LINEAR ANTENNA ARRAY OPTIMIZATION TECHNIQUES

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***Abstract*— Linear Antenna arrays provide alternative solution to dimensional structure of Antennas such as paraboloidal cylinders, paraboloids, offset focus paraboloids etc. This paper presents the survey of various evolutionary approaches for linear array optimization like genetic algorithm, Particle swarm optimization, Simulated Annealing, Bacteria Foraging and Biogeography Based Optimization. From the survey It was observed that biogeography based optimization is better for antenna geometries.**

***Keywords*— Genetic Algorithm, Particle Swarm Optimization, Simulated Annealing, Bacteria Foraging, Biogeography Based optimization.**

I. INTRODUCTION

In many communication systems, one is interested in point to point communication and for this, a highly directive beam of radiation is required. By arranging several dipoles (or other elementary radiators) in the form of an array, a directive beam of radiation can be obtained [1]. For maximum power radiation, the antenna gain in the desired direction (main lobe) should be maximum and should be minimum in the undesired direction (sidelobes). That is antenna should have favorable radiation pattern. Also input impedance of antenna should be such that the maximum power can be fed to the antenna. Above parameters i.e. output gain, input impedance and desired radiation pattern can be optimized by carefully choosing the design of antenna. In the design of antenna, we have to specify element length, element spacing, feed current amplitude, and feed current phase. Optimized selection of above multiple parameters can be efficiently achieved using evolutionary optimization (EO) techniques like Genetic algorithm (GA), Particle swarm optimization (PSO), Simulated Annealing, Bacteria Foraging and Biogeography Based Optimization.

Consider a linear array of *n* isotropic elements of equal amplitude and separated by distance *d* as shown in Fig. 1 [2]. The total field, *E* at a far field point, P in the given direction, ϕ is given by,

$$E = 1 + e^{j\psi} + e^{j2\psi} + e^{j3\psi} + \ldots\ldots\ldots\ldots\ldots\ldots + e^{j(n-1)\psi} \quad (1)$$

Where, Ψ is the total phase difference of the fields from adjacent sources and is given by;

$$\psi = 2\pi(d/\lambda) * \cos\phi + \alpha \quad (2)$$

Here, α is the phase difference between the feed currents of adjacent sources i.e. source 2 with respect to source 1 and source 3 with respect to source 2… and so on. The point P is considered very far away from the sources, thus the angle ϕ that it makes with x-axis as shown in Fig. 1, will be same for all the sources. The amplitudes of fields from the sources are all equal and taken as unity. Source 1 is the phase reference.

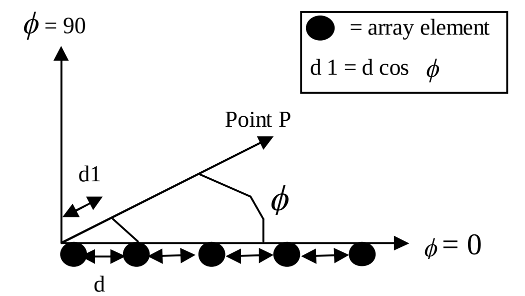


Figure 1: Geometry of a linear array of *n* isotropic elements of equal amplitude and separated by distance *d*.

In an array of identical elements, there are five controls that can be used to shape the overall pattern of the antenna array [3]. These are:

a. geometrical configuration of an array (linear, circular, rectangular, spherical etc.)
b. the relative displacement between the elements
c. the excitation amplitude of individual elements
d. the excitation phase of individual elements
e. the relative pattern of individual elements

Antenna arrays provide alternative solution to dimensional structure of Antennas (such as paraboloidal cylinders, paraboloids, offset focus paraboloids etc.) and have the ability to reduce the antenna dimensions to 1 or 2D [4]. Such structures are called as linear or planar array radars. In case of linear phased arrays, elements are equally spaced at λ/2 distance. Antenna array processing also finds its use in complex random environment in mobile communication [5]. The received signal is a multipath signal and for a noise limited system, it is important to absorb all the energy. If the channel power transfers from all the elements, then it is possible to maximize the total transfer power by jointly adjusting the antenna weights in the arrays. Another, there is the possibility for two arrays, in a scattering environment, to create parallel channels, resulting in, in effect, act as many independent antennas at the same time, which will carry much more traffic over the same bandwidth. Array of antennas can be mounted on vehicles, ships, aircraft, and satellite and base stations to fulfill the increased channel requirement for these services [6]. Many researchers have worked on linear array optimization techniques. Murino *et.al.* in [7] have used the simulated annealing for antenna array synthesis in order to reduce the peaks in side lobes by adjustment of array positions and weights of array elements. R.L. Haupt in [8] successfully applied Genetic algorithm for optimal thinning of linear and planar arrays. M. Shimizu in [9], has applied GA for determination of excitation coefficients to shape the radiation pattern. Tennant *et.al.* in [10], have applied GA for array pattern nulling in a desired direction. The analytical technique permits only small perturbations, but GA allows much more perturbations and gives superior results and maintains the required null depth. Marcano *et.al.* in [11], have applied GA for the synthesis of radiation pattern having dual beam and low side lobes. To search effectively and reduce the computing time, gray code was employed for coding of GA unlike binary code present in traditional GA. K.K. Yan et.al. in [12] have applied a simple and flexible GA for side lobe reduction that employs direct linear crossover unlike binary crossover in traditional GAs. This approach simplifies software programming and reduces CPU time. It has been applied to linear and circular arrays. E.A. Jones *et.al.* in [13] have applied the GA for the design of Yagi Uda array. The performance evaluation of design generated by GA has been done using a method of moment's code, NEC2. J.D. Lohn et.al. in [14] have applied a relatively less complex evolutionary technique for optimization of Yagi-Uda array. Recently PSO algorithm has been applied for Electromagnetics and Linear Antenna Array Design problems [15, 16]. Minimum side lobe level and control of null positions in case of linear antenna array has been achieved by optimization of element positions using PSO [16]. Baskar *et.al.* in [17] have applied the PSO and Comprehensive learning PSO (CLPSO) for design of Yagi-Uda arrays, and have found that CLPSO gives superior performance than PSO for this design. In 2010, U. Singh et al. used a new biogeography based optimization (BBO) algorithm to determine an optimum set of amplitudes of antenna elements. Further, they suggested that BBO is fast and reliable global search algorithm and encourage its use for optimization of other antenna geometries [18].

II. Algorithms used for optimization**:**

Various algorithms are used to optimize antenna array. The complete descriptions of each algorithm are as follows

A. The Genetic Algorithm

GA optimizers are particularly effective when the goal is to find an approximate global maximum in high dimension, multi modal function domain in optimal manner. GA Optimizers have been found to be much better than local optimization methods at dealing with solution spaces having discontinuities, constrained parameters, and/or a large no. of dimensions with many potential local maxima. The basic Genetic Algorithm performs the following steps [19]:

1. Generate an initial population randomly or heuristically.
2. Compute and save the fitness for each individual in the current population.
3. Define selection probability for each individual so that it is proportional to its fitness.
4. Generate the next current population by probabilistically selecting the individuals from the previous current population, in order to produce offspring via genetic operators.
5. Repeat step 2 until a satisfactory solution is obtained.

B. Particle Swarm Optimization

PSO is an evolutionary algorithm based on the intelligence and co-operation of group of birds or fish schooling. It maintains a swarm of particles where each particle represents a potential solution. In PSO algorithm particles are flown through a multidimensional search space, where the position of each particle is adjusted according to its own experience and that of its neighbors[20 , 21]. Algorithm is:

1. Define the solution space: Initialize an array of the population of particles with random positions and velocities in D dimensions in problem space.
2. Evaluate the fitness function in D variables for each particle. The fitness function and the solution space must be specifically developed for each optimization; the rest of the optimization, however, is independent of the physical system being optimized.
3. Compare each particle's fitness evaluation with pbest. If the current value is better than pahse best (pbest), then save the current value as pbest and let the location correspond to the current location in D dimensional space.
4. Compare the fitness evaluation with the population's overall previous best i.e. gbest. If the current value is better than gbest, then save the current value as gbest to the current particle's array index and value.
5. Update the position and velocities of particles.
6. If the desired criterion is not met, go to step 2, otherwise stop the process.

C. Simulated Annealing

Simulated annealing (SA) is a random-search technique which exploits an analogy between the way in which a metal cools and freezes into a minimum energy crystalline structure (the annealing process) and the search for a minimum in a more general system. It forms the basis of an optimization technique for combinatorial and other problems. The idea of SA comes from a paper published by Metropolis et al in 1953 [22]. Metropolis algorithm simulated the material as a system of particles. The algorithm simulates the cooling process by gradually lowering the temperature of the system until it converges to a steady, frozen state.

In each step of Metropolis algorithm, a particle is given a small random displacement and the resulting change, δf , in the energy of the system is computed. If $\delta f \leq 0$, the displacement is accepted. The case $\delta f > 0$ is treated probabilistically. A certain number of iterations are carried out at each temperature and then the temperature is decreased. This is repeated until the system freezes into a steady state. The probability of accepting a worse state is given by the equation

$$P = \exp\left(-\frac{\delta f}{T}\right) > r , \qquad (2)$$

Where,

δ = the change in objective function

T = the current temperature

r = a random number uniformly distributed between 0 and 1.

The probability of accepting a worse move is a function of both the temperature of the system and of the change in the objective function. As the temperature of the system decreases, the probability of accepting a worse move is decreased. If the temperature is zero, then only better moves will be accepted.

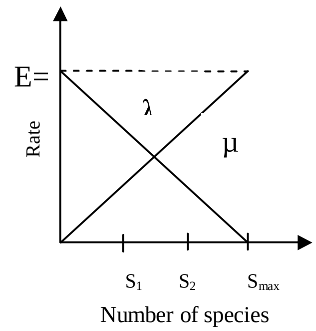
D. Bacteria Foraging

Bacteria foraging optimization (BFO) [23] is based on the foraging (i.e. searching food) strategy of *Escherichia coli* bacteria. In BFO, the optimization follows chemotaxis, swarming, reproduction and elimination and dispersal events to reach global minima. During chemotaxis, the bacteria climb nutrient concentration and avoid noxious substances. During swarming, the bacteria move out from their respective places in ring of cells by moving up to the minimal value. Bacteria usually tumble, followed by another tumble or tumble followed by run or swim. If the cost at present is better than the cost at the previous time or duration then the bacteria takes one more step in that direction. During reproduction, the least healthy bacteria dies and others split into two, which are placed in the same location. This causes the population of bacteria to remain constant. During reproduction the fitness of the bacteria are stored in ascending order. The elimination and dispersal events are based on population level long-distance motile behavior. During elimination and dispersal events, each bacterium is eliminated with a probability.

E. Biogeography Based Optimization (BBO)

Mathematical models of biogeography describe how species migrate from one island to another, how new species arise, and how species become extinct. Geographical areas that are well suited as residences for biological species (S) are said to have a high habitat suitability index (HSI).

HSI can be considered the dependent variable. Habitats with a high HSI tend to have a large number of species, while those with a low HSI have a small number of species. Habitats with a high HSI have many species that emigrate (μ) to nearby habitats. Habitats with a high HSI have a low species immigration rate (λ) because they are already nearly saturated with species. Therefore, high HSI habitats are more static in their species distribution than low HSI habitats. Habitats with a low HSI have a high species immigration rate because of their sparse popula- tions. Low HSI habitats are more dynamic in their species distribution than high HSI habitats[24].



Where, λ = immigration
μ = emigration

Figure2: Illustrating of two candidate solutions to some problem.

The emigration and immigration rates of each solution to probabilistically share information between habitats. With probability P_{mod}, we modify each solution based on other solutions. If a given solution is selected to be modified, then we use its immigration rate λ to probabilistically decide whether or not to modify each suitability index variable (SIV) in that solution. If a given SIV in a given solution S_i is selected to be modi- fied, then we use the emigration rates of the other solutions to probabilistically decide which of the solutions should migrate a randomly selected SIV to solution S_i.

Biogeography-Based Optimization algorithm:

1. Initialize the maximum species count S_{max} and the maximum migration rates, E and I, the maximum mutation rate, m_{max}, and elitism parameter set of solutions to a problem.
2. Compute "fitness" (HSI i.e.is a measure of the goodness of the solution represented by the habitat) for each solution.
3. Compute S, λ, and μ for each solution.
4. Modify habitats (migration) based on λ, μ.
5. Update Mutatation based on probability.
6. Typically we implement elitism.
7. Go to step 2 for the next iteration if needed.

III. Conclusion

PSO has been found to work better than GA in certain kind of optimization problems as compared to GA. As PSO can be easily implemented and has least complexity. PSO has only single major operator (i.e. velocity) calculation whereas GA has three major operators (selection, crossover and mutation). In some cases GA gives better results. It has been successfully used for the optimization of linear array and yagi uda antenna. In case of optimal solutions, use of PSO results in low computations & quick design computation. Beamforming can be faster by using PSO compared to SA through control of amplitude and phase. PSO preformed better than the Bacteria Foraging Algorithm(BFA) for null steering cases, althought sidelobe suppression was slightly better with the BFA. PSO converged faster, and had an average cost function that was smaller than that of the BFA. BBO has achieved better results than PSO. The BBO is fast and reliable global search algorithm. This paper will encourage the use of BBO for optimization of the other antenna geometries.

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