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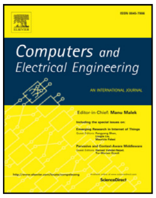

Beam pattern synthesis based on improved biogeography-based optimization for reducing sidelobe level[☆]

Han Li[a], Yanheng Liu[a,b], Geng Sun[a,d,*], Aimin Wang[a,b,*], Shuang Liang[c]

[a] College of Computer Science and Technology, Jilin University. Changchun, Jilin 130012, China
[b] Key Laboratory of Symbolic Computation and Knowledge Engineering of Ministry of Education, Jilin University, Changchun, 130012, China
[c] College of Software, Jilin University, Changchun, Jilin 130012, China
[d] School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, 30332, USA

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ABSTRACT

This study deals with a design problem of linear and circular antenna arrays (LAAs and CAAs, respectively) for suppressing the sidelobe levels (SLLs). By adding a new local search strategy and a selection operator into the normal biogeography-based optimization, this work develops a biogeography-based optimization based on local search (BBOLS) algorithm to determine an optimal set of excitation current values for LAAs and an optimal set of excitation current as well as spacing values for CAAs. Various simulations are performed to examine the effectiveness of the proposed BBOLS algorithm in optimizing the radiation beam patterns of LAAs and CAAs, and the results show that BBOLS algorithm has a better performance in reducing the maximum SLL compared with other algorithms such as firefly algorithm.

1. Introduction

Antenna arrays play an important role in modern wireless communications, especially in mobile communications, satellite communications, and radar systems. Given the rapid development of the fourth generation (4 G) communication systems, researchers across the world have begun to focus on the fifth generation (5 G) cellular networks, which are known for their high density, self-organization, massive antenna arrays, multi-carriers based on filter banks and full duplex reuse. With the exponential increase in the volume of data traffic, the millimeter-wave (mm-wave) spectrum technology which can provide channels with large bandwidths is adopted in the 5 G wireless communication systems [1]. Moreover, in order to fully utilize the spectrum resources generated by the mm-wave spectrum technology, the massive multi-input-multi-output (MIMO) technology with high spectral efficiency has been proposed [2,3]. Space division multiple access (SDMA) is an important practical example of the massive MIMO technologies in 5 G communication systems, and it can make the electromagnetic wave propagate to a certain direction so that reducing the cost of the transmission energy.

The technology of propagating the electromagnetic wave in a specific direction is called beamforming which can be generated by antenna arrays. In addition, even though the licensed spectrums are the basic resources of 5 G communication systems, the unlicensed spectrums are being expanded to use to build a network with higher speed, lower latency and less electricity consumption. This will also meet the needs of link demands for the huge number of devices in the Internet

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[*] Corresponding author.

E-mail addresses: sungeng207@foxmail.com (G. Sun), wang_ai_min@126.com (A. Wang).

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of things. Moreover, the communication range is an important property for 5 G communication systems, thus the antenna arrays can be used to improve the communication range of these communication systems efficiently. Antenna arrays can also be used to enhance the signal quality, the coverage area, the connectivity rate and the spectral efficiency of these systems [4]. With the fast development of the antenna arrays, it trends to involve incorporating higher frequency bands (including optical), larger bandwidth, larger power levels and higher gain with larger size, and then making possible to decrease the input impedance to the required level [5]. However, the radiation beam patterns of antenna arrays still have a decisive role in the performance of communication systems. The performance criteria of antenna arrays include beam width, sidelobe level (SLL), noise sensitivity, directivity and robustness. To evaluate the beam pattern performances of antenna arrays, this study considers a design criterion of minimum SLL by using an improved biogeography-based optimization (BBO) algorithm.

The rest of this paper is organized as follows. Section 2 introduces some prime existing achievements in the field of radiation beam pattern optimization problems. Section 3 discusses the geometry and array factors for both linear antenna arrays (LAAs) and circular antenna arrays (CAAs), and creates the fitness function based on these models. Section 4 introduces the proposed optimization method, while Section 5 presents its numerical results. Section 6 summarizes the findings and concludes the paper.

2. Related work

The techniques for designing antenna arrays are mainly focused on two classes that are the uniform spacing and the non-uniform spacing antenna arrays. The main difference of these two classes is that the uniform case is analytically tractable, and the non-uniform case can be only treated by numerical approximations. Moreover, the techniques for designing these two kinds of antenna arrays are usually based on the mathematical programming, such as constrained programming [6]. However, in recently years, some techniques based on the swarm intelligence approaches have been gradually used to the design of antenna arrays.

Zhang et al. propose a real-coded genetic algorithm (RGA) optimization method to optimize the weight of each antenna element to minimize the SLL of the uniform spacing LAA with a certain main beam width [7]. Florence et al. utilize the accelerated particle swarm optimization (PSO) algorithm to synthesize two classes of uniform spacing arrays that use unequal phases with equal and unequal amplitudes [8]. Singh, et al. use cuckoo optimization algorithm (COA) to determine a set of parameters of antenna elements that provides the required radiation beam patterns [9]. COA is a novel nature inspired computing algorithm which is motivated by the life of cuckoo, and it is also a population-based method. Pappula et al. propose a new evolutionary technique, named cat swarm optimization (CSO), for the synthesis of LAAs [10]. CSO has a better performance for solving linear and non-linear optimization problems, and it is also applied to optimize the antenna element positions for suppressing SLLs and for achieving nulls in desired directions. Swain et al. apply gravitational search algorithm (GSA) to linear dipole antenna array (LDAA) optimizations [11], and GSA is used to achieve narrow beam width and lower SLL for LDAA. Qubati et al. use the central force optimization algorithm into the optimal design of two wideband micro-strip patch antennas [12]. To synthesize thinned linear antenna arrays with low SLLs, Guney et al. introduce a method based on the bees algorithm, which is inspired by the behavior of the honeybees in finding an optimal way of harvesting food resources around the hive [13]. Ram et al. use the firefly algorithm (FA) to design non-uniform CAAs for minimum the SLLs and reducing the first null beam widths (FNBWs) [14]. This method is used to determine an optimal set of excitation weights as well as inter-element separations for optimizing the beam patterns and the FNBWs.

This study proposes a BBO based on local search (BBOLS) algorithm to optimize the radiation beam patterns of LAAs and CAAs. BBOLS improves the precision of the BBO algorithm by adding a local search strategy and a selection operator. For solving the multi-dimensional optimization problems, BBOLS can not only ensure the normal computational capabilities, but also reduce the convergence speed of BBO, thereby avoiding local convergence.

The main contributions of this paper are highlighted as follows.

(1) A novel BBOLS algorithm is introduced to the design of LAAs and CAAs for suppressing the sidelobe levels.
(2) The proposed BBOLS adds the local search strategy and selection operator into the original BBO algorithm. The differential evolution algorithm with a new local search strategy (DELSS) can increase the diversity of the population for BBO because of its randomness, parallelism and effective expansion. Moreover, the selection operator can make the final solution tend to the optimal location.
(3) According to the numerical results, the performance of BBOLS is better than normal BBO, FA and PSO in suppressing the SLLs of LAAs and CAAs.

3. System model

3.1. LAA

LAA is a kind of antenna arrays with the simplest fabrication and implementation. Fig. 1(a) shows an LAA model with $2N$ elements that are symmetrically distributed along the x axis. The array factor of an LAA is expressed as follows [15]:

$$AF(\phi) = \sum_{\substack{n=-N \\ n\neq 0}}^{N} I_n \exp(j[kx_n\cos(\phi) + \alpha_n]) \tag{1}$$

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