Optimization of Linear Antennas - A Survey

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ABSTRACT
Linear antennas are used as an alternative solution for large dimensioned antennas such as paraboloidal cylinders, offset focus paraboloids. This paper presents a review of various algorithms used for optimization of linear array such as Genetic Algorithm (GA), Particle swarm Optimization Algorithm (PSO), Accelerated Particle Swarm Optimization Algorithm (APSO), Simulated Annealing Algorithm (SA),Cuckoo Search Optimization Algorithm (CS), Flower Pollination Algorithm (FPA), Ant-Lion Optimization Algorithm (ALO), Invasive Weed Optimization Algorithm (IWO), Grey Wolf Optimization Algorithm (GWO), from the review it was observed that ant-lion Algorithm (ALO) is better for optimizing antenna currents

Keywords
Antenna Arrays, optimization algorithms, Side Lobe Level (SLL).

1. INTRODUCTION
Higher directivity is the basic requirement in point-point communication, radars and space applications. This goal, up to some extent, can be achieved by increasing the size of antennas in terms of electrical length. For still higher directivity, an assemblage of antennas (point sources, dipoles, wire antennas, micro-strip (patch) antennas) and combinations thereof called an array is used [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 (side-lobes). That is antenna should have favorable radiation pattern. Also input impedance of antenna should be such that maximum power can be fed to the antenna. The parameters such as output gain, input impedance and desired radiation pattern can be optimized by carefully choosing antenna design. In design of antenna, we have to specify element length, element spacing, feed current amplitude and feed current phase. Precise selection of these parameters can be efficiently achieved by using evolutionary and metaheuristic algorithms such as Genetic Algorithm (GA), Particle swarm Optimization Algorithm (PSO),Simulated Annealing Algorithm (SA), Bacteria Foraging algorithm (BF), Biogeography based Optimization Algorithm (BBO), Cuckoo Search Optimization Algorithm (CS), Flower Pollination Algorithm (FPA), Ant-Lion Optimization Algorithm (ALO), Invasive Weed Optimization Algorithm (IWO),Grey Wolf Optimization algorithm (GWO), Accelerated Particle Swarm Optimization Algorithm (APSO)

Consider a linear array of n isotropic point sources of equal amplitude and separated by a distance of d as shown in the figure1. [1]

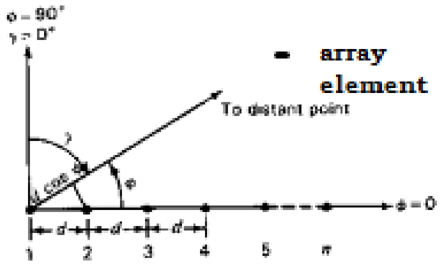

Fig.1 Linear Array Geometry of Equal Amplitude and spacing of d

The total field E at a large distance in the direction of ϕ is given by

$$E=1+e^{j\psi}+e^{2j\psi}+e^{j3\psi}+\ldots\ldots+e^{j(n-1)\psi} \quad (1)$$

Where ψ is the total phase difference of the fields from adjacent sources as given by

$$\psi=\frac{2\pi d}{\lambda}cos\phi + \delta=d_r cos\phi + \delta \quad (2)$$

Where δ is the phase difference of adjacent sources, i.e., source 2 with respect to source 1, 3 with respect 2.etc. the point p is considered far way from point sources, thus angle ϕ that it makes with x-axis as shown in figure1 will be same for all sources. The amplitudes of the fields from sources are all equal and taken as unity.

In an array of identical elements, there are five controls that can be used to shape the overall pattern of the antenna array [2]. They are

a. Geometrical configuration of antenna 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

The process of determining the parameters of the antenna array to obtain the required antenna radiation pattern is known as pattern synthesis [3]. Pattern synthesis of antenna arrays can be carried out by careful control of above mentioned five parameters. For linear arrays, optimization of excitation amplitude and phase with uniform element spacing and optimizing element spacing with uniform excitation amplitude and phase can be achieved by adopting various deterministic and stochastic methods. Many researchers have worked on linear antenna array optimization techniques. R.L. Haupt in [4] used Genetic Algorithm for optimal thinning of linear and planar arrays. M. Shimizu in [5] applied GA for determination of excitation coefficients to shape the radiation pattern. Tenant et.al in [6] 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. Marcanoet.al. in [7], 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[8].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 [9].have applied GA for design of yagu-Uda array. The performance evaluation of design generated by GA has been done using method of Moment's code. Minimum side lobe level and control of null positions in case linear antenna array has been achieved by optimization of element position using PSO [9]. P Victoria Florence in [10] have applied APSO and achieved optimized excitation amplitudes and element spacing and obtained desired side lobe level minimization and Null depths. Murino et.al in [11] have applied SA for antenna array synthesis in order to reduce the peaks in side lobes by adjusting array positions and weights of arrays. Haffane Ahmed in [12] have applied CS for excitation amplitudes and obtained optimized antenna parameters. Prerna Saxena in [13] used FPA in order to optimize the element spacing of antenna array. Prerna Saxena in [14] have applied GWO for optimizing both element spacing and excitation amplitudes of linear antenna arrays. Pal. Siddarth in [15] have applied IWO and optimized element spacing for minimizing side lobe level and null placement control. Prerna Saxena in [16] used ALO for optimizing antenna currents by suppressing peaks of SLL as well as Null placement in specified directions.

2. ALGORITHMS USED FOR OPTIMIZATION

Many Algorithms have been used for antenna array optimizing, the over view of each algorithm is as follows

2.1 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 [17]:

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.

2.2 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 [18, 19]. 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.

2.3 Accelerated Particle Swarm Optimization

APSO is an evolutionary algorithm based on the behavior of swarm of bees and flock of birds generally seen in nature [20]. Algorithm is

1. Define the solution space: initialize the solution space i.e., primary population generation with initial position and velocities for all
2. Find the global best for t=0
3. Calculate particle velocity and position
4. Evaluate the objective function for the position
5. Find the actual position
6. Meeting the final criteria if not repeat the step 2
7. Return the best solution

2.4 Simulated Annealing optimization

Simulated annealing (SA0) 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 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 SAO comes from a paper published by Metropolis et.al in 1953.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. The algorithm is [21]

1. Generate a randomly initial point, set temperature $t=t_{int}$ and iteration number k=0
2. Evaluate the objective function, generate a random neighborhood random position and evaluate the objective function.
3. The resulting displacement δf, *in* the objective function is evaluated, if $\delta f<0$, the displacement is accepted.

4. *The case δf > 0 is* treated probabilistically. A certain number iterations are carried out at each temperature and then temperature is decreased.
5. This is repeated until the system freezes into steady state. If the temperature is zero, then only better moves will be accepted.

2.5 Cuckoo Search Optimization

CS is a population-based algorithm. where, solution are represented by eggs in hosts nests and the cuckoo eggs represent the new solutions, The aim is to use the new and potentially better solutions(cuckoos) to replace the not-so-good solutions in the nests. The CS is based on three idealized rules [22].

1. Each cuckoo lays only one egg at a time, and dumps it in a randomly chosen nest.
2. The best nests with high quality of eggs (solutions) will carry over to the next generations.
3. The number of available hosts nests is fixed, and a host can discover an alien egg with probability $P_a \epsilon [0,1]$. In this case, the host bird can either throw the egg away or abandon the nest to build a completely new nest in a new location.

The third assumptions can be approximated as the fraction P_a of the n nests is replaced by new nests (new random solutions). The quality of fitness of a solution can be defined in a similar way to fitness function in genetic algorithm

2.6 Flower Pollination Algorithm optimization (FP)

FP was inspired by the pollination process of flowering plants, the FP algorithm was developed by Xin-She Yang in 2012. FP is extensively used for optimization of multi-objective real world design problems. FP is based on the following rules. [14]

1. Biotic and cross-pollination can be considered processes of global pollination and pollen –carrying pollinators move in a way that obeys levy flights
2. For Local pollination, abiotic pollination and self pollination are used
3. Pollinators, such as insects, can develop flower constancy. This in turn is equivalent to a reproduction probability that is proportional to the similarity of two flowers involved.
4. The interaction or switching of local pollination and global pollination can be controlled by switch probability $p \epsilon [0, 1]$.

2.7 ANT-LION Optimization Algorithm (ALO)

ALO is inspirited from the foraging behavior of antlions. Antlions commonly known as doodlebugs are net-winged insects whose names are derived from their unique hunting behavior and their favorite prey, namely ants.[16]

The ALO is governed by the following rules:

1. Ants move around the search space of different random walks.
2. Random walks are affected by the traps of antlions.
3. Antlions can build pits proportional to their fitness (the higher the fitness, the larger the pit).
4. Size of the pits is proportional to the probability of catching prey. Hence, antlions with larger pits have higher probability to catch ants.
5. Each ant can catch by antlion as well as the elite (fittest antlion) in each iteration.
6. As discussed above, when ants try to escape from the pit, the antlions throw sand towards the top of the trap to slide the ants inside the bottom of the trap. In order to simulate this behavior of sliding ants towards antlion, the range of random walk is decreased adaptively.
7. If an ant becomes fitter than an antlion, this means that it is caught and pulled under sand by the antlion.
8. After each hunt, an antlion repositions itself to the latest caught prey and builds a pit to improve its chance of catching another prey

2.8 Invasive Weed Optimization (IWO)

IWO is a metaheuristic algorithm that mimics the colonizing behavior of weeds. The algorithm for IWO may be summarized as follows.[15]

1. *Initialization:* A finite number of weeds are initialized at the same element position of the conventional array.
2. *Reproduction:* Each member of the population is allowed to produce seeds depending on its own, as well as the colony's lowest and highest fitness. Such that, the number of seeds produced by a weed increases linearly from lowest possible seed for a weed with worst fitness to the maximum number of seeds for a plant with best fitness.
3. *Spatial Distribution:* the generated seeds are being randomly distributed over the d dimensional search space by normally distributed random numbers with mean equal to zero, but varying variance. This step ensures that the produced seeds will be generated around the parent weed, leading to a local search around each plant. However, the standard deviation (SD) of the random function is made to decrease over the iterations. This step ensures that the probability of dropping a seed in a distant area decreases nonlinearity with iterations, which results in grouping fitter plants and elimination of inappropriate plants. Therefore, this is a selection mechanism of IWO

2.9 Grey Wolf Optimization(GWO)

GWO is a metaheuristic algorithm which mimics the social hierarchy and hunting mechanism of grey wolves. The hierarchy of grey wolves is as follows: [14] The leaders are male and female, called alphas (α). The second level in the hierarchy comprises the beta (β) wolves followed by delta (δ) wolves and the lowest ranking grey wolves are the omegas (ω). The hierarchy of grey wolves is mathematically modeled by considering α as the fittest solution followed by the second and third best solution, β and δ, respectively. The rest of the candidate solutions are assumed to be ω.

The main phases of grey wolf hunting are as follows.

1. Tracking, Chasing and approaching the prey.
2. Pursuing, Encircling and harassing the prey until it stops moving.
3. Attack towards the prey.

3. CONCLUSION

In this paper, various algorithms are mentioned which clearly proposes the potential usage of metaheuristic algorithms that help to simplify the task of antenna array design and each algorithm proved to be best in applying them, in optimizing the two essential important parameters current amplitude and element spacing .The results got from various algorithms mentioned proved to be best fitting. GA, PSO performs best depending upon the parameter tuning and requires more iterations and mathematical preprocessing. IWO is applied for antenna array locations and found to be producing best solution than GA, PSO. GWO is found to be best compared to ACO, PSO, CSO and shown significant difference in SLL calculation. ALO has few parameters to optimize, the best part is that search mechanism used is random walk and roulette wheel assist, which helps to explore the search space globally, so all tends to best solution. This paper encourages the use of evaluatory algorithms for optimization problems in antenna community.

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