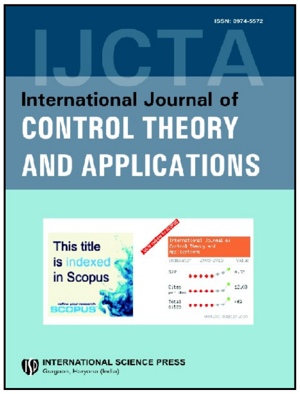

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Ant Colony Optimization Based Side Lobe Reduction in Linear Arrays

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Abstract: In this paper, side lobe level of linear antenna arrays is reduced by using Ant colony optimization technique. ACO technique is far superior to other optimization techniques like GA and PSO. ACO based approach converges to an optimal solution faster than GA and PSO based approaches. Side lobe reduction is achieved by varying amplitudes of the elements of the array in a random manner and also by simultaneously varying the amplitudes and phases of the elements of the array in a random manner using ACO and GA. Comparative studies between results obtained with ACO based approach and results obtained with Genetic Algorithm (GA) based approach are done.

Keywords: Linear antenna arrays, SLL, amplitude control, phase control, ACO, GA

1. INTRODUCTION

Reduction of SLL is very essential in applications like radar and microwave point to point communication systems. Smaller side lobe level eliminates false echoes in radar and reduces the effect of interference arriving from unwanted directions or spreading the signal in unwanted directions. There are various techniques to optimize SLL and beam width of linear antenna arrays. Traditional techniques of antenna array synthesis for reducing SLL have many limitations which precludes their use in practical applications, whereas random stochastic methods like Genetic Algorithm, Particle Swarm Optimization and Ant Colony Optimization have many advantages when used for reduction of SLL in Antenna Array synthesis, compared to conventional methods. The Ant Colony Optimization is an optimization technique based on foraging behaviour of ants and this technique can be used for reduction of SLL in linear arrays. ACO converges to a solution faster than PSO and GA with a smaller error.

2. METHODOLOGY

(A) Ant Colony Optimization

Ant Colony algorithms uses a group of ants, where each ant is supposed to be a potential solution for a situation to be optimized. Ants search for their food randomly and while traversing along a path they lay a chemical substance called pheromone along their path and a similar amount of pheromone is laid on the path on their return journey after obtaining food. The ants which obtain their food after travelling only a short distance will return home earlier and the amount of pheromone on that short path will be more as the evaporation of pheromone is less. On longer paths the amount of pheromone will be less as the evaporation with time will be more. Other ants searching for food will follow paths with larger amount of pheromone.

Initially, a set of feasible solutions (ants) are generated randomly. Then, each ant updates its pheromone values to memorize its path. The pheromone level is proportional to the proximity to food i.e., more pheromone intensity, more solution quality. So, after certain time this path has more traffic because that path is the shortest path to food. In the next iteration, ants will evaluate the pheromone levels generated from the previous ant. This algorithm is used in antenna array synthesis to obtain better radiation characteristics of the linear array.

The ACO algorithm is used in antenna array synthesis. Here, food is considered as desired side lobe level. Ant is considered as an array solution for which we need to find the side lobe level. Initially a set of antenna array solutions are randomly generated. The side lobe level of each solution is evaluated and the results obtained with each solution (ant) are then compared with a predefined cost function. If the SLL obtained in all the cases is very poor compared to the desired SLL, another set of array solutions are randomly generated. If SLL obtained in any one of the cases is closer to the desired SLL, then a set of nodes (array solutions) is generated by changing one element at a time in that array solution.

Then the next best node is selected based on the probability given by:

$$p_{i,j}(t) = \frac{[\eta_j(t)]^\alpha [CF_j]^\beta}{\sum_{l \in \theta_i} [\eta_l(t)]^\alpha [CF_l]^\beta}$$

Pheromone function $\eta_j(t)$ is defined as

$$\eta_j(t+1) = \eta_j(t) + \Delta\eta_j(t) - c(t)$$

where $\Delta\eta_j(t) = 1$ is the pheromone addition at node. *c(t)* is the pheromone evaporation

factor and is defined as:

$$c(t) = \begin{cases} \rho \bmod \left(\frac{t}{\gamma}\right) = 0 \\ 0 \bmod \left(\frac{t}{\gamma}\right) \neq 0 \end{cases}$$

where γ is the number of iterations, and $\rho = 1$ is the pheromone evaporation constant. The empirical variables α, β are constants greater than 1 and the values of α, β are arbitrarily selected as 1 and 5 respectively β. The best solutions are retained, which are used during the next iterations to influence the generation of better solutions (ants) and the solution with the best SLL is selected

In this paper, a non-uniform linear array is synthesized for a reduced side lobe level by controlling the amplitudes of elements of the array randomly and also by simultaneous variation of amplitudes and phases of array elements randomly. The Array Factor (AF) of the non-uniform linear array can be written as

$$AF = I_1 + I_2\, e^{j(\varphi_2 + kd\cos\theta)} + I_3\, e^{j(\varphi_3 + 2kd\cos\theta)} + \ldots + I_N\, e^{j[\varphi_N + (N-1)kd\cos\theta]}$$

Where I and φ represent the amplitude and phase distributions of the array, d is the distance between the successive elements and θ is observation angle in azimuthal plane. [2]

Algorithm

1. ACO parameters are to be defined.
    - Initial number of ants (i.e., initial number of array solutions).
    - Number of elements in the solution.
    - Other parameters like alpha, beta, evaporation factor, number of iterations.
2. Cost function is defined as

    $$CF_j = |SLL|_{obtained} - |SLL|_{\min desired}$$

3. Concentration of pheromone function is to be defined.
4. Control parameter (amplitude, amplitude and phase) of the array is to be chosen.
5. Generation of initial population set.
6. Calculation of array factor and SLL for each ant (array solution).
7. Evaluation of cost function.
8. Evaluation of probability for each solution and choosing the best solution in the generated set based on the probability.
9. If the best solution is not the desired SLL, then alternate solutions called nodes are generated by changing amplitude and/or phase of only one element of the array at a time and this is done for all the elements. Each of the new solution set represents one node.
10. Updating the pheromone function.
11. Repeating the above steps for the next best node based on the probability until the stopping criteria is satisfied.
12. If the best solution in current iteration is best when compared to previous one, then replacing the value with new best solution.
13. Plotting a graph of best global solution between normalized array factor and observation angle when the termination criterion is met.

(B) Genetic Algorithm

Genetic Algorithm is a well-known evolutionary algorithm used in optimization problems. It is based on the principle of survival of the fittest.GA starts by randomly generating a population of individuals/chromosomes. For each chromosome array factor is evaluated and side lobe level is obtained using the generalized array factor expression given by

$$AF = I_1 + I_2 e^{j(\varphi_2 + kd\cos\theta)} + I_3 e^{j(\varphi_3 + 2kd\cos\theta)} + ... + I_N e^{j[\varphi_N + (N-1)kd\cos\theta]}$$

These chromosomes are evaluated for their fitness by comparison with a predefined fitness function. Chromosomes (array solutions) with higher fitness scores are selected and they further undergo the process of crossover and mutation to create a new set of chromosomes. The newly created chromosomes are again tested for their fitness. This process continues until the termination criterion is satisfied.

Algorithm

1. Input data to be given
    - Number of elements in an array.
    - Spacing between elements.
    - Minimum Desired SLL value.
    - Number of chromosomes in initial population.
2. Control Parameter of the array is to be chosen.
3. Generation of initial population randomly.
4. Defining the fitness function.
5. Calculation of array factor and finding side lobe level of each chromosome of initial population.
6. Ranking all the chromosomes according to their fitness values and choosing the best ones.
7. Performing crossover and mutation.
8. Evaluating the fitness of each chromosome as generated above.
9. Going to step 5 and repeating this process until optimum side lobe level is reached.
10. Plotting a graph between normalized array factor and observation angle when the termination criterion is met.

3. RESULTS AND DISCUSSION

(A) Amplitude Control

This case includes only varying the amplitudes of the elements of the linear array for different number of elements i.e., N=10, 16, 20. Two different synthesis methods ACO and GA are employed for optimization. For N=10 elements case, the best result obtained is -39.95 dB using ACO. The best side lobe level obtained in 16, 20 elements cases are -31.89 dB and -21.02 dB respectively. ACO has given better results when compared to GA. The best side lobe level obtained in 10, 16, 20 elements cases are -22.54 dB, -23.48 dB, -17.8 dB respectively. Figures 1, 2, 3 represents ACO results in 3 different cases. Figures 4, 5, 6 represents GA results in 3 different cases.

(B) Amplitude and Phase Control

This case includes simultaneously varying the amplitudes and phase distribution of the elements of the linear array for different number of elements i.e., N=10, 16, 20. Two different synthesis methods ACO and GA are employed for optimization. For N=10 elements case, the best result obtained is -30.6 dB using ACO. The best side lobe level obtained in 16, 20 elements cases are -17.92 dB and -19.76 dB respectively. ACO has given better results when compared to GA. The best side lobe level obtained in 10, 16, 20 elements cases are -29.37 dB, -16.99 dB, -16.25 dB respectively. Figure 7, 8, 9 represents ACO results in 3 different cases. Figure 10, 11, 12 represents GA results in 3 different cases.

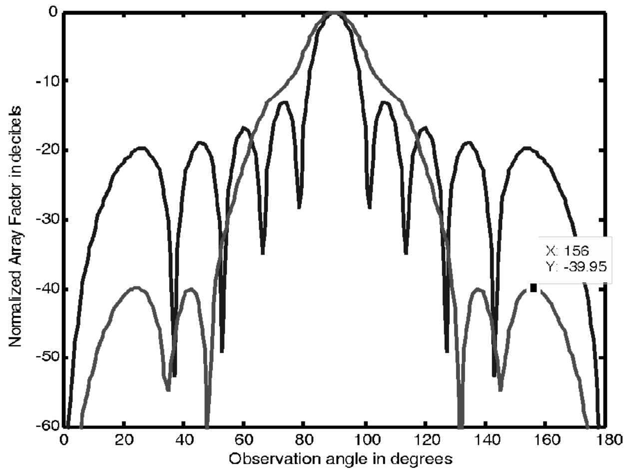

Figure 1: The Normalized radiation pattern of 10-element linear array obtained by ACO

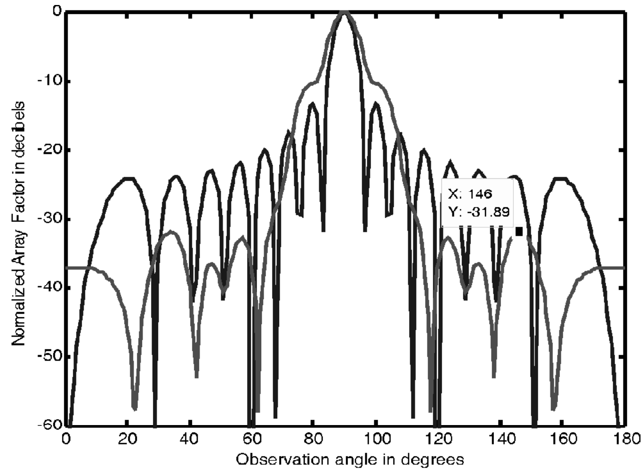

Figure 2: The Normalized radiation pattern of 16-element linear array obtained by ACO

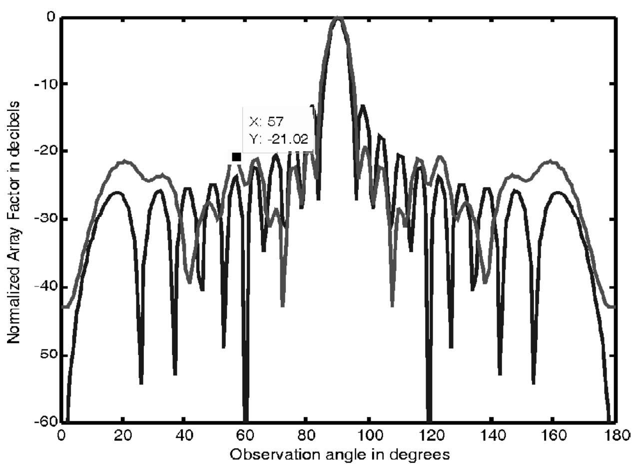

Figure 3: The Normalized radiation pattern of 20-element linear array obtained by ACO

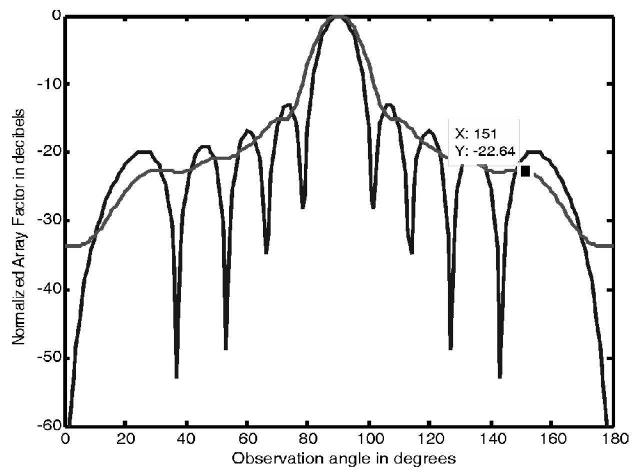

Figure 4: The Normalized radiation pattern of 10-element linear array obtained by GA

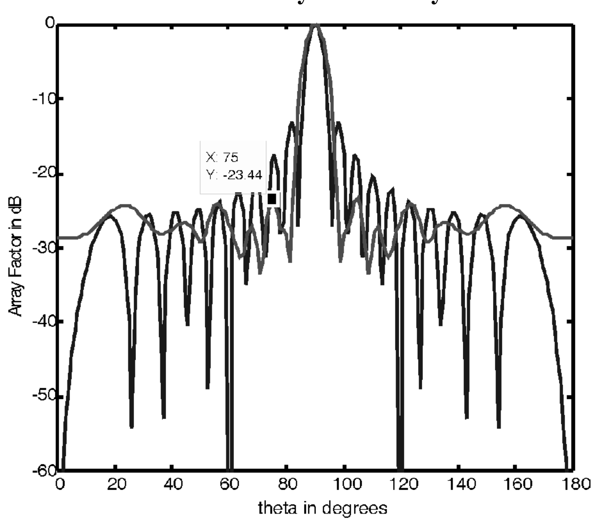

Figure 5: The Normalized radiation pattern of 16-element linear array obtained by GA

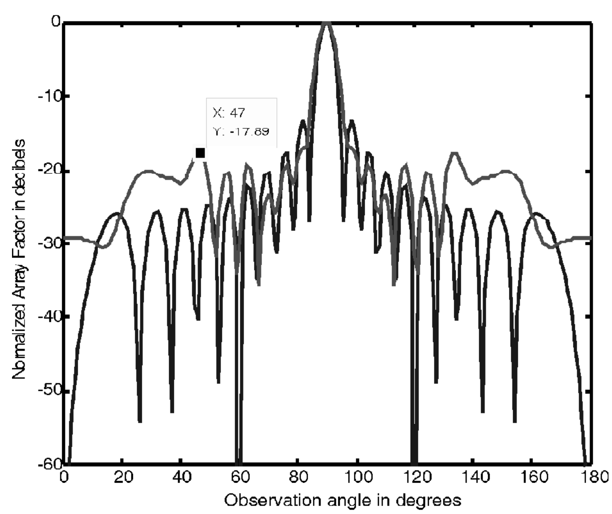

Figure 6: The Normalized radiation pattern of 20-element linear array obtained by GA

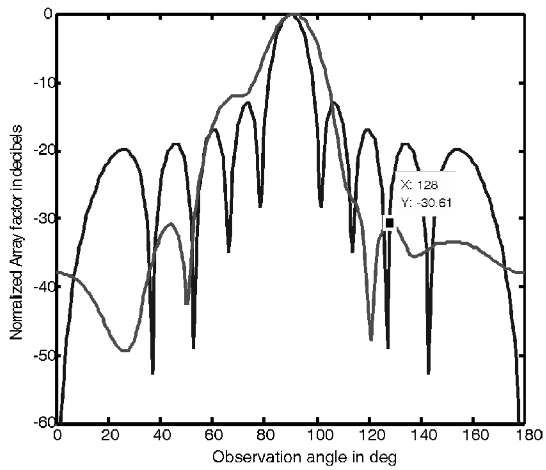

Figure 7: The Normalized radiation pattern of 10-element linear array obtained by ACO

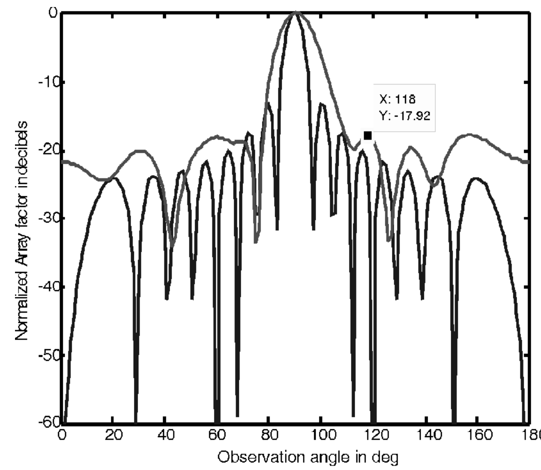

Figure 8: The Normalized radiation pattern of 16-element linear array obtained by ACO

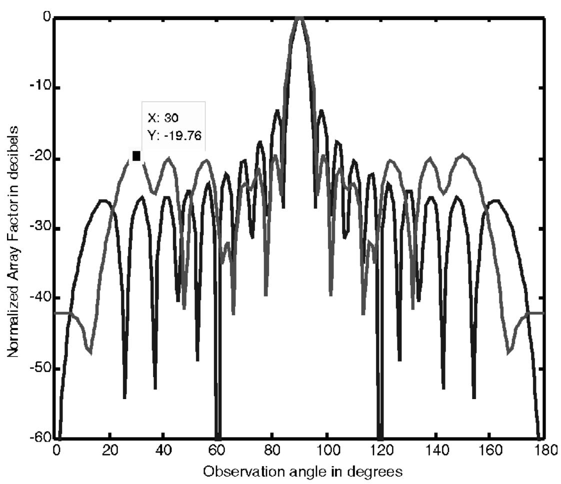

Figure 9: The Normalized radiation pattern of 20-element linear array obtained by ACO

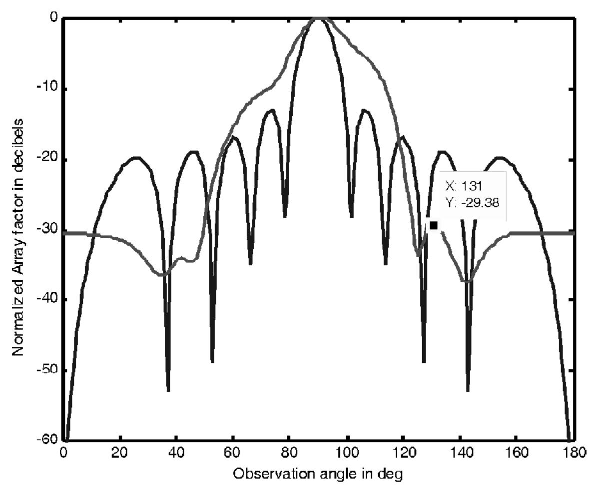

Figure 10: The Normalized radiation pattern of 10-element linear array obtained by GA

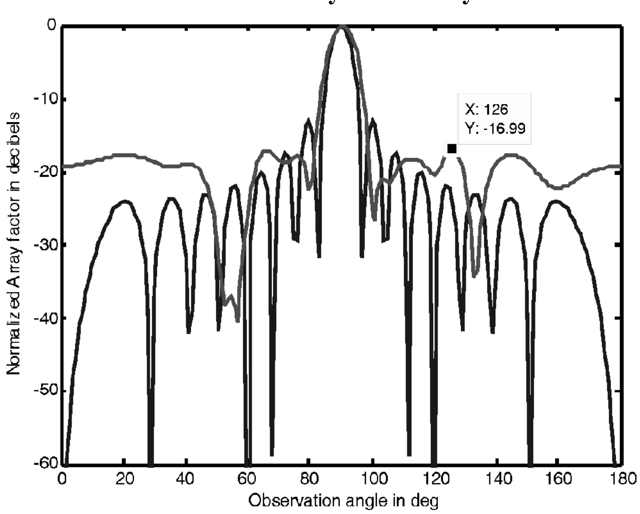

Figure 11: The Normalized radiation pattern of 16-element linear array obtained by GA

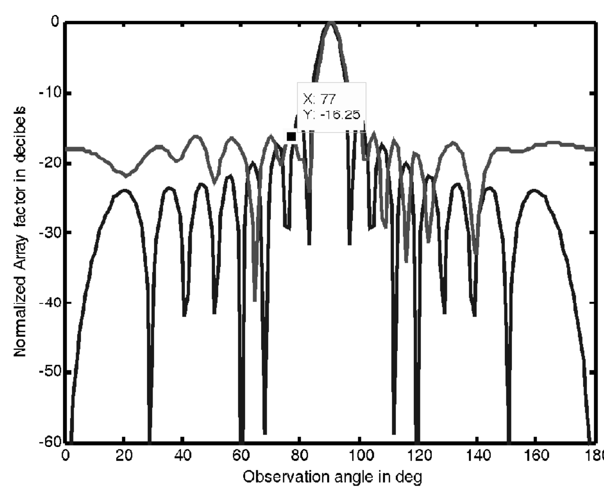

Figure 12: The Normalized radiation pattern of 20-element linear array obtained by GA

The best values obtained in these two cases for ACO and GA are listed in tables 1 and 2 respectively. Comparison between results obtained with ACO and GA are listed in tables 3 and 4.

Table 1
Best values obtained for ACO

No of elements	*Amplitude excitation*	*Phase Excitation*	*SLL (ACO)*
10	1 3 6 8 7 4 2 2 2 1	-	-39.94 dB
	1 2 5 9 10 8 5 4 3 1	0 60 82 76 70 67 77 95 94 78	-30.60 dB
16	1 2 5 8 10 10 8 6 4 3 3 3 3 2 2 1	-	-31.89 dB
	5 8 10 9 8 9 8 4 2 3 5 9 10 2 7 6	0 38 24 43 47 48 40 37 38 17 61 29 26 15 57 68	-17.92 dB
20	4 6 7 6 10 10 8 7 10 10 10 6 10 8 6 7 4 5 3 6 4 4 6 4 4 7 6 7 9 10 5 9 8 8 8 6 9 3 4 4	- 0 25 44 37 83 80 42 84 42 61 75 67 54 40 51 87 25 25 73	-21.02 dB -19.76 dB

Table 2
Best values obtained for GA

No of elements	*Amplitude excitation*	*Phase Excitation*	*SLL (GA)*
10	2 1 4 6 4 7 9 9 5 2	-	-22.54 dB
	1 3 7 10 9 4 1 1 2 1	0 11 31 40 39 47 67 32 23 22	-29.37 dB
16	1 2 3 3 4 4 6 8 9 8 8 9 8 8 5 9	-	-23.48 dB
	1 3 2 4 7 8 6 5 7 9 8 7 6 3 4 2	0 26 15 57 24 68 18 29 45 53 59 44 47 48 41 61	-16.99 dB
20	5 3 1 3 5 3 8 5 8 9 4 9 7 9 10 9 6 6 7 1 6 10 5 10 8 10 5 9 6 76 7 9 3 3 3 2 5 3 1	- 0 21 21 32 41 35 44 44 68 44 59 68 20 21 85 9 54 43 47 74	-17.80 dB -16.25 dB

Table 3
Only Amplitudes case Table 4. Amplitude and phase case

N	*ACO*	*GA*	*N*	*ACO*	*GA*
10	-39.94 dB	-22.54 dB	10	-30.60 dB	-29.37 dB
16	-31.89 dB	-23.48 dB	16	-17.92 dB	-16.99 dB
20	-21.02 dB	17.80 dB	20	-19.76 dB	-16.25 dB

4. CONCLUSION

It is observed that ACO is giving better results in side lobe reduction compared to genetic algorithm based approach. In ACO based approach, amplitude control technique is found to be the best in side lobe reduction. The best value of SLL obtained is -39.94 dB for 10 elements. Simultaneous control of amplitude excitations and phase excitation of different elements is also good in side lobe reduction. The value of SLL in this case is -30.6 dB. This work can also be extended to other array synthesis problems with different geometries like planar, circular arrays etc. Not only SLL, it can be extended to optimization of BWFN.

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