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Synthesis of Linear, Planar, and Concentric Circular Antenna Arrays Using Rao Algorithms

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ABSTRACT

The aim of this paper is to display the efficacy of three newly proposed optimization algorithms named as Rao-1, Rao-2, and Rao-3 in synthesizing antenna arrays. The algorithms are applied to three different antenna array configurations. Thinned arrays with isotropic radiators are considered and the main objective is to find the optimal configuration of ON/OFF elements that produce low side lobe levels. The results of Rao-1, Rao-2, and Rao-3 algorithms are compared with those of improved genetic algorithm (IGA), hybrid Taguchi binary particle swarm optimization (HTBPSO), teaching-learning-based optimization (TLBO), the firefly algorithm (FA), and biogeography-based optimization (BBO). The Rao-1, Rao-2, and Rao-3 algorithms were able to realize antenna arrays having lower side lobe levels (SLL) when compared to the other optimization algorithms.

KEYWORDS

Antenna Arrays, Optimization, Rao Algorithms, Side Lobe Level, Thinned Arrays

1. INTRODUCTION

Antenna arrays are commonly used in communication systems and are preferred over single-antenna systems when there is a need to improve the gain, directivity, have electronic beam steering at different directions, cancel interference and to have diversity (MIMO). The performance of a communication system is dependent also on the antenna system it has and hence a proper and efficacious antenna design is an important task. An antenna array's radiation pattern has a main lobe directed towards the user and side lobes and nulls in the other directions. For efficient operation, the radiation pattern should have high directivity and low side lobe level (SLL). However, these two are conflicting features of an antenna pattern and one cannot be improved without degrading the other. Since side lobes cause wastage of power and can create interference with neighbouring systems it becomes necessary to suppress it and therefore the low SLL criterion is usually fulfilled at the cost of sacrificing gain and beamwidth. The array structure, the inter-element distance, individual amplitude and phase excitations, the number of excited (ON) elements, etc. affect the radiation pattern.

Literature shows that various researchers have applied different types of evolutionary algorithms to antenna problems to achieve certain synthesis goals. Few among them are Moth Flame Optimization (Das, Mandal, Ghoshal & Kar, 2018), comprehensive learning particle swarm optimizer (Ismaiel et al., 2018), Cuckoo search algorithm (Nora, Oudira & Dumond, 2019), probability-based coevolving particle swarm optimization (Pan, Wang, Guo & Wu, 2019), improved fruit-fly optimization algorithm (Darvish & Ebrahimzadeh, 2018), genetic algorithm (GA) (Cen, Yu, Ser & Cen, 2012; Chen, He & Han, 2006), differential evolution (DE) (Lin, Qing & Feng, 2010; Zhang, Jia, & Yao, 2013), particle

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swarm optimization (PSO) (Bhattacharya, Bhattacharyya & Garg, 2012; Khodier & Al-Aqeel, 2009), ant colony optimization (ACO) (Rajo-lglesias & Quevedo-Teruel, 2007), invasive weed optimization (IWO) (Karimkashi & Kishk, 2010), bacteria foraging algorithm (BFA) (Guney & Basbug, 2008), firefly algorithm (FA) (Zaman & Abdul, 2012), biogeography based optimization (BBO) (Singh, 2010), ant lion optimization (ALO) (Saxena & Kothari, 2016), cat swarm optimization (CSO) (Pappula & Ghosh, 2014; Pappula & Ghosh, 2017),etc. All these algorithms try to suppress the SLL or achieve a target SLL by optimizing the inter-element spacing, position of the antenna elements, weights of amplitudes and phases of complex feeding currents, ON-OFF element combinations (thinning), time-modulated pulse width for time-modulated arrays, or placing nulls in the desired interference directions. Few more recent optimization works on antenna arrays are mentioned in section 3.

All the aforementioned algorithms have shown an efficient performance in finding optimal solutions to antenna design problems as well as for other electromagnetic optimization problems. However, their performance is dependent on the tuning of their algorithm-specific parameters. E.g. selection operator, mutation probability, cross-over probability, etc. in GA, mixing ratio in CSO, inertia weight and social and cognitive parameters, etc. in PSO and likewise for other optimization algorithms. The improper tuning of any algorithm's control parameters may lead to convergence at a local optimum or increase the time for convergence. This parameter tuning is in addition to that of the common control parameters such as population size and the number of iterations. The user effort increases since many trial runs have to be run to get a proper combination of the algorithm-specific parameters and the effort is, obviously, proportional to the number of algorithm-specific parameters.

Optimization algorithms that use only common control parameters have been proposed in the literature. Rao, Savsani & Vakharia (2011) had introduced the teaching-learning- based algorithm that is based only on common control parameters such as population size and number of iterations and has gained wide acceptance from the research community for producing significant optimization results. Rao (2016) had developed another algorithm-specific parameter-less optimization algorithm known as Jaya algorithm that has also been greatly used in various optimization scenarios (Huang et al.,2018; Rao & More, 2017; Rao & More, 2017; Ravipudi & Neebha, 2018; Singh, Prakash, Singh & Babu, 2017; Rao & Saroj, 2017; Wang & Huang, 2018; Warid, Hizam, Mariun & Abdul, 2018).

There are many meta-heuristic algorithms that are based on the metaphor of a natural process or animal, birds, insects, societies, etc. The authors of these algorithms prove their algorithms to be better than the other existing ones. However, not every algorithm receives enough success or receives a little because of the lack of researches applying the algorithms. Therefore, there cannot be enough progress in the field of optimization if the basis of new optimization algorithms is on some imitation of a natural process rather than focussing on the main idea of developing simple optimization techniques that can give effective solutions. Keeping this in view, Rao (2020) and Rao & Pawar (2020) recently introduced three simple yet powerful metaphor-less optimization algorithms named Rao-1, Rao-2, and Rao-3.

The Rao algorithms (three in number) have not been applied to any electromagnetic problems yet. They are independent of any algorithm-specific parameters that make them easier to implement. These algorithms have good search capability and have a good convergence rate as well. Therefore, the main contribution of this paper is to show their efficacy by applying them to the problem of antenna array synthesis, *for the first time*, with the intention to motivate researchers to apply the same to other optimization problems as well.

In this paper, the Rao-1, Rao-2, and Rao-3 algorithms are used to find the optimum combination of ON-OFF antenna elements of a linear antenna array, a 50*50 planar antenna array, 2-rings concentric circular antenna array, and 10-rings concentric circular antenna array. The codes are written in MATLAB R2018b and an Intel Core i3 computing platform with a 2.30 GHz processor and 4 GB RAM is used.

This structure of the paper is as follows. Some more recent works in antenna array optimization are mentioned in Section 2. Rao-1, Rao-2 and Rao-3 algorithms are briefly described in Section 3.

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