Statistical Study of Bioinspired Metaheuristic Algorithms Applied to the Optimization of Triangular Frequency Selective Surface Parameters

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ABSTRACT

Frequency selective surfaces are structures used in the telecommunication field. Therefore, it has become objective of studies that evaluate the format of structures, the fabrication materials and the use of algorithms capable of optimize structures parameters always searching for applications in usual is frequency bands. This article applies the statistic tolls for evaluate two optimization algorithms bio-inspired used in the project of frequencies selective surfaces slot track of triangular format made from fiberglass. The optimized frame parameters were the dimensions that provided a higher bandwidth that resonates at the 11GHz frequency. The algorithms used in the research have a stochastic approach in generating candidate points for optimal values. The updating of these points that approximate each iteration of the optimal values occurs through mechanisms inspired by nature, known as bioinspireds metaheuristics approaches. The evaluation of the specific behavior of these algorithms for this project was performed, will be described in the results.

KEYWORDS: Telecommunications structures. Frequencies Selective Surfaces (FSS), Optimization study, Optimization Metaheuristc Algorithms and Statistic Tools.

1 INTRODUCTION

The wireless mobile telecommunications systems of broadband or ultra-wideband has become a means of execution of various society actives, making possible the communication and access of information in quickly, efficiently and practically way. These benefits become possible because the technology progress occurred in the electronics along the last decades, when electronics devices, even the smaller ones, turned integrated to the wireless communication equipment. Thereby, the area of telecommunications also evolved developing modern systems, in that the devices have reduced weight and reduced dimensions.

For this advancement to continue, it`s necessary to intensify the researches in the field of applied electromagnetism in order to have more and more control over the propagation of the electromagnetic waves through the surfaces or layers frontiers. Regarding that context, the microwave integrated circuits, in special the microfite, have been meeting desired specifications for specific bandwidths [1].

As an example of this, it has the frequencies selective surfaces that are periodic array with metallic elements (patch array) or cracks in metals film (slot array), printed on dielectric substrate.

This periodic array has the capacity to control characteristic such as: intensity, polarization and the phase in required frequency bands.

The frequencies selective surfaces (FSS) has various applications. As an example, we have the FSS for filter wave in the industrial microwave and applictions militaries, as the communications systems, radar systems, antennas of high directive and microwave ovens, among other utilities [2].

The efficiency of a FSS is due to the proper design of the FSS, which stands out as project parameter material of fabrication, the format of a FSS and the structural dimension of FSS [1-10]. The FSS efficiency in to resonate at a desired frequency is mainly caused for dimensional length, being one of the main challenges (problems) in the FSS project.

This problem has been solving by the optimization algorithms such as the bioinspired metaheuristic since they have been implanted in FSS project as practical tools [3, 8, 10].

The present paper evaluated the algorithms we used in the project of a triangular format FSS fabricated with glass fiber, by means of statistics tools, once metaheuristic algorithm generate candidates for optimal solutions at random.

Thus, it is necessary to study the behavior of such algorithms, because randomly generated values have no guarantee of convergence for an optimal one. However, statistical tools can evaluate the behavior of these algorithms by conducting the randomly generated value to the optimal value. The investigations into optimization algorithms have been the objective of many researchers [11-14]. These investigations aim to verify the effectiveness of optimization algorithms and make them more efficient.

In this paper, the section 2 deals with important concepts about the FSS project, the section 3 concerns on metaheuristic bioinspireted algorithm and the fitness function used to optimize FSS, the section 4 shows a methodology used in the research, the section 5 shows the results obtained and section 6 presents the conclusions.

2 FSS PROJECT

Telecommunication engineering projects of structures such as FSS fall into the problem of adjusting the structure parameters so that the FSS resonates at the desired frequency. The use of old methods, such as trial and error, has been replaced by modern optimization techniques that are implemented in the computational codes that find the values of parameter lengths, thus achieving the goal that the FSS resonate at the desired frequency. Since these parameter values provide a maximum bandwidth for the desired frequency, such values are considered optimal.

When these optimal values are found, the FSS are designed with the aid of Computer Simulation Technologies (CST Studio Suite) software, which use the finite integrals method in the frequency domain [25].

In simulations by CST, that perform a parametric analysis of the FSS, the electromagnetic (EM) behavior is described as a function of shapes, elements and the permittivity of the dielectric substrate. The EM data obtained were used to train a general regression neural network (MLP), which performs the FSS modeling [3,7].

The FSS studied in this article has a geometry with triangular ring patch elements. These FSS behave as band-stop spatial filters with specific values for the central resonant frequency and bandwidth in the frequency range from 8 to 12 GHz. An FSS bandstop spatial filter, centered at 11 GHz with a bandwidth of 4 GZ, was synthesized by varying periodic arrays, t, and with physical dimensions of a triangular patch element ring, w, as shown in Table 1. Statistical analyzes will be done with the randomly generated values of the variable t, periodic arrays.

The frequency of this structure resonates with the X and Ku bands. Such frequency bands are used in satellite communication for commercial purposes, making it possible to transmit both analog and digital data. Among the main characteristics of this bandwidth can be the signal stability that allows information to continue to travel even under adverse climatic conditions such as closed weather (heavy clouds and heavy rains), much pollution or even the evaporation of forests [6].

Table 1 FSS STRUCTURE PARAMETER

Parameters	**Parameters Values**
Periodic Array (mm)	t=T_x=T_y=[10; 10,5; 11; 11,5]
Dimension of conductor (mm)	w=W_x=W_y=[4; 4,4; 5; 5,5]
Substrate Lenght (mm)	h=1,67
Relative Permissiveness	ε_r=4,4

3 BIO-INSPIRED ALGORITHM

The Bioinspired algorithms are methods with stochastic characteristic of optimization and the candidate values for optimal solution of problem are randomly generated. Later, each of these candidates to the optimal solution are evaluated by the fitness function (this function will be detailed in the item A), which determines which candidate is the best for that interaction. After that, a convergence process starts for an optimal value, based on the values of the best candidates for optimal and by means of a sequential rule, generally inspired by nature. It can be said these methods generate initial samples that subsequently undergo an updating and convergence process. Taking it in considerations the comprehension that the difference from one method to another are defined by the updating and convergence procedures that each methods employ.

3.1 Fitness Function

The fitness function guides the bio-inspired algorithms responsible to determine who the best candidate for each iteration is. It has already been said in this article about the electromagnetic behavior of the structure to determine if the FSS resonates in the frequency of the X and Ku bands, based on the element shapes and the permittivity of the dielectric substrate. These EM data are trained by a GRNN neural network that is derived from a radial base function, a type of network widely used for the universal approximation of functions. GRNN needs a fraction of samples for training and does not use backpropagation. These characteristics reduce the computational cost of the network, maintaining the same power of generalization of other types of neural network. As particular characteristics of the network architecture used in this work we can highlight four inputs in the first layer: a hidden layer with five neurons and two output nodes, namely the resonance frequency and the desired bandwidth.

3.2 Genetic algorithm with elitism approach

This algorithm relies on the natural selection process proposed by Charles Darwin. The individuals (candidates for the optimal of the problem) are generated randomly, these values are calculated by the fitness function in order to verify the fittest, then crosses with the fittest individual so the next generations are provided by the converging to the optimal value [23].

3.3 Genetic algorithm with roulette approach

This algorithm concerns to the natural selection process proposed by Charles Darwin. The individuals (candidates for the optimum of the problem) are randomly generated, these values are calculated by the fitness function in order to verify the fittest, then crosses with probabilistic approaches so that the next generations are generated converging to the value great [23].

4 METHODOLOGY

In order to reach the objective of evaluating optimization algorithms, the Xi-Che-Yang (2010) article methodology was used, [26], where it is suggested to simulate each algorithm 100 times for the same problem, thus generating sample data for the evaluation.

Each of the algorithms evaluated will have its parameters as population and generation modified in four different ways in order to verify how the alteration of these parameters influence the results. The values used for the parameters are in Table 2.

Considering that the algorithms used in FSS optimization were multiobjectives. The objectives were the *w* and t parameters of FSS. Each of these results will be analyzed by us separately.

Statistical analyzes with boxplot's and t-student and chi-square tests were done with software R 3.2.5 which is free [22].

Table 2 Variation of Parameters Used

Parameters	**1st Case**	**2nd Case**	**3rd Case**	**4rd Case**
Generation	25	50	25	50
Population	150	150	300	300

5 RESULTS

The results of the statistical tests of each algorithm are shown with their respective analysis of the graphs and distributions. For the t-student distribution software R 3.2.5 used a default of 95% for the confidence intervals and a default of 98% for the calculation of the point t. The chi-square distribution used a 98% default for point calculation χ^2_ϕ.

5.1 Genetic Algorithm with Elitism

The results are:

1st Case:

Test t-student confidence interval [6.956464, 7.790331] and point t=35.095. Test chi-square χ^2_ϕ=58.082.

2nd Case:

Test t-student confidence interval [6.458072, 7.407506] and point t=28.981. Test chi-square χ^2_ϕ=80.082.

3rd Case:

Test t-student confidence interval [7.178499, 8.027134] and point t=35.557. Test chi-square χ^2_ϕ=58.342.

4th Case:

Test t-student confidence interval [5.877901, 6.703492] and point t=30.242. Test chi-square χ^2_ϕ=66.734.

The results displayed by the points t and χ^2_ϕ show that there is a distribution close to the Gaussian curve. The confidence intervals, except for the one obtained in the third case, generate values close to each other, the values of the medians and means are not distant from each other more than one unit of the sample data obtained with the genetic algorithm by Elitism.

The other statistical parameters of these samples are exposed in Table 3 and the distributions can be observed in the boxplot graph of Figure 1.

Table 3 Genetic Algorithm with Elitism

	Data 1	Data 2	Data 3	Data 4
Minimum	4.172	2.836	3.707	1.837
1º Quartile	5.693	5.268	6.019	5.025
Median	6.951	6.274	7.173	5.895
Average	7.373	6.933	7.603	6.291
3º Quartile	8.696	8.558	9.398	7.190
Maximum	13.037	11.547	12.756	12.596

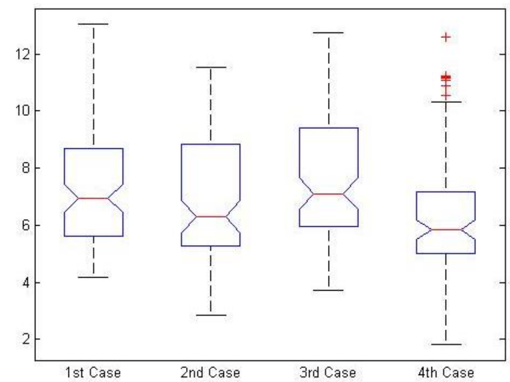

Figure 1: Boxplot of the data obtained with the AG with elitism.

5.2 Genetic Algorithm of Roullet

The results are:

1st Case:

Test t-student confidence interval [9.496229, 10.210087] and point t=54.782. Test chi-square χ^2_ϕ =31.854.

2nd Case:

Test t-student confidence interval [9.706335, 10.334080] and point t=63.353. Test chi-square χ^2_ϕ =24.222.

3rd Case:

Test t-student confidence interval [9.266997, 9.993866] and point t=52.585. Test chi-square χ^2_ϕ =33.789.

4th Case:

Test t-student confidence interval [9.548811, 10.210706] and point t=59.242. Test chi-square χ^2_ϕ =27.311.

The points t and χ^2_ϕ show that the distributions in the four cases are close to the Gaussian curve. The confidence intervals generated are close to each other. The values of averages and medians are close to each other.

The other statistical parameters of these samples are shown in Table 4 and the distributions can be observed in the boxplot graph of Figure 2.

Table 4 Genetic Algorithm of Roullet

	Data 1	Data 2	Data 3	Data 4
Minimum	5.784	5.535	5.321	5.912
1º Quartile	8.668	9.003	8.420	8.906
Median	10.214	10.467	9.991	10.118
Average	9.853	10.020	9.630	9.880
3º Quartile	11.114	11.192	10.882	11.089
Maximum	13.184	13.112	13.102	13.822

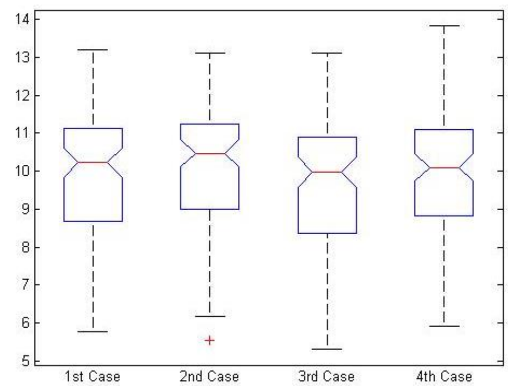

Figure 2: Boxplot of the dice obtained of roulette AG.

6 CONCLUSION

The algorithms randomly generate values, and then obtain an optimal value with these values, each using its particular rule. The distribution of the generated numerical values may or may not occur so as to approximate the so-called normal distribution. The values before reaching the optimum approximate, at each iteration, a central value, known as measures of central tendency, which can be understood as the value that the sample data accumulate in the environment, namely, the average and the median.

When analyzing the boxplots obtained with each algorithm, it is seen that for different values of the number of generations and populations the distributions, although distant from the normal distribution, approach the same central value as the median. It is concluded that there is a centralization of the values obtained with the bio-inspired algorithms, something that approaches the concept of convergence.

Even distributions that have an asymmetric behavior tend to accumulate their values around the median value, a fact that once again leads us to conclude that there is a convergence of the points that are randomly generated and then converge to an optimal value by the algorithm.

The use of the t-student and chi-square tests show which of the distributions of the optimal values generated by the bio-inspired algorithms are close to the normal distribution, or even with an asymmetric behavior. However, even in the case of symmetric or asymmetric behavior, we can see that there is an accumulation in the median central tendency measure. In the case of the t-student test, we also obtain the confidence intervals, something that shows us the range of numbers that the optimal values are being generated, one can thus conclude that the values are actually sweeping a space of search to find the optimal point.

Algorithms with a distribution of randomly generated values close to the Gaussian curve can sweep a wider search space to find the optimal solution of the problem. Algorithms that do not have a distribution close to normal or even zero variance run the risk of clinging to optimal locations.

Analyzing the statistical results it can be observed that for the genetic algorithm with elitism, the random values generated for the variable t, periodic arrays, first objective, approached the normal distribution.

Statistical results with the roulette genetic algorithm were analyzed, showing that the first objective had a distribution close to normal. The values of central tendency (average and median) obtained are close to each other. This algorithm generates random values that converge to solve the problem. Its result is better than that of the genetic algorithm of elitism.

Among the results presented, those with a distribution closer to the normal curve have a willingness to concentrate around the central tendency values, thus, they are those that become closer to actually converging to an optimal value.

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