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Phase-only Pattern Synthesis of Antenna Arrays Based on A Modified Genetic Algorithm

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1 Introduction

In modern wireless communication systems, the smart antenna has played an important role, which may be one of indispensable techniques in 4G & beyond 3G. Antenna pattern synthesis is an important topic in the smart antenna, in which the speed and robustness of algorithms are the key point.

In smart antenna systems, it is needed to adjust many parameters adaptively to form the required beam. In a complicate system, however, the optimization of the parameters is always very difficult because in many situations the number of the parameters exceeds the capability of conventional optimization method. As an important part of evolutionary computation, GA is an adaptive artificial intelligence technology in solving an extremum problem based on biology evolution theory of the nature. As a stochastic search and optimization method, GA operates many possible results, instead of a single one. The algorithm has several searching paths, so it is a parallel algorithm. The algorithm only uses an objective function without any statistical information. So the genetic algorithm is useful in optimizing large scale, high nonlinear, non-continuous functions even special objective functions that don't have analytic expressions.

GA has been often used in the antenna design, such as array antenna thinning, side lobe reducing, nulls forming by the adjustment of the excitation or the space of elements. Using a binary-coded GA, Edward E. Altshuler [1] has designed a loaded monopole antenna with a modified folded dipole that is omni-directional over the hemispherical coverage. But this binary-coded GA is time-consuming for computation so it cannot be used in real-time processing. Compared with conventional binary-coded GA, real-coded GA has clear physical background. For continuous variable, the length of chromosome restricts binary-coded method. Additionally, binary-coded GA requires coding and decode ceaselessly, which needs a lot of computation time. Therefore, for continuous variable optimize problem, real-coded GA has good efficiency. Randy L. Haupt[2]、Francisco J. Ares-Pena[3] introduced GA into pattern synthesis of antenna arrays. F. Ares[4] used GA and simulated annealing technique to optimize the antenna pattern. Some other reports about GAs used in electromagnetic problem can be found in [5-8]. Most of them use binary-coded GAs and need a lot of computation time.

2 Modified real-coded genetic algorithm

Because optimized parameters are often contradictory in many real applications, it is usually difficult to solve a multi-objective optimization problem. The motivation of the system design is not only to optimize every parameter, but also choose tradeoff point among all correlative parameters. In

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this situation, a complex objective function that combines all kinds of parameters with proper weights is often used. Therefore if some chromosomes that correspond to one parameter increase rapidly at the beginning of the algorithm, the algorithm will often stick into a local minimize. To solve such a problem, checking close relative or increasing mutation ratio is often adopted, which may result in the incertitude of the algorithm.

In this paper, a modified real-coded GA is proposed, in which a combination of objective functions and a relative selecting scheme is used. The detail process of the algorithm is shown in Fig.1 as below:

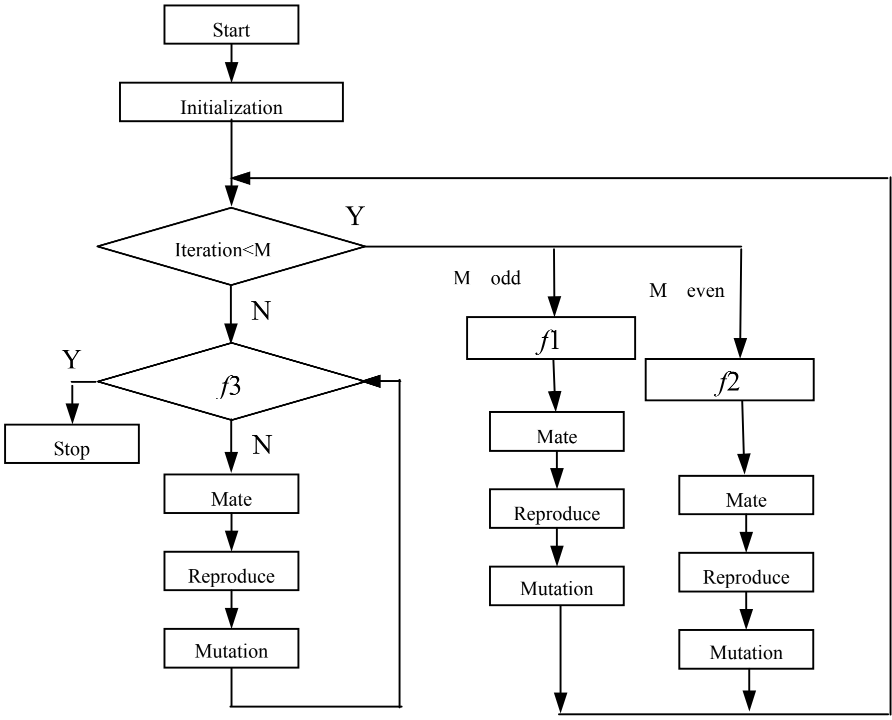

Figure 1 Basic process of the modified genetic algorithm

In initial stages of this GA, all chromosomes are optimized with different objective functions. So different good genes of chromosomes corresponding to different parameters will be increased uniformly. Meanwhile, since different parameters are considered alternately, local optimum result and prematurity are avoided.

In the anaphase of the GA, all parameters about pattern are combined to form a new objective function with different weigh. Because each of good genes about each parameter has accumulated in the former computation, this GA can get the best chromosome on the basic of each parameter's good genes.

3. Pattern synthesis of phase-only antenna arrays based on the GA

Considering a uniform array antenna composed with 10 elements, the initial current amplitudes are same. The aim is to optimize the phases of all elements using the GA. The design object is to make the main beam be located at 90^0 with beam width 10^0 (first-null beam width), forming –80dB nulls at 30^0、40^0、50^0, side lobe is less than -15dB. Three objective functions are defined as follows:

$$f1 = \left| MSLL - SLVL \right| \tag{1}$$

$$f2 = \beta \left| NULL\_PAT - NLVL \right| + \gamma NULL\_STD \tag{2}$$

$$f3 = \alpha \left| MSLL - SLVL \right| + \beta \left| NULL\_PAT - NLVL \right| + \gamma NULL\_STD \tag{3}$$

Where: $MSLL = \max_{\varphi \in S} \{F(\varphi)\}$ is the maximum of side lobe level. *SLVL* is the required side lobe level. *NULL_PAT* is the depth of mean nulls; *NLVL* is the depth of desired nulls3. *NULL_STD* is the variance of those depths. α, β, γ are the weigh factors of each term

In the simulation, the initial population is 200 and interim is 150. Before the 100th generation, $f1$ is the objective function in odd iterations and $f2$ is the objective function in even iterations. After the 100th generation, $f3$ is used as the objective function.

The final objective function in (3) combines three characters of the antenna pattern. The weigh factors can be taken empirically as $\alpha = 0.8$, $\beta = 0.2$, $\gamma = 1.0$. To ensure balance of nulls, in this paper, the variance of the null depth is added to the objective function. To ensure convergence, the proposed algorithm protects the best chromosome in each generation from being destroyed in mutation. The excitation phase of arrays is obtained as M=[174.3388, 150.5975, 159.4311, 153.7652, 157.8797, 175.5241, 185.7640, 162.3440, 171.5961, 166.0217]^T by 150 iterations. Figure 2 shows the antenna pattern. Another simulated result is shown in Fig. 3, in which the main beam is located at 110^0 and nulls are located at $50^0, 60^0$ and 70^0. As a comparison, the result by a conventional GA that uses sole objective function is also given with dash line. Obviously, the conventional GA had stuck in local minima and failed in this situation. By a lot of simulations, it can be seen that when the main beam is not located at 90^0, the conventional GA usually fails because of the improper objective function. To escape this bad situation, it is needed to select initial chromosomes by using other method. But it is often difficult in complex systems. Compared with the conventional GA, the proposed GA can get rid of the dependence of the convergence of conventional GAs on the initial population. The third simulated result is shown in Fig. 4, in which the main beam is located at 90^0 and nulls are located at 60^0, 80^0, 100^0, 130^0 and 140^0. Obviously, when the nulls are located at both sides of the main beam, the proposed algorithm works well

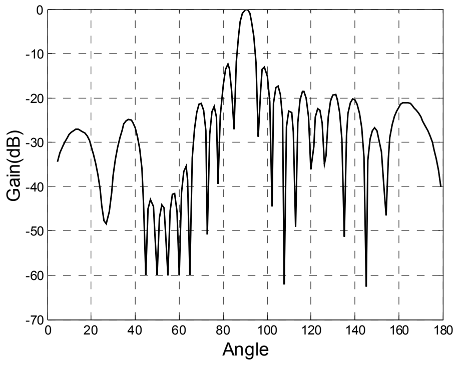

Figure 2 Normalized antenna pattern

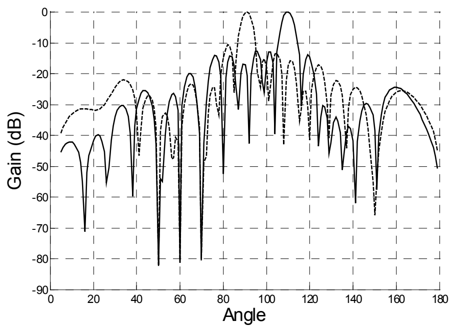

Figure 3 Normalized antenna pattern

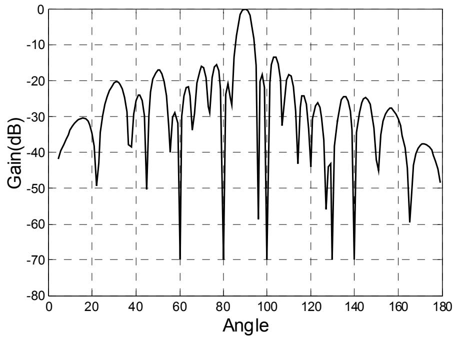

Figure 4 Normalized antenna pattern

4. Conclusion

An application of antenna arrays has been suggested in recent years for mobile communication systems to overcome the lack of the channel resource, thereby satisfying an ever growing demand for a large number of mobiles on communication channels [9]. Conventional array antenna technology is difficult to meet actual requirements. Pattern synthesis based on GA is showing advantages in this application. In this paper, a new GA is presented, which can optimize a series of parameters and get best tradeoff in applications. Though this technology is restricted by computer's ability and difficult to be used in real-time processing immediately, it will show more advantages and get more and more applications with the development of computer technology and further research of GA.

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