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Optimization of SLL of Linear Array Antennas using Enhanced Firefly Algorithm

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ABSTRACT
Firefly Algorithm is a stochastic and meta heuristic approach inspired from nature having a wide range of applications in solving various optimization problems. Firefly Algorithm (FA) suffers from problem of slow convergence speed. This problem can be solved by using modified Firefly algorithm called as Enhanced Firefly Algorithm. By using this algorithm side lobe level can be reduced considerably without appreciable effect on beam width. Low SLL in the radiation pattern of the optimized antenna array can be achieved by considering phase and amplitude of the excitation currents of antennas as variables to be controlled having fixed spacing between inter elements. In this paper SLL of symmetriclinear array antennas is optimized using Enhanced Firefly algorithm (EFA) and its results are compared to that of Genetic Algorithm.

Key Words- beam width, Enhanced Firefly Algorithm, Genetic Algorithm, Symmetric linear array antennas, sidelobe level.

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I. INTRODUCTION

In many applications like radar, point-to-point links low side lobe and narrow antenna beams are required. Using random stochastic methods like Firefly Algorithm (FA) side lobe level can be reduced considerably without appreciable effect on beam width. FA based on location update process of fireflies is applied for solving difficult optimization problems. In this process attraction between one insect to the other and their moment is used for updating the location. It is because of random motion of fireflies, there are chances for solution to get stuck in local minima leading to slow convergence and sometimes even failures. In this paper slow convergence problem is solved by using enhanced firefly algorithm (EFA). This approach achieves faster convergence and better accuracy by using Levy Distribution Function. For long distance communication, antenna array is used in place of single antenna because of their increased gain. Basically, antenna arrays refer to a cluster of antennas arranged in suitable manner. The antenna array factor depends on shape of the antenna arrays (linear, rectangular etc.), inter-element spacing, amplitudes and phases of excitations of elements. Interference suppression and Side lobe reduction can be obtained by controlling these parameters. The antenna array radiation pattern is controlled by the phases and amplitudes of the excitation currents. The spacing between the elements can also be controlled in order to get the optimized antenna array. The antenna array is synthesized to optimize SLL and half power beam width of the pattern. In this paper, optimization of symmetric linear antenna array is attempted using Enhanced Firefly Algorithm (EFA) by taking phases and amplitudes of the excitation currents as the variables to be controlled.

II. ANTENNA ARRAYS

2.1. Linear Antenna Array (LAA)

The linear antenna array is a set of antenna elements in a straight line. Linear array is a one-dimensional array structure. The elements can be equally or arbitrarily spaced with progressive or arbitrary phase shift.

2.2. Symmetric Linear Antenna Array

In a symmetric LAA, equal number of elements are arranged symmetrically on both sides of the origin. Symmetric arrangement of elements also helps to decrease the computational cost as only N elements are to be optimized in place of 2N.

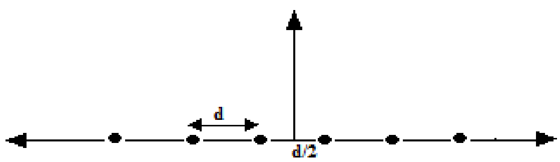

Fig1. Symmetric linear antenna array

In an equally spaced antenna array, the positions of antenna elements are fixed equal to $\lambda/2$. Element antennas are excited with different amplitudes and phase shifts in order to obtain the required radiation pattern. The aim of optimization is to reduce the maximum SLL of antenna array by optimizing amplitude and phase excitations. The first element on both side of origin is placed at a distance of $\lambda/4$ so that the distance between the first two elements about the origin is $\lambda/2$.

The Array Factor (AF) for 2N element symmetric linear antenna array

$$AF=2\sum_{n=1}^{N} I_n \cos((n-0.5)(\beta d\cos\theta+\alpha)) \quad (1)$$

WhereAF = Array factor, I_n= current excitation of nth element, Phase constant = $\beta = 2\pi / \lambda$, Antenna phase = $\beta d \cos\theta+\alpha$. 'd' is inter element spacing between the antennas and 'α' is the progressive phase shift.

III. OPTIMIZATION TECHNIQUES

3.1. Genetic Algorithm (GA)

Population of GA is made up of data structure of individuals or chromosomes. Population of individual solutions are modified repeatedly by genetic algorithm. The generated initial population is random. Parents from older generation are used for creation of next generations (children). Selection of parents for reproduction is done by using a process called recombination. GA uses two types of genetic operators. The first, being Crossover and the second is Mutation. Based on cost or fitness function the newly generated individuals are tested for fitness and the best of them survives for future generation. It is the genes of best individuals which are transferred throughout the population makes the newer generation better than older generation.

3.2. Firefly Algorithm (FA)

FA is a search technique inspired from nature to achieve global optimization. Its application mainly focuses on optimization problems with highly non- linear and multi-modal characteristics. It takes inspiration from behaviour of fireflies and is basically an intelligence algorithm of swarm based. Fireflies has unique flashing pattern. Flashes is used to attract others for predation or mating. FA depends on following assumptions (1) Attractiveness between fireflies does not depend on their sex. (2) The proportionality between attractiveness and brightness is direct referring that moment always occurs from firefly with less brightness towards that of high brightness. If there is no presence of fireflies with high brightness, the moment of a particular firefly in the space will be random. (3)Objective function determines brightness of firefly. FA has many parameters that can be controlled, for example, the population size, the randomization factor, and the light absorption coefficient whose values determines the efficiency of FA. For FA, selection of control parameters depends on the problem. In case of complex problems with various local optima many optimization techniques are failed.

The two important issues related to FA are attractiveness β and light intensity variations. The brightness *I* of a firefly determines its attractiveness and is related to an objective function f(x) i.e., $I(x)\propto f(x)$.

For a given medium, the light intensity *I(r)* is given by:

$$I=I_0 e^{-\gamma r} \quad (2)$$

where $\gamma$is the absorption coefficient of light and I_0 is the original intensity of light. Due to the proportionality between light intensity and the attractiveness β of firefly, β can be written as:

$$\beta=\beta_0 e^{-\gamma r^2} \quad (3)$$

where $\beta_0$refers to attractiveness at $r = 0$, and the distance r between two fireflies iand j can begiven by:

$$r_{ij}=||x_i - x_j||=\sqrt{\sum_{k=1}^{d}(x_{i,k} - x_{j,k})^2} \quad (4)$$

where formula for position updating from non-optimal firefly i towards the best located firefly j, is given by

$$x_{new}=x_i+\beta_0 e^{-\gamma r_{i,j}^2}(x_j - x_i) + \alpha \in_i \quad (5)$$

Where the term $\beta_0 e^{-\gamma r_{i,j}^2}(x_j - x_i)$ is due to attraction, $\alpha \in_i$ is randomization and $\in_i$, $\alpha$are the random number vector that are generated from uniform or Gaussian distribution and randomization parameter respectively. Here $x_i$and x_j are random solution,x_{new} is the obtained new solution, and γ is the absorption coefficient. For most applications $\beta_0=1$, $\alpha \in[0,1]$. By adjusting the parameters γ, α and β_0, the performance ofFA can be improved.

3.3. Enhanced Firefly Algorithm (EFA)

In various fields of research FA has been applied as it provides better results even with its basic form. Even though FA is found to work better for numerical optimization problems, the time taken to achieve global optimization increases with an increase in complication of problem, leading to increased time to obtain appropriate results. This problem is a result of random moment of fireflies in different directions. The value of attractiveness in the initial phase is significantly small due to large separation between fireflies, which results in slow moment rate leading to slower convergence of FA. As FA approaches to final stage a higher value of attractiveness is obtained as the distance between the fireflies decreases. In contrast to this the solution converges slowly because of their random moment resulting to a need of improvisation of FA. In this paper effort is made to design and implement updated version of basic algorithm called EFA to find optimal solutions for antenna design problems. The EFA uses Levy stable distribution and hence helps in solving slow convergence problem and increases the efficiency of algorithm. In metaheuristic algorithms, random walk (representation of random steps) has a key role to play can be generated using Levy flight.

For EFA fireflies position updating can be achieved by:

$$x_{new} = x_i + \beta_0 e^{-\gamma r_{i,j}^2}(x_j - x_i) + L(rand) \quad (6)$$

where the term $\beta_0 e^{-\gamma r_{i,j}^2}(x_j - x_i)$ is due to the attraction and the term $L(rand)$ is randomization using Levy's flights. L represents the Levy's flight and is given by:

$$L = 0.01\left(\frac{r_1\sigma}{|r_2|^{\frac{1}{\beta}}}\right) \quad (7)$$

Here r_1 and r_2 represents random numbers where r_1, $r_2 \in [0,1]$ and $\beta=1$ and σ can be given by:

$$\sigma = \left\{\frac{\Gamma(1+\beta)\sin\left(\frac{\pi\beta}{2}\right)}{\Gamma\left(\frac{1+\beta}{2}\right)\beta\, 2^{\left(\frac{\beta-1}{2}\right)}}\right\}^{\frac{1}{\beta}} \quad (8)$$

Where Γ is the gamma function.Levy distribution is a special case of the inverse-gamma distribution with high stability.

Flight can be defined as the maximum distance between two points that an object in motion covers without any change in its direction.

The variation of attractiveness is characterized by parameter γ , whose value is of great importance in determination of convergence speed and behavior of FA. Using EFA both the local and global optima can be found simultaneously and effectively.

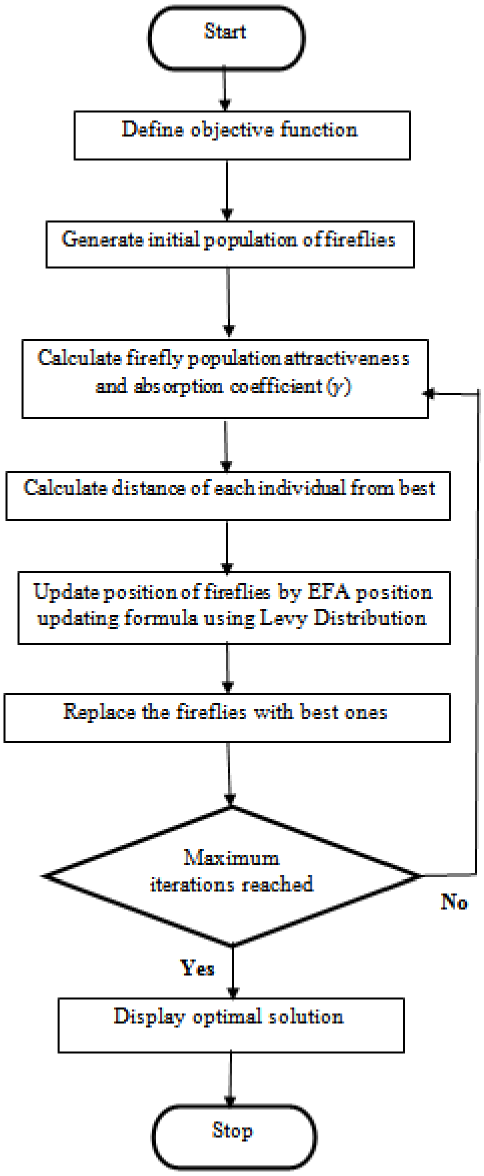

Fig.2. Flowchart of EFA

IV. RESULTS AND DISCUSSION

In this paper, optimization of SLL of symmetric linear antenna arrays is obtained by using EFA. The amplitudes and phases of the excitations of the antenna elements are synthesized to obtain the optimized value of SLL without any appreciable effect on beam width. Comparative studies are done among results obtained with GA and EFA.

The objective function used for optimization of SLL in EFA is:

Cost function=abs (SLL)-abs ($SLL_{uniform}$) (9)

Here abs ( ) indicates absolute value. The cost function increases with increase of iterations. MATLAB R2019a is used for simulation.

The parameters used in GA are 0.85 crossover probability and 0.01 mutation probability.The parameters used in EFA are the attractiveness at r = 0i.e., β_0= 1 and absorption coefficient γ=1.
For both GA and EFA,Number of flies=50, Number of variables=30 and Number of iterations=100.
The linear array antenna is synthesized with spacing between the elements $\lambda/2$.In case of amplitude excited linear array antenna phase shift along x and y axis is taken as zero.In case of phase excited linear array antenna, current excitation of antenna element at (n, m) = I_{mn}=1.

Table 1: Comparison of SLL and FNBW of amplitude excited Symmetric Linear Array Antenna

Algorithm	Number of elements (2N)	SLL (dB)	FNBW (degrees)
GA	30	-36.587	11.0
EFA	30	-40.759	14.4

Table 2: Amplitude excitations of symmetric Linear Array Antenna

Algorithm	Amplitude excitations
GA	[1.0000, 0.9848, 0.5883, 0.8093, 0.5785, 0.6793, 0.6941, 0.2786 0.7651, 0.2831, 0.2389, 0.3859 0.7130, 0.0975, 0.1074]
EFA	[1.0000, 1.0000, 0.9590, 0.8954 0.8268, 0.7525 0.6576, 0.5571 0.4940, 0.3887, 0.3060, 0.2339 0.1689, 0.1143, 0.1000]

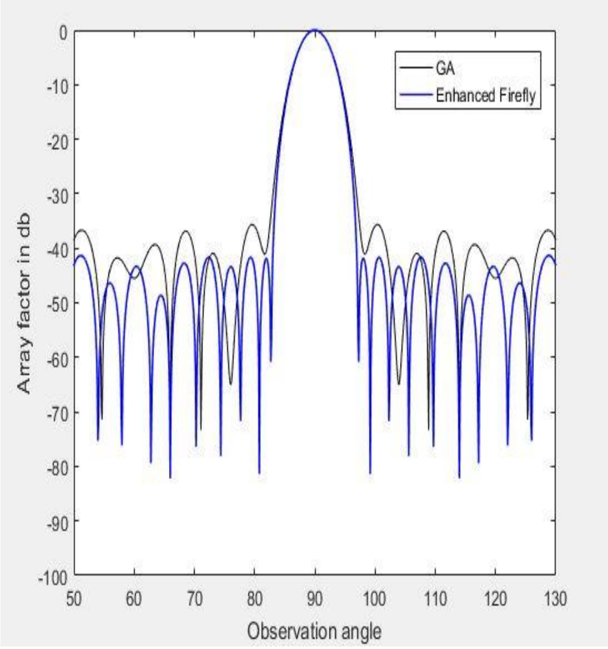

Fig.3. Pattern of radiation for amplitude excited linear Array Antenna

Table 3: Comparison of SLL and FNBW of phase excited Symmetric Linear Array Antenna

Algorithm	Number of elements (2N)	SLL (dB)	FNBW (degrees)
GA	30	-15.3870	7.9000
EFA	30	-16.1309	8.1000

Table 4: Phaseexcitations of Symmetrical Linear Array Antenna

Algorithm	phase excitations
GA	[0, 15, 17, 16, 18, 16, 15, 18, 14, -13, -18, -15, -13, -10, -7]
EFA	[0, -20, -18, -16, -18, -19, -14, -17, -17, 20, -8, -19, -17, -17, -17]

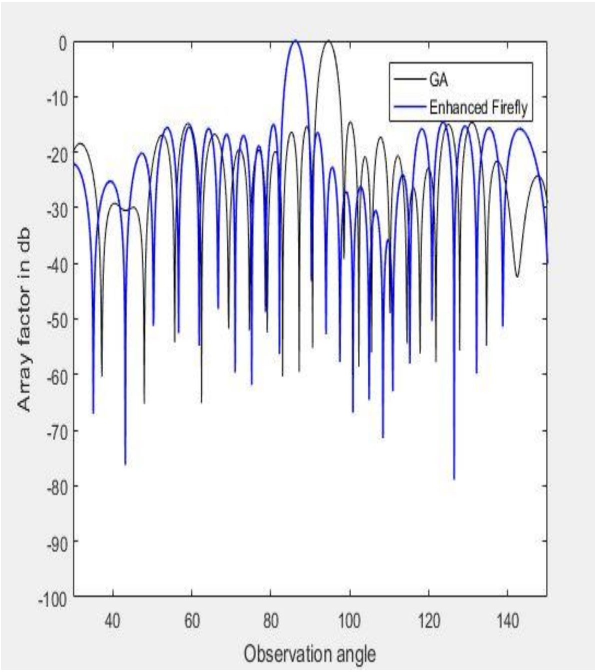

Fig.4. Pattern of radiation for phase excited Linear Array Antenna

V. CONCLUSIONS AND FUTURE SCOPE

It is found that EFA provides much better optimization of SLL without appreciable effect on beam width when compared to GA. From the results, it is evident that the best values of SLL are obtained for random amplitude excitations when compared to random phase excitations of the antenna elements in linear array antennas. For amplitude excited linear array antenna, SLL is reduced to-40.759dB and FNBW of 14.4 degrees is obtained by using EFA. In case of phase excited rectangular array antenna, the best SLL of -16.1309dB and FNBW of 8.1000 degrees is obtained by using EFA. Further extension of this work can be done by optimization of SLL using other random stochastic techniques.

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