Application of Ant Colony Optimization Algorithm to Pattern Synthesis of Uniform Circular Antenna Array

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Abstract **─** The radiation pattern of the antenna arrays is most important problem in communications technology. In this paper, the optimization of uniform circular antenna array is efficiently solved by ant colony optimization (ACO) Method. The proposed method of optimization is used to determine the suitable cost function which leads to achieve the maximum reduction in side lobe level and provide the maximum directivity towards the direction. To optimize the desired antenna array pattern also one parameter is considered to be optimized which is the angular position of each element.

Index Terms **─** Ant colony optimization, array factor, directivity, side lobe level, uniform circular antenna array.

I. INTRODUCTION

Circular antenna array has been widely used in communications technology in radar, sonar and as it is useful in high power transmission, reduced power consumption and enhanced spectral efficiency [1], [22].The design of this structure is a growing avenue of research in electromagnetics [7], [10], [11], [12] and is very useful in different applications like radio direction finding, space navigation and third generation wireless communication systems [7]-[9].The techniques of the arrays pattern optimization has received considerable attention in the past and is still of great interest [2] and are very important in communications systems. The technique of pattern optimization including the control of the complex weights (the amplitude and phase), the excitation amplitude only and phase-only, and the element position only have been extensively considered in the literature [1], [2], [7]-[30]. The position-only is of particular interest in pattern optimization [22]. In some of the articles [7], [19], [22] the author presents a method of control by phase and angular position for forming signals in prescribed directions with low SLL high directivity and also high signal to interference ratio (SIR) [22]. The technique proposed in this paper is based on ant colony optimization [23], [32]-[34] and ACO will be applied to find the angular positions of the antenna array elements that are optimum to provide the radiation pattern of uniform circular array (UCA). Hence, in this paper the synthesis problem is finding the angular positions of each element by ACO to provide the radiation pattern with maximum reduction in the side lobe level and high directivity at a fixed main beam width. In the final section the performance of ACO is compared GA (genetic algorithm) and IWO (invasive weeds optimization). The parameters used in GA and IWO are selected to be the same as those used in ACO, which ensure a fair comparison in computation efficiency and solution quality.

II. CIRCULAR ANTENNA ARRAY FUNCTION

Consider a circular antenna array of N antenna elements non-uniformly spaced on a circle of radius a in the x-y plane, Fig. 1 .The elements in the circular antenna array are taken to be isotropic sources, so the radiation pattern of this array can be described by its array factor. In the x-y plane, the array factor for the circular array shown in Fig. 1 is given by [4]:

$$AF(\phi,\theta)=\sum_{n=1}^{N} I_n \, e^{j[\beta a \sin\theta \cos(\varphi-\varphi_n)+\alpha_n]}, \tag{1}$$

$$\varphi_n=\frac{2\pi(n)}{N}. \tag{2}$$

In the above equations, I is the excitation amplitude value and is the same for each antenna components. α_n represents the excitation phase of the n-th element and φ_n is the angular position of the n-th element in x-y plane. To direct the peak of the main beam in the φ_0 direction,

Submitted On: December 24, 2013
Accepted On: May 25, 2015

the excitation phase of the *n*-th element is chosen to be:

$$\alpha_n = -\beta a \sin\theta_0 \cos\left(\varphi_0 - \varphi_n\right). \quad (3)$$

The array factor can be obtained by considering the elements to be point sources which is given by:

$$AF\left(\varphi,\theta\right) = \sum_{n=1}^{N} e^{j\beta\, a\left[\sin\theta\cos\left(\varphi-\varphi_n\right) - \sin\theta_0\cos\left(\varphi_0-\varphi_n\right)\right]} = \sum_{n=1}^{N} e^{j\beta\, a\left(\cos\psi - \cos\psi_0\right)}. \quad (4)$$

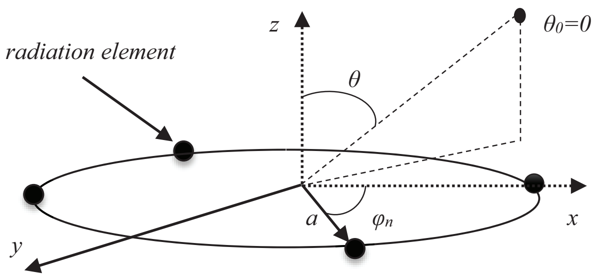

Fig. 1. Geometry of circular antenna array

A general function of optimization that we study consists of the number of objectives. This function value is important to optimize the side lobes level and directivity and also will be obtained by ACO. In this cause the performance of a uniform circular array will be improved substantially, with respect to the circular array with the conventional progressive angular positions of the elements (in terms of the side lobe level and directivity). We should present the basis function to improve the array factor amount which leads to SLL reduction and high directivity [6]. Mathematical problem can be written as follows:

$$\begin{gathered} Minimize \quad f(\varphi) \Rightarrow \; Objective\ function \\ Subject\ to \;\; \varphi \in \chi, \\ \chi\ is\ known\ as\ the\ feasible\ set,\ it\ leads\ to\ \left(\chi_{Optimum}\right): \\ f\left(\varphi_{Optimum}\right) \le f\left(\varphi\right) \\ \min SLL \\ s.t. \;\; f\left(\varphi_{optimum}\right), \\ 0 \le \varphi_n \le 2\pi \quad n = 1,2,\ldots N \end{gathered} \quad (5)$$

where:

$$f_\theta(\varphi) = 2\sum_{n=1}^{N} \cos\left(\beta a\left(\cos\psi - \cos\psi_0\right)\right).$$

The final equation of the notation (5) is the basis function for optimization problem which will be discussed in this paper. In our design, to demonstrate the advantages of the proposed design, the results obtained using angular positions excitations will be displayed in different states of φ_0, therefore in desired design problem we choose φ_0 to be $90°$ and $0°$ for receiving better experimental results. The peak of the main beam is in the *x* direction [4], [5].

III. ANT COLONY OPTIMIZATION

In this part, it will be presented how the ACO can be used for solving the problems. ACO has a very strong ability to solve any hard combinatorial optimization problems and can be a powerful method for the synthesis of antenna array radiation pattern in adaptive beamforming [32]. Desired method inspired by the ant's foraging behavior proposed by Dorigo in his Ph.D. thesis in 1992 and it has been used to solve a different type of problems by employing different realizations of the algorithm [34]. ACO means algorithms based on the ant behavior in searching for food and posterior transportation to the colony have to be stored. These insects have the ability to find the "shortest path" in this task using pheromone. Some ant species use pheromone for making paths on the ground, in their way from the food to the nest. This helps other ants, by sensing pheromone, to follow the path towards food discovered by other ant. Because ants deposit pheromone while walking, a larger number of ants on a path results in a larger amount of pheromone, this larger amount of pheromone stimulates more ants to choose that path and so on until finally, the ants converge to one single (short) path. Also, these pheromone evaporate with time to "delete" the path to an exhausted food source [34].

A. Implementation of the algorithm

The idea behind ACO is to mimic this behavior by using artificial ants. The outline of a basic ACO algorithm is shown in Fig. 2. The ACO version implemented is capable to deal with both continuous and discrete variables. The question that arises is how ACO (first used to solve combinatorial problems) can deal with continuous variables. A possible answer to this question would be the conversion of the continuous optimization problem into a discrete one as proposed in the past in some of the papers. Instead, the present continuous version extends ACO in order to work directly with continuous variables. In this way, the first point that has to be taken into account is how the colony is represented. Following the idea of directly using continuous variables, a colony of *m* ants can be expressed as a $m \times n$ matrix C = [ant_1, ant_2, . . . , ant_m]^T, where ant = [x_1, x_2, . . . , x_n]^T is a vector of design variables that corresponds to a single ant [33]-[34].

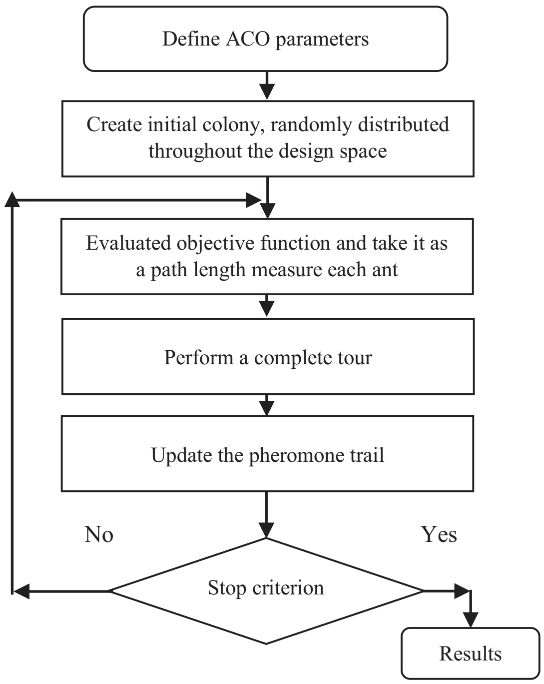

Fig. 2. Basic scheme for ACO.

The second point is how to model the pheromone communication scheme. The continuous version of ACO models the pheromone trail as an amount of pheromone laid on the path. As suggested by Pourtakdoust and Nobahari and Socha, for the continuous model implementation this can be achieved by using a normal probability distribution function (PDF). In this formulation, for the dimension i of the design space, the pheromone trail, τ_i, can be described as follows:

$$\tau_i(x_i) = e^{-\frac{(x_i - x_i^*)^2}{2\sigma_i^2}}, \tag{6}$$

where x_i^* is the i-th coordinate of the best point found by the optimization task within the design space until the current iteration and σ_i is an index related to the ants aggregation around the current minimum for the i-th coordinate of the design space. To close the definition of pheromone, τ, the aggregation index, σ, must be defined. Thus, by taking y as the i-th column of the colony matrix C, the aggregation index for the i-th dimension, σ_i, is given by:

$$\sigma_i = \sqrt{\frac{1}{m-1}\sum_{j=1}^{m}(y_i - \overline{y})}, \tag{7}$$

where $\overline{y}$ is the mean value of the vector y. It is worth making some remarks about the updating process of the values of each design variable for all ants of the colony. This is the process in which, for a given iteration, each ant sets the values for the trial solution based on the probability distribution given by Eq. 6. Computationally, this can be achieved through a random number generator based on a normal PDF that plays the role of a variable transition (update) rule to choose the next design variable value associated with each ant. From Eq. 6, it can also be noticed that each variable uses a different random number generator together with its respective PDF. About the pheromone scheme, it is possible to see that the concentration of pheromone increases in the area of the candidate to the optimum. This approach (also called as positive update) reinforces the probability of the choices that lead to good solutions [23], [33], [34]. The number generating and updating processes will be done continuously until the solution meets the error criteria. In other words if best solution does not change after some iteration, the process will be terminated and the best solution is the best value which optimizes the defined cost function. Fast convergence to the best global solution is the most important and desirable feature of the ant colony optimization method. The number of ants and/or iterations in the algorithm can be selected based on the computational capacity. Actually, in the following examples we have used a relatively low number of ants but a number of iterations large enough to guarantee the convergence of the algorithm to the desired solution. The food is defined as the desired condition, i.e., the angular position of the array elements. Finally, the adopted stopping criterion is to complete the selected number of iterations [33].

IV. NUMERICAL RESULTS

In this section, some computer simulations are conducted to verify the validation of the proposed method. We consider circular antenna array with *10* and *12*-element arrays with element spacing $d = \lambda/2$, where λ denotes the wavelength corresponding to the operating frequency of the narrow band sources [3]. As mentioned to illustrate the performance of the ant colony optimization method, some examples were simulated; Figs. 3 and 4 show the normalized unmodified patterns of the uniform circular antenna array with high level of side lobes comparing to main beam. We can point to the some places like: ($\theta=22.2°$ and $\theta=46.3°$ at $\varphi_0=90°$ $N=10$), ($\theta=90°$ at $\varphi_0=0°$ $N=10$), ($\theta=23°$ and $\theta=45°$ at $\varphi_0=90°$ and $\varphi_0=0°$ $N=12$). Table 1 consists of the desired unmodified states numerical results.

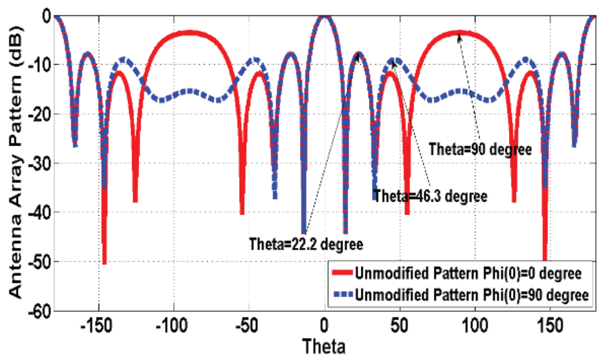

Fig. 3. Unmodified patterns at $\varphi_0 = 90°$ and $\varphi_0 = 0°$ $N=10$.

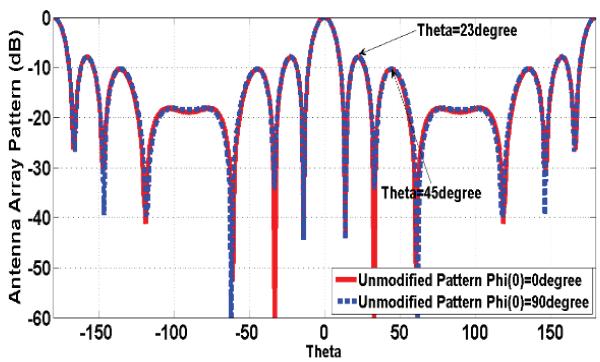

Fig. 4. Unmodified patterns at $\varphi_0 = 90°$ and $\varphi_0 = 0°$ $N=12$.

Table 1: Unmodified patterns information

SLL	Directivity	FNBW	AF	φ0	SIR	N
-7.9 dB	8.2 dB	28°	84.4	90°	7.3 dB	10
-3.6 dB	3.4 dB	28°	112	0°	5.3 dB	10
-7.9 dB	8.53 dB	28°	72.2	90°	7.5 dB	12
-8 dB	8.93 dB	28°	72.8	0°	7.9 dB	12

We assigned the especial way using MATLAB for synthesis the antenna array pattern with the desired values of the proposed antenna parameters and reducing array factor value by optimizing angular positions of the antenna elements after some iterations to optimize the unmodified signals, the number of iterations needed to reach an acceptable solution is *1000-3000*, these values will be investigated and the results will be presented in two different modes, for *10* and *12*-element circular arrays at $\varphi_0=90$ and $\varphi_0=0°$. The cost function will be constructed for maximizing the SLL reduction with high directivity as well as minimizing the array factor value. Finally, the optimized parameters which lead to SLL reduction and high directivity for each directional beam steering will be illustrated all. The excitation positions for each antenna element are constrained to lie between 0 and 2π. The excitation angular positions of the antenna elements are now obtained by ACO to improve the desired parameters values. These obtained results will be computed as given in Tables 2-5.

Table 2: The ACO optimized values (φ_n) at $\varphi_0 = 90°$ for Fig. 5

Iter. 3000	Iter. 2760	Iter. 2340	Iter. 1800	Iter. 870	
79°	90°	90°	90°	90°	φ_1
9°	10°	10°	10°	10°	φ_2
36°	36°	30°	36°	36°	φ_3
12°	9°	7°	12°	7°	φ_4
30°	30°	36°	30°	30°	φ_5
259°	270°	270°	270°	270°	φ_6
189°	190°	190°	190°	190°	φ_7
216°	216°	210°	216°	216°	φ_8
192°	189°	187°	192°	187°	φ_9
210°	210°	216°	210°	210°	φ_{10}

Table 3: The ACO optimized values (φ_n) at $\varphi_0 = 0°$ for Fig. 6

Iter. 3000	Iter. 2678	Iter. 2115	Iter. 1653	Iter. 675	
78.3°	78.3°	78.3°	78.3°	78.3°	φ_1
2.25°	18°	15°	12°	9°	φ_2
60°	60°	60°	60°	60°	φ_3
98°	98°	99°	99°	99°	φ_4
50°	50°	50°	45°	36°	φ_5
258.3°	258.3°	258.3°	258.3°	258.3°	φ_6
182.25°	198°	195°	192°	189°	φ_7
240°	240°	240°	240°	240°	φ_8
278°	278°	279°	279°	279°	φ_9
230°	230°	230°	225°	216°	φ_{10}

Table 4: The ACO optimized values (φ_n) at $\varphi_0=90°$ for Fig. 7

Iter. 3000	Iter. 2835	Iter. 2215	Iter. 1945	Iter. 908	
49°	48°	51°	56°	60°	φ_1
9°	9°	9°	9°	9°	φ_2
26°	23°	22°	30°	21°	φ_3
6°	6°	7°	6°	6°	φ_4
30°	30°	30°	30°	30°	φ_5
90°	90°	90°	90°	90°	φ_6
229°	228°	231°	236°	240°	φ_7
189°	189°	189°	189°	189°	φ_8
206°	203°	202°	210°	201°	φ_9
186°	186°	187°	186°	186°	φ_{10}
210°	210°	210°	210°	210°	φ_{11}
270°	270°	270°	270°	270°	φ_{12}

Table 5: The ACO optimized values (φ_n) at $\varphi_0 = 0°$ for Fig. 8

Iter. 3000	Iter. 2942	Iter. 2321	Iter. 1825	Iter. 893	
78°	78°	78°	78°	78°	φ_1
40°	45°	36°	30°	30°	φ_2
64°	64°	64°	60°	64°	φ_3
90°	90°	90°	90°	90°	φ_4
60°	58°	50°	50°	50°	φ_5
3.6°	12°	12°	10°	10°	φ_6
258°	258°	258°	258°	258°	φ_7
220°	225°	216°	210°	210°	φ_8
244°	244°	244°	240°	244°	φ_9
270°	270°	270°	270°	270°	φ_{10}
240°	238°	230°	230°	230°	φ_{11}
183.6°	192°	192°	190°	190°	φ_{12}

There are twenty states of array antenna patterns at $\varphi_0=90°$ and $\varphi_0=0°$ in Section 4 that can provide the best conditions for uniform circular array pattern. The Figs. 5-8 present the results obtained with *10* and *12* ants, after *3000* iterations for uniform circular antenna array with *10* and *12* elements (foods were defined as antenna elements angular positions). The figures which we want to present, show the ability of ACO algorithm to improve the circular antenna array pattern in both angles ($\varphi_0=90$ and $\varphi_0=0°$) with good radiation parameters values such as the side lobe level, directivity, SIR, and main pattern beam width, but some of them are right to introduce as optimized signals. We have presented Tables 6-9 to choose the best states.

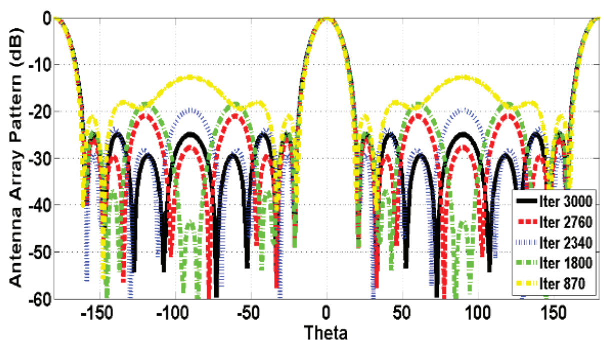

Fig. 5. 10-element array pattern synthesis by ACO $\varphi_0=90°$.

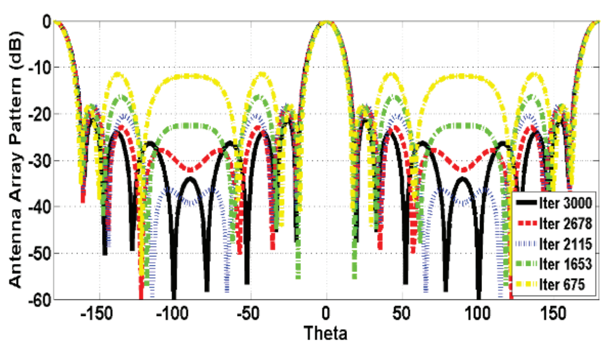

Fig. 6. 10-element array pattern synthesis by ACO $\varphi_0=0°$.

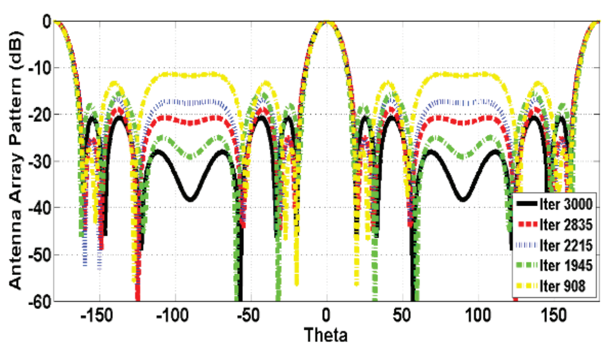

Fig. 7. 12-element array pattern synthesis by ACO $\varphi_0=90°$.

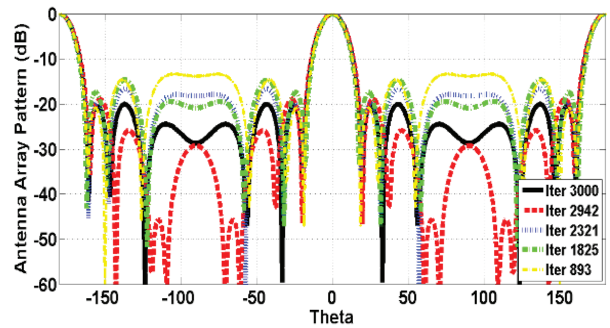

Fig. 8. 12-element array pattern synthesis by ACO $\varphi_0=0°$.

Table 6: Computed parameters for best results at $\varphi_0=90°$ $N=10$

SLL (dB)	-12.8	-18.5	-19.8	-21	-24.9
Directivity	8.9 dB	9.5 dB	9.8 dB	10.3 dB	11 dB
FNBW	45°	44°	42°	42°	41°
AF	60	49	47	46	44
Figure	5	5	5	5	5
Iteration	870	1800	2340	2760	3000
Time (sec)	1234	1700	2361	2678	2856
SIR	25.37 dB	31.2 dB	37.16 dB	37.18 dB	38 dB

Table 7: Computed parameters for best results at $\varphi_0=0°$ $N=10$

SLL (dB)	-11.5	-17.9	-18.21	-18.6	-21.4
Directivity	8.43 dB	9.33 dB	9.58 dB	9.7 dB	10.75 dB
FNBW	35.2°	37.4°	39.8°	39.6°	39.6°
AF	73.3	54.1	48.7	48.3	45.1
Figure	6	6	6	6	6
Iteration	675	1653	2115	2678	3000
Time (sec)	1165	1543	2034	2539	2771
SIR	22.21 dB	25.4 dB	25.6 dB	26.81 dB	34 dB

Table 8: Computed parameters for best results at $\varphi_0=90°$ $N=12$

SLL (dB)	-11.3	-15.5	-16.8	-19	-21.1
Directivity	8.22 dB	8.94 dB	9.18 dB	10.02 dB	10.32 dB
FNBW	40°	39°	40°	42°	40°
AF	74	52.3	59	53.5	47
Figure	7	7	7	7	7
Iteration	908	1945	2215	2835	3000
Time (sec)	1334	1854	2204	2712	2954
SIR	21.7 dB	24.3 dB	30.06 dB	33.7 dB	34.3 dB

Table 9: Computed parameters for best results at $\varphi_0=0°$ $N=12$

SLL (dB)	-13.4	-14.6	-16.6	-18.9	-20.1
Directivity	8.68 dB	8.72 dB	9.11 dB	9.97 dB	10.08 dB
FNBW	39°	39°	39°	40°	40°
AF	67	58.2	58	46	45.7
Figure	8	8	8	8	8
Iteration	893	1825	2321	2942	3000
Time (sec)	1271	1735	2192	2856	2977
SIR	23.1 dB	25.16 dB	26.7 dB	29.7 dB	34.8 dB

Best values include last modified iterations and lesser amounts have been shown in the first modes in Tables 6-9. The information which will be discussed, are presented in Tables 6-9. In these tables the values of directivity and the SLL using ACO are illustrated for array patterns at $\varphi_0=90°$ and $\varphi_0=0°$, which are shown in Figs. 5-8. In Fig. 5 at $\varphi_0=90°$, the best value of directivity for an 10-element array is *11* dB and the best SLL using ACO is *-24.9* dB (3000th iteration). In another mode, Fig. 6 shows 10-element uniform circular array optimized patterns with suitable values of radiation parameters at $\varphi_0=0°$. The best values of directivity and SLL, respectively, for Fig. 6 at $\varphi_0=0°$ (3000th iteration) are *10.75* dB and *-21.4* dB. The best values for 12-element array in Fig. 7 are as follows: directivity is *10.32* dB and SLL is equal to *-21.1* dB at $\varphi_0=90°$ (3000th iteration), the results which are shown in Table 8 are computed for 12-element uniform circular array. In the final state, Fig. 8 shows the 12-element uniform circular array optimized patterns with the suitable measure of desired parameters at $\varphi_0=0°$. The best values of directivity and SLL in this case in order are *10.08* dB and *-20.1* dB (3000th iteration). We analyzed the numerical results from the simulated structures of the antenna patterns and finally we found that the final states (3000th iterations) present better computed results with maximum reduction in SLL and the suitable measures of directivity, so we can introduce them as the states optimized propagations in Figs. 9-12.

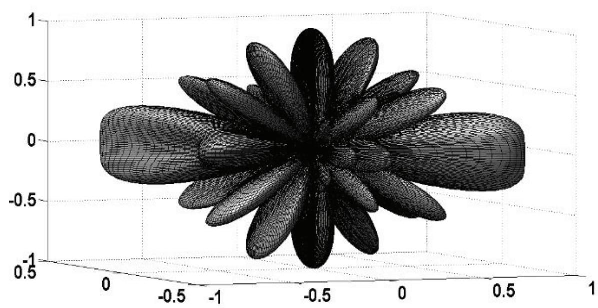

Fig. 9. Optimized state by ACO iteration *3000* at $\varphi_0=90°$ *N=10.*

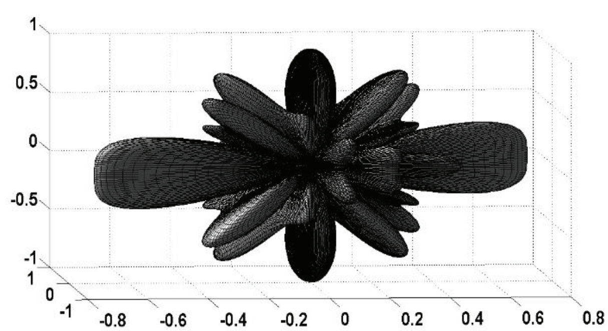

Fig. 10. Optimized state by ACO iteration *3000* at $\varphi_0=0°$ *N=10.*

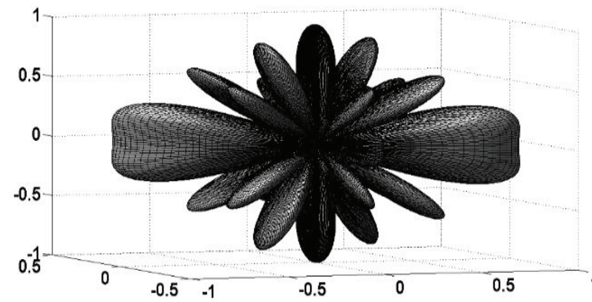

Fig. 11. Optimized state by ACO iteration *3000* at $\varphi_0=90°$ *N=12.*

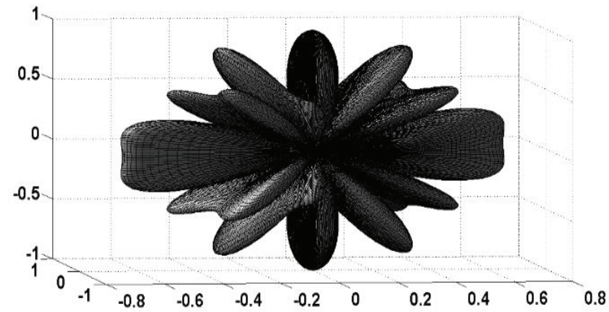

Fig. 12. Optimized state by ACO iteration *3000* at $\varphi_0=0°$ *N=12.*

The methods of ACO, GA and IWO were compared to study the behavior of the desired method to optimize the array pattern [7], [8], [16], [31]. The number of antenna elements was set as *N= 10* at the first case and *N=12* at the second mode in both angles ($\varphi_0=90$ and $\varphi_0=0°$). We also give all algorithms the same computation time with equal computational resources. The stopping criterion is, in both algorithms GA and IWO, the number of *3000* iterations like ACO. The obtained results of excitation angular positions of array elements by GA and IWO have been presented in Tables 10 and 11.

Table 10: The IWO and GA optimized values (φ_n)

GA	IWO	GA	IWO	
78°	40°	90°	40°	φ_1
15°	108°	10°	77°	φ_2
60°	7°	30°	5°	φ_3
99°	90°	8°	14°	φ_4
47°	120°	36°	205°	φ_5
258°	220°	270°	220°	φ_6
195°	288°	190°	257°	φ_7
240°	187°	210°	185°	φ_8
279°	270°	188°	194°	φ_9
227°	300°	216°	25°	φ_{10}
0°	0°	90°	90°	φ_0
3000	3000	3000	3000	Iteration
10	10	10	10	N

Table 11: The IWO and GA optimized values (φ_n)

GA	IWO	GA	IWO	
78	40	90	40	φ_1
15	77	10	77	φ_2
60	7	35	5.5	φ_3
99	90	7.2	14	φ_4
52	120	60	206	φ_5
3.6	58	30	60	φ_6
258	220	270	220	φ_7
195	257	190	257	φ_8
240	187	215	185.5	φ_9
279	270	187.2	194	φ_{10}
232	300	240	26	φ_{11}
183.6	238	210	240	φ_{12}
0°	0°	90°	90°	φ_0
3000	3000	3000	3000	Iteration
12	12	12	12	N

The best results for each run are considered and Tables 12 and 13 show the comparison results; we can say that Figs. 13-16 illustrate the best array factor obtained for all of the algorithms. The numerical values of the side lobe level, directivity and other parameters results shown in Figs. 13-16 are presented in the Tables 12 and 13.

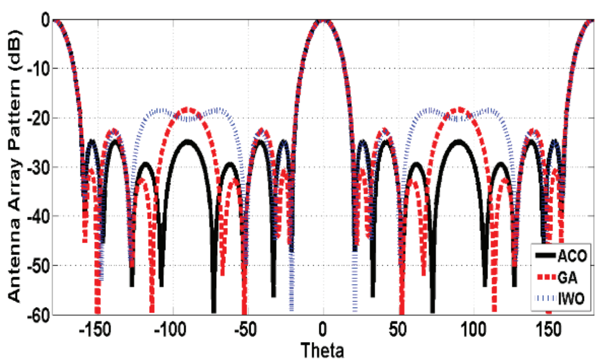

Fig. 13. Compared algorithms results, $\varphi_0 = 90°$ $N=10$.

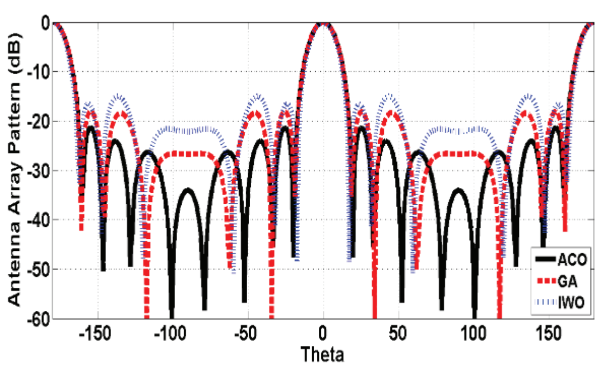

Fig. 14. Compared algorithms results, $\varphi_0 = 0°$ $N=10$.

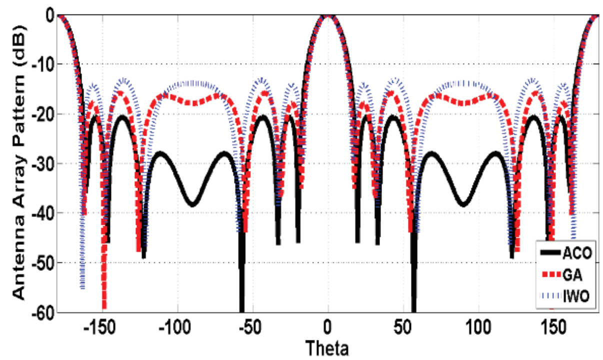

Fig. 15. Compared algorithms results, $\varphi_0 = 90°$ $N=12$.

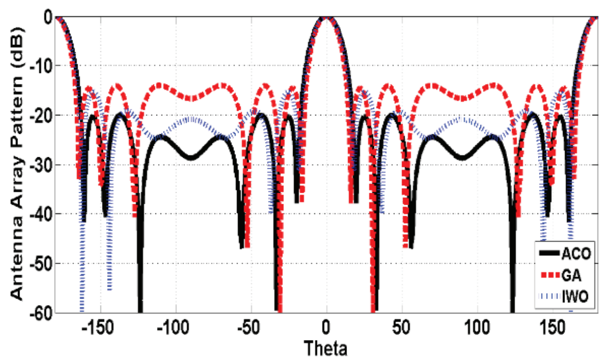

Fig. 16. Compared algorithms results, $\varphi_0 = 0°$ $N=12$.

Table 12: Computed radiation parameters for comparing *N=10*

Method	φ0	SLL (dB)	Directivity	FNBW	SIR	AF
ACO	90°	-24.9	11 dB	41°	38 dB	44
IWO	90°	-18.6	9.16 dB	42°	35.6 dB	55
GA	90°	-18.9	10.13 dB	45°	36.2 dB	49
ACO	0°	-21.4	10.75 dB	39.6°	34 dB	45.1
IWO	0°	-16	8.87 dB	35°	22 dB	56.2
GA	0°	-18	9.5 dB	37°	24.4 dB	51

Table 13: Computed radiation parameters for comparing *N=12*

Method	φ0	SLL (dB)	Directivity	FNBW	SIR	AF
ACO	90°	-21.1	10.32 dB	40°	34.3 dB	47
IWO	90°	-13	8.46 dB	36°	20.5 dB	58.5
GA	90°	-16	8.81 dB	35°	22.8 dB	60
ACO	0°	-20.1	10.08 dB	40°	34.8 dB	45.7
IWO	0°	-15.3	8.53 dB	38°	22.6 dB	56
GA	0°	-14.1	8.71 dB	33°	19.5 dB	66

The method of ACO presents a better performance in terms of the side lobe level with respect to GA and IWO, maintaining very similar values for the directivity in the performance of these three optimization methods. The results of the side lobe level and the directivity for the optimized design are really surprising. In the case of the optimized designs for uniform circular array with 10 elements at $\varphi_0=90°$, it is obtained a SLL = *-24.9* dB and DIR = *11* dB for ACO, a SLL = *-18.9* dB and DIR = *10.13* dB for GA, and a value of SLL = *-18.6* dB and DIR = *9.16* dB for IWO. The obtained results in this case at $\varphi_0=0°$ are a SLL = *-21.4* dB and DIR = *10.75* dB for ACO, a SLL = *-18* dB and DIR = *9.5* dB for GA, and a value of SLL = *-16* dB and DIR = *8.87* dB for IWO. In another mode of optimization, the values for 12-element uniform circular array are as follows: directivity is *10.32* dB and SLL is equal to *-21.1* dB for ACO, a SLL = *-16* dB and DIR = *8.81* dB for GA and a value of SLL = *-13* dB and DIR = *8.46* dB for IWO at $\varphi_0=90°$. The computed results at $\varphi_0=0°$ in order are a SLL = *-20.1* dB and DIR = *10.08* dB for ACO, a SLL = *-14.1* dB and DIR = *8.71* dB for GA, and a value of SLL = *-15.3* dB and DIR = *8.53* dB for IWO. These values mean a substantial improvement in the performance of the array for the design optimized by the method of ACO, with respect to the conventional case of progressive angular positions excitation, a substantial improvements were obtained in the sense of the side lobe level and the directivity. It can be seen that using the ACO method gives radiation patterns which are generally better than that obtained from the GA and IWO results. Specifically, in range of the SLL and directivity [22], [7].

V. CONCLUSION

In this paper, ant colony optimization (ACO) is used to obtain maximum reduction in side lobe level relative to the main beam and improve the directivity. The ACO method was used to adjust elements angular position in the circular antenna array to optimize the array pattern. This method is very effective and can be used in practice to synthesize other structures. The results of the comparison express that antenna array patterns obtained from ACO are generally have better SLL and directivity than uniform circular array applying the desired algorithm in [22], [7]. All these factors together have been considered for optimal results in our design problem and these accounts for the understatement of this work.

ACKNOWLEDGMENT

We wish to thank everyone who helped us to complete this research. Without their continued efforts and support, we would have not been able to bring our investigations to a successful completion. Prof. Josef. Giglmayr: for guidance. Dr. Ali. Hashemi Talkhunche: for his participation in our study.

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