

LINEAR ARRAY SYNTHESIS USING BIOGEOGRAPHY BASED OPTIMIZATION

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Abstract—This paper presents a novel optimization technique biogeography based optimization (BBO) for antenna array synthesis. BBO is a relatively new evolutionary global optimization technique based on the science of biogeography. It is capable of solving linear and non-linear problems. In this paper, BBO algorithm is used to determine an optimum set of amplitudes of antenna elements that provide a radiation pattern with maximum side lobe level reduction and/or null placement in the specified directions. The results obtained show the effectiveness of the BBO algorithm, and they are better than previous published results.

1. INTRODUCTION

Antenna array pattern synthesis in the past has received much attention as antenna arrays find their application in different communication systems such as radar, sonar, satellite, wireless [1–30]. The communication systems depend heavily on the antenna arrays for their performance. Antenna array synthesis aims at obtaining a

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physical structure whose radiation pattern is close to the desired. The majority of applications intend to achieve high main lobe to sidelobe ratio. Others aim to place the null in specified direction so as to nullify the effect of interference and thus maximize the signal to noise interference ratio. The antenna synthesis methods achieve the desired pattern generally by controlling the complex weights (both amplitude and phase), amplitude only, phase only and array element positions only. Each of these methods has its merits and demerits, which have been discussed in [19].

Antenna array optimization has been performed successfully using different techniques. The array optimization is a non-linear problem and has many local minima. The gradient methods are not a good choice for these problems as they rely heavily on the initial guess, and if the guess is not good they can stuck in the local minima. This has led to the use of stochastic global algorithms which escape the local minima and are able to find the global minima. The stochastic optimization techniques that have been used for antenna array synthesis include genetic algorithm (GA) [5–16], simulated annealing (SA) [17, 18], bees algorithm [19], particle swarm optimization (PSO) [20–24], ant colony optimization (ACO) [25, 26], tabu search (TS) [27], bacterial foraging (BF) [28], differential evolution (DE) [29] and Taguchi method [30]. These algorithms have provided better results than the gradient methods. In this paper, an alternative global optimization method, biogeography based optimization (BBO), is introduced for the antenna array optimization for obtaining single and multiple nulls and required sidelobe levels by controlling only the amplitudes of the elements. BBO is an optimization problem which is based on the nature’s way of distributing habitats. BBO has been proven to have good convergence properties on different benchmark functions by Simon [31]. To the best of our knowledge, it is being used for the first time for the antenna array optimization.

2. ANTENNA ARRAY PATTERN FORMULATION

For a linear array consisting even number of $2N$ uniformly spaced isotropic elements the array factor (AF) is given by:

$$AF(\phi) = 2 \sum_{n=1}^N I_n \cos[kx_n \cos(\phi) + \varphi_n] \quad (1)$$

where k is the wave number, and I_n , φ_n , x_n are, respectively, the excitation amplitude, phase, and location of the n th element. The antenna geometry is shown in Figure 1.

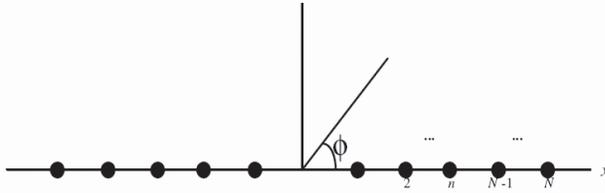


Figure 1. The geometry of a $2N$ -element symmetric linear array.

In this paper, BBO is used to find the current amplitudes $\{I_1, I_2, \dots, I_n\}$ of the array elements that will give an array radiation pattern with minimum SLL and if the nulls are needed in the desired direction. Since in this paper only amplitudes of the elements are optimized, the phase of each element φ is taken as zero. Therefore, the AF for this optimization can be written as:

$$AF(\phi) = 2 \sum_{n=1}^N I_n \cos[kx_n \cos(\phi)] \quad (2)$$

3. BIOGEOGRAPHY BASED OPTIMIZATION

BBO is a new population-based evolutionary algorithm which is based upon the theory of biogeography. Biogeography is the study of distribution of biodiversity over space and time. Many species like plants and animals migrate to different habitats or islands for their survival and better living. In the science of biogeography, an island is defined as the ecological area that is inhabited by particular plant or animal species and which is geographically isolated from the other habitats. Each island has its characteristics such as food availability, rainfall, temperature, diversity of species, security, population of species etc. The quality of an island is measured by its suitability index (SI). Islands with high SI are more suitable for living and therefore have large population while those with low SI have sparse population due to the fact that they are not suitable or friendly for living. High SI islands have low immigration rate λ and high emigration rate μ simply due to high population, so they are less dynamic. By the same virtue, islands with low SI have high immigration rate λ and low emigration rate μ , so they accept more species from high SI islands to move to their islands, which may lead to increase in the SI of the island. The immigration and emigration rates depend on the number of species in the habitats. The values of emigration and immigration rates are given

as:

$$\lambda = I \left(1 - \frac{k}{n} \right) \quad (3)$$

$$\mu = \frac{E}{n} \quad (4)$$

where I is the maximum possible immigration rate; E is the maximum possible emigration rate; k is the number of species of the k -th individual; n is the maximum number of species.

In BBO, a solution is represented by an island. A good solution is analogous to high SI island while a poor solution is given by low SI island. Islands consist of solution features named suitability index variables (SIV), equivalent to GA's genes. The value of SI of an island in BBO is similar to fitness of solution in the other algorithms. The method to generate the next generation in BBO is by migrating the solution features from one island to the other, and then the mutation is performed for the whole population just like in GA.

The aim of optimization is to find an optimal solution in terms of the variables of the problem. An array of variable values to be optimized is formed. In GA terms, this array is called "*chromosome*", but in BBO the term "*island*" is used for this array. In an N_{var} -dimensional optimization problem, an island is a $1 \times N_{var}$ array. This array is defined by:

$$Island = [SIV_1, SIV_2, \dots, SIV_{N_{var}}]$$

In GA terminology these SIVs are called "*genes*". The SIVs or variables values in the island are represented by floating-point numbers. The SI or cost of the island is found by evaluating the cost function f at the above given array or island. Therefore,

$$Cost = f(island) = f(SIV_1, SIV_2, \dots, SIV_{N_{var}})$$

Firstly, the initial population of islands NP is generated. Then, migration between the solutions is applied to share the features between the islands. To apply the migration operator, immigration and emigration rates of each solution is evaluated. As discussed above, good solutions have high emigration rate and low immigration rate while it is opposite for the poor solutions. Now, for every SIV or feature in each solution or island S_i , the probability to immigrate or not is proportional to λ_i . If immigration is selected for a given SIV, then the emigrating island S_k is selected probabilistically based upon the emigration rate μ_k . After migration process, mutation is probabilistically applied to the island though mutation is not an essential feature of BBO. The purpose of mutation is to increase diversity among the population. The algorithm for migration and

Table 1. Comparison between GA and BBO terminology.

GA	BBO
Gene	SIV
Chromosome	Island
Crossover	Migration

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1. for  $i=1$  to NP do
2.   Select  $I_i$  with probability based on  $\lambda_i$ 
3.   if  $I_i$  is selected then
4.     for  $j=1$  to NP do
5.       Select  $I_j$  with probability based on  $\mu_j$ 
6.       if  $I_j$  is selected
7.         Randomly select a SIV  $v$  from  $I_j$ 
8.         Replace a random SIV in  $I_i$  with  $v$ 
9.       end if
10.    end for
11.  end if
12. end for

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Figure 2. Migration process of BBO.

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1. for  $j=1$  to length (SIV) do
2.   Use  $\lambda_i$  and  $\mu_i$  to compute the probability  $P_i$ 
3.   Select a variable  $I_i$  (SIV) with probability based on  $P_i$ 
4.   if  $I_i$  (SIV) selected then
5.     Replace  $I_i$  (SIV) with a randomly generated SIV
6.   end if
7. end for

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Figure 3. Mutation process of BBO.

mutation process is shown in Figures 2 and 3. The mutation process shown in Figure 3 is just an example, and other standard mutation processes work as well. As with the other population-based algorithms, elitism is incorporated in BBO to preserve the best solutions in the population. This prevents the best solutions from being ruined by immigration.

Similar to GA and PSO, BBO share its information between solutions. Therefore, BBO can be applied to many of the similar types of problems that GA and PSO are used for. But, BBO also has some distinct features which differentiates it from the other algorithms. One of them is that the original population is not discarded after each generation. It is rather modified by migration. Also, for each generation, BBO uses the fitness of each solution to determine its emigration and immigration rates [31]. The comparison of terminology between GA and BBO is given in Table 1.

4. DESIGN EXAMPLES

In this section, BBO algorithm is implemented for the equally spaced symmetric linear array. The problem is to optimize the amplitudes of the elements to achieve minimum SLL or/and with null placement. For this antenna arrays, different numbers of elements are taken. The amplitudes of the elements allowed to vary between $[0, 1]$. The element positions and phases are fixed as in the case of conventional array, i.e., x_n is $\lambda/2$ and phases $\varphi_n = 0$ for $n = 1, \dots, N$ (in a conventional array x_n is $\lambda/2$, $\varphi_n = 0$ and $I_n = 1$). The simulation is run on P-IV 1.8 GHz computer with 1 GB of RAM. The algorithm of BBO is implemented using Matlab. The following parameters of BBO are taken for this optimization: Maximum species count $n = 60$, maximum migration rates $E = 1$ and $I = 1$, population size $NP = 60$, no. of generations = 50, mutation probability = 0.04, habitat modification probability = 1 and elitism = 2.

4.1. Minimization of the Maximal Sidelobe

In the first example, BBO is used to minimize the maximum SLL of a 24-element linear array in a specific region by varying amplitudes only. The objective function is taken as follows:

$$\begin{aligned} \text{Fitness} &= \min(\max \{20 \log |AF(\phi)|\}) \\ \text{subject to } \phi &\in \{[0^\circ, 76^\circ] \& [104^\circ, 180^\circ]\} \end{aligned} \quad (5)$$

The simulation was run for 25 times, and the best result obtained by BBO is listed in Table 2. The consistency of BBO algorithm in 25 runs is listed in Table 3. The results of other algorithms such as TS [27] and PSO [23] are also tabulated in Table 2. The radiation plots of the array obtained by BBO and TS are shown in Figure 8. The maximum SLL level for the BBO is 2.5 dB and 1 dB lower than TS and PSO respectively. The amplitude distributions with the array elements are shown in Figure 5. It can be seen that it decreases from center to the edges of the array.

Table 2. Normalized amplitudes of 24-element Linear Array optimized for minimizing peak SLL.

Element		SLL(dB)
$ I_n $ (BBO)	1.00, 0.9765, 0.9270, 0.8581, 0.7749, 0.6750, 0.5757, 0.4671, 0.3716, 0.2728, 0.2003, 0.2001	-35.5
$ I_n $ (TS) [27]	1.00, 0.9811 0.9373 0.8850 0.7883 0.7294 0.5984 0.5319 0.4051 0.3381 0.2123 0.3197	-33.0
$ I_n $ (PSO) [23]	1.00, 0.9712, 0.9226, 0.8591, 0.7812, 0.6807, 0.5751, 0.4768, 0.3793, 0.2878, 0.2020, 0.2167	-34.5

Table 3. Performance of BBO algorithm for 24-element linear array obtained in 25 runs.

Best SLL (dB)	-35.5
Mean (dB)	-34.4
Worst (dB)	-33
SD (dB)	0.6017

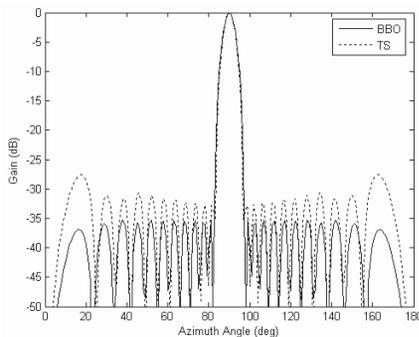


Figure 4. Radiation pattern of 24-element antenna array optimized for minimizing peak SLL.

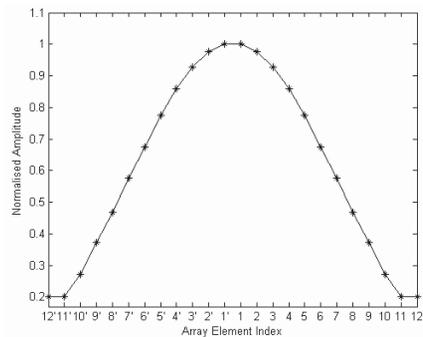


Figure 5. Normalized amplitude distribution of 24-element antenna array.

For some applications, it is required to have an antenna array that has low sidelobes just neighboring the main lobe to avoid interference. For this purpose, the objective function was used by [23], and it is given in equation [6]. This objective function helps in reducing the near sidelobe as well as controlling the other sidelobes. In the second example, 10-element linear array is optimized for the above said

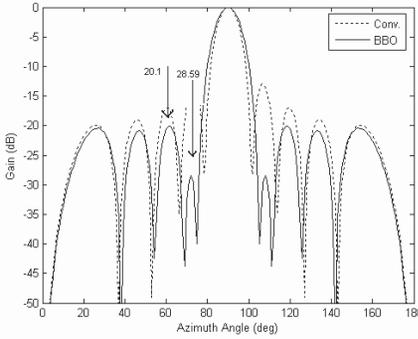


Figure 6. Radiation pattern of 10-element antenna array optimized for controlling near SLL.

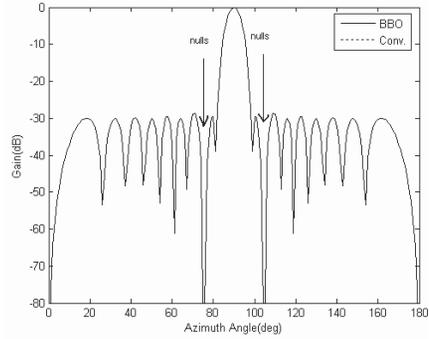


Figure 7. Radiation pattern of 20-element antenna array optimized for controlling nulls and SLL suppression. Nulls are placed at 76° and 104° .

Table 4. Normalized amplitudes of 10-element linear array optimized for minimizing near SLL.

Element	1	2	3	4	5
$ I_n $	1.0000	0.8526	0.6586	0.4601	0.5101

Table 5. Normalized amplitudes of 20-element Linear Array optimized for minimizing peak SLL and obtaining nulls at 76° and 104° .

Element	1	2	3	5	6	7	8	9	10
$ I_n $	1.0000	0.9769	0.9082	0.8034	0.7664	0.6267	0.5551	0.4397	0.0309

purpose. The values of a , b are taken as 1 and 2 which are the same as those taken by [23]. The results obtained are shown in Table 4. The radiation pattern is plotted in Figure 6 which shows the near sidelobe being reduced as compared to the one in conventional array

$$\begin{aligned}
 \text{Fitness} &= \min(a * \max \{20 \log |AF(\phi_{ES})|\} \\
 &\quad + b * \max \{20 \log |AF(\phi_{NS})|\}) \\
 &\text{subject to } \phi_{ES} \in \{[0^\circ, 76^\circ] \& [104^\circ, 180^\circ]\} \\
 &\quad \text{and } \phi_{NS} \in \{[69^\circ, 76^\circ] \& [104^\circ, 111^\circ]\}
 \end{aligned} \tag{6}$$

4.2. Minimizing Sidelobe Level and Null Steering

The third example for BBO optimization is taken for minimizing the average SLL and controlling the nulls of the linear antenna array. In the simulation, the pattern value lower than -60 dB is viewed as the null. For this, the following objective function is used:

$$\text{Fitness} = \sum_i \frac{1}{\Delta\phi_i} \int_{\phi_{li}}^{\phi_{ui}} |AF(\phi)|^2 d\phi + \sum_k |AF(\phi_k)|^2 d\phi \quad (7)$$

where the first term in right hand side (RHS) is responsible for controlling the SLL, and the second term in RHS side is the term for controlling the nulls. In this equation, $\Delta\phi_i$ represents the bandwidth to suppress and is given by $[\phi_{ui} - \phi_{li}]$. ϕ_k is the direction of the nulls.

In this example, 20-element array is designed for minimum SLL in bands $[0^\circ, 82^\circ]$ and $[98^\circ, 180^\circ]$ and nulls at 76° and 104° . The results obtained are shown in Table 5, and the radiation pattern is plotted in Figure 7 which shows nulls at 76° and 104° . The radiation plot shows that nulls as deep as -80 dB are achieved.

In the fourth example, 20-element array has been designed for minimum SLL in bands $[0^\circ, 82^\circ]$ and $[98^\circ, 180^\circ]$ and has nulls at 64° ,

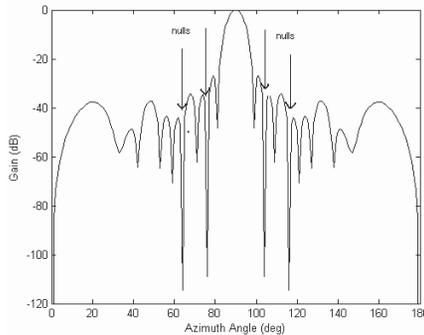


Figure 8. Radiation pattern of 20-element antenna array optimized for controlling nulls and SLL suppression. Nulls are placed at 64° , 76° , 104° and 116° .

Table 6. Normalized amplitudes of 20-element Linear Array optimized for minimizing peak SLL and nulls at 64° , 76° , 104° and 116° .

Element	1	2	3	4	5	6	7	8	9	10
$ I_n $	1.0000	0.9747	0.9264	0.8575	0.7022	0.6242	0.4799	0.3607	0.2369	0.1234

76°, 104° and 106° by using the same objective function as in the previous example. The optimized amplitudes obtained are tabulated in Table 6. The gain pattern of the optimized amplitudes is shown in Figure 8 which shows nulls in the desired direction.

5. CONCLUSION

This paper illustrates the use of BBO for the linear array synthesis. Results show that the amplitudes are successfully optimized to obtain patterns with satisfactory null depth and minimum SLL. BBO has achieved better results than PSO and TS algorithms. The BBO is fast and reliable global search algorithm. It is easy to implement and simple to understand. In this paper, a simple example of synthesis of linear array in which only amplitudes have been optimized, but BBO can also be applied to control the array pattern by optimizing other parameters such as the element locations and phases. This paper will encourage the use of BBO for optimization of the other antenna geometries, and it will become useful tool for an antenna designer.

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