3073, 0.6355]
PSO	[1.0000, 0.9282, 1.0000, 0.8841, 0.9500 , 0.8927, 0.2925, 0.9148 0.5349, 0.2710, 0.5202, 0.8514]
BBO	[1.0000, 0.3891, 0.6181, 0.6046 0.5698, 0.8271, 0.1646, 0.4996 0.4158, 0.1733, 0.2307, 0.6601]
DE/BBO	[1.0000, 0.6385, 0.5631, 0.7699 0.6269, 0.5304, 0.5248, 0.4803 0.2661, 0.3919, 0.0871, 0.8086]

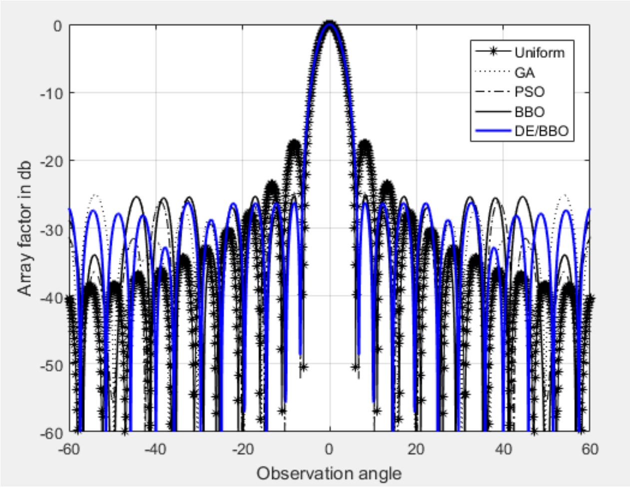

Fig. 3. Radiation pattern of 12-ring CCAA (G=4)

TABLE III

SLL OF DIFFERENT CCAA (N = 10, G = 6)

Algorithm	SLL(dB)	Beamwidth
Fully populated	-17.3735	14^0
GA	-23.1949	15.4^0
PSO	-24.1540	15.2^0
BBO	-24.9631	15.4^0
DE/BBO	-25.4858	15.4^0

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TABLE IV

CURRENT EXCITATIONS OF CCAA (N = 10, G = 6)

Algorithm	Current excitations
Fully populated	[1,1,1,1,1,1,1,1,1,1]
GA	[1.0000,0.2020,0.8191,0.5548,0.9945, 0.2947,0.4090,0.3059,0.3583,0.5822]
PSO	[1.0000,0.9807,0.9436,0.5856,0.9197, 0.6328,0.4444,0.3412, 0.4699,0.9142]
BBO	[1.0000,0.7876,0.9725,0.8337,0.6155, 0.5975,0.4092,0.6698,0.1594,0.8578]
DE/BBO	[1.0000,0.6134,0.8852,0.5612,0.7218, 0.4120,0.6380,0.1278, 0.3618,0.7486]

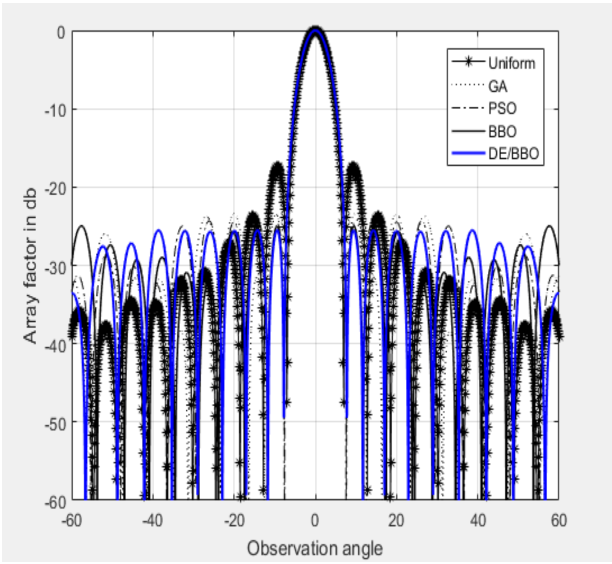

Fig. 4. Radiation pattern of 10 ring CCAA (G = 6)

V. CONCLUSIONS AND FUTURE SCOPE

It is found that DE/BBO provides the best SLL compared to the other optimization techniques. The SLL is reduced to -26.2601 dB for 12-ring CCAA and -25.4858dB for 10-rin CCAA using DE/BBO with just a small increase in beamwidth of 1.4^0 compared to beamwidth of uniformly excited antenna array. DE/BBO works efficiently because of its hybrid migration operator. The synthesis of SLL can be further done using other random stochastic techniques like ACO, MFO etc.

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