EVOLUTION OF 18-ELEMENTS YAGI-UDA ANTENNA USING BBO

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***Abstract*—**Biogeography Based Optimization is based on the study distribution of biological species, overspace and time, among random habitats known as biodiversity. Recently introduced BiogeographyBased Optimization (BBO) is a technique, where solutionsof the problem are termed as habitats. Feature, i.e., SuitabilityIndex Variable (SIV), sharing among various habitats is madeto occur with exploitation and exploration of new SIVsis done with mutation operator. Yagi-Uda antenna is a widely used antenna design due to various useful properties of high gain, low cost and ease of construction.Designing a Yagi-Uda antennainvolves determination of element lengths and spacings betweenthem to get desired radiation characteristics. The gain of Yagi-Udaantenna is difficult to optimize as there is no direct formula to calculate its gain, it makes relationship between antennaparameters and its characteristics highly complex and non-linear.In this paper, 18-elementsYagi-Uda antenna is optimized formaximum gain using BBO. The obtained results are compared with previous work done on nine element Yagi-Uda antenna.

***Keywords*—** *Yagi-Uda Antenna, Optimization, BBO, Gain, Impedance*

I. INTRODUCTION

Antenna is an electrical device which converts electric signal into free space radiations and vice-versa. The various radiation characteristics that affect the design of an antenna are gain, impedance, bandwidth, frequency of operation, Side Lobe Level (SLL) etc. Yagi-Uda antenna is a widely used directional antenna design due to various desirable features, i.e., high forward gain, low cost and ease of construction. It is basically a parasitic linear array of parallel dipoles, one of which is energized directly by transmission line while the others act as parasitic radiators whose currents are induced by mutual coupling.

Yagi-Uda antenna was invented in 1926 by H. Yagi and S. Uda at Tohoku University [29] in Japan, however, published in English in 1928 [33]. The main objective, in design of Yagi-Uda antenna, is to find an optimum structure that meet certain radiation criteria like gain, impedance, SLL and beamwidth. However, due to its parasitic elements, it is extremely difficult to obtain an optimum design of Yagi-Uda antenna. Since its inception, Yagi- Uda antenna has been optimized several times for gain, impedance, SLL and bandwidth using different optimization techniques based on traditional mathematical approaches and Artificial Intelligence (AI) techniques

In 1949, Fishenden and Wiblin [15] proposed an approximate design of Yagi aerials for maximum gain, however, the approach was based on approximations. In 1959, Ehrenspeck and Poehler proposed a manual approach to maximize the gain of the antenna by varying various lengths and spacings of its elements [14].

Later on, with the availability of high performance computing, it became possible to optimize antennas numerically. Bojsen et al. in [5] proposed an optimization technique to find the maximum gain of Yagi-Uda antenna arrays with equal and unequal spacings between adjacent elements. Cheng et al. in [8] and [7] have used optimum spacings and lengths to optimize the gain of a Yagi-Uda antenna. In [10], Cheng has proposed optimum design of Yagi- Uda antenna where antenna gain function is highly non-linear. The performance of these gradient based techniques depends on choice of initial solution. In 1975, John Holland introduced Genetic Algorithms (GAs) as a stochastic, swarm based AI technique, inspired from natural evolution of species, to optimize arbitrary systems for certain cost function. Since then many researchers have used GAs to optimize Yagi-Uda antenna designs for gain, impedance and bandwidth separately [1, 16, 11] and collectively [32, 30, 17]. Jones et al. in [16] have used GA to optimize Yagi-Uda antenna for various radiation characteristics and compared the result with steepest gradient method. Baskar et al. in [4], have used Comprehensive Learning Particle Swarm Optimization (CLPSO) to optimize Yagi-Uda antenna and obtained better results than other optimization techniques. In [18], Li has optimized Yagi-Uda antenna using Differential Evolution (DE) and illustrated the capabilities of the proposed method with several Yagi-Uda antenna designs. In [28], Singh et al. have analyzed another useful, stochastic global search and optimization technique known as Simulated Annealing (SA) for the optimization of Yagi-Uda antenna.

In 2008, Dan Simon introduced a new optimization technique based on science of biogeography, in which information sharing among various habitats, i.e., potential solutions, is obtained via migration operator and exploration of new features is done with mutation operator [26]. In [13], Du et al. have proposed the concept of immigration refusal in BBO aiming at improved performance. Singh et al. have presented BBO as a better optimization technique for Yagi-Uda antenna designs, as compared to other optimization techniques in [27].

In 2013, Kansal et al. apply BBO to optimize Nine-elementsYagi-Uda antenna for maximum gain.

In this paper, 18-elementsYagi-Uda antenna has been optimized for gain maximization using BBO and results are compared. A method of moments based freeware programme, Numerical Electromagnetics Code 2 (NEC2), is used to evaluate the antenna designs for gain.

After this brief introduction, the paper is structured as follows: In Section 2, Yagi-Uda antenna is briefly discussed. Section 3 is dedicated to biogeography terminology, BBO technique. In Section 4, the design problem of nine-element Yagi-Uda antenna for gain maximization is presented and results obtained with BBO are compared with other optimization techniques. Finally, paper is concluded in Section 5.

II. ANTENNA

Yagi-Uda antenna is basically made of three types of elements: (a) Reflector (b) Feeder and (c) Directors. Reflector is longest of all elements and blocks radiations in one direction. Feeder or driven element is fed with the signal to be transmitted, directly from transmission line. Directors are usually more than one in number and are responsible for unidirectional radiations. Normally, there is no limit on number of directors, however, as the number of directors are increased beyond a certain limit there is a reduction in the induced current in the most extreme elements. Figure 1 presents a basic Yagi-Uda antenna design where all elements are placed along y-axis and parallel to x-axis. Middle segment of the reflector is placed at origin and signal to be transmitted is fed to the middle segment of the feeder element. An incoming field induces resonant currents on all the antenna elements which causes parasitic (reflector and directors) elements to re-radiate signals. These re-radiated fields are then picked up by the feeder element, that makes total current induced in the feeder equivalent to combination of the direct field input and the reradiated contributions from the director and reflector elements.

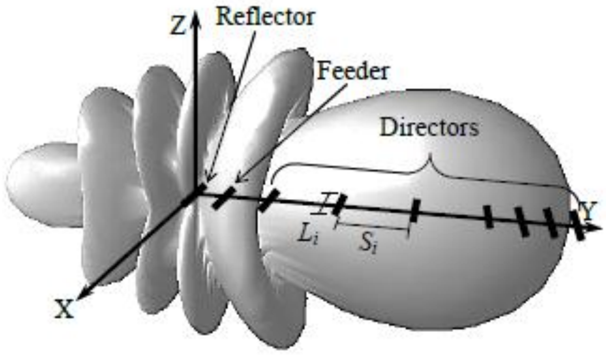

Figure1: Yagi-Uda Antenna

III. BIOGEOGRAPHY BASED OPTIMIZATION

Biogeography Based Optimization is a population based global optimization technique based on the science of biogeography, i.e., study of the distribution of animals and plants among differ-ent habitats over time and space. BBO results presented by re-searches, to optimize Yagi-Uda antenna, are better than other op-timization techniques like PSO, GAs, SA, DE etc. [16, 32, 4, 25].

Initially, biogeography was studied by Alfred Wallace [3] and Charles Darwin [12] mainly as descriptive study. However, in 1967, the work carried out by MacAurthur and Wilson [22] changed this perception by introducing a mathematical model for biogeography which made it possible to predict the number of species in a habitat. Mathematical models of biogeography describe the migration, speciation and extinction of species in various habitats.

A habitat or island is an ecological area inhabited by a particular animal species which is geographically isolated from other habitats. Each habitat is characterized by its Habitat Suitability Index (HSI). Habitats which are well suited as living places for biological species are referred to have high HSI value. HSI is analogues to fitness in other Evolutionary Algorithms whose value is a function of many features of the habitat such as rainfall, diversity of vegetation, diversity of topographic features, land area, and temperature etc. The features/variables that characterize habitability are known as Suitability Index Variables (SIVs). In other words, HSI is dependent variable whereas SIVs are independent variables.

The habitats with high HSI have large probability of emigration (hence high emigration rate) simply due to large number of species they host and small probability of immigration (low immigration rate) as they are already saturated with species. Immigration can be defined as the arrival of new species into a habitat, while emigration is the process of leaving one's native habitat. Similarly, habitats with low HSI tend to have low emigration rate, , due to sparse population, however, they will have high immigration rate, . Suitability of habitats having low HSI value is likely to increase with more number of species ar-riving from habitats having high HSI as suitability of a habitat depends upon its biological diversity. For sake of simplicity, it is safe to assume a linear relationship between HSI (or population) and immigration and emigration rates. Also maximum emigra-tion and immigration rates are assumed equal, i.e., E = I, as shown graphically in Figure 2.

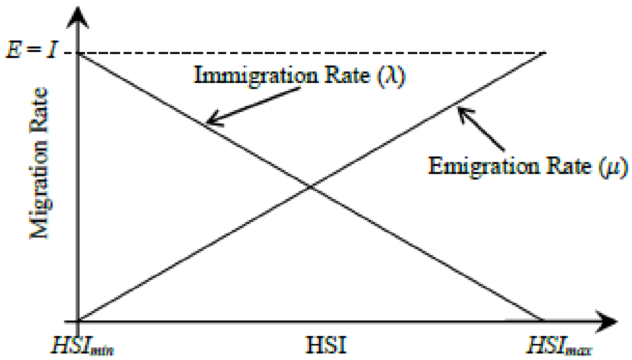

Fig. 2. Migration Curves

For k-th habitat, values of emigration rate, k, and immigration rate, k, are given by (2) and (3).

μ_k=EK/n................ (2)

λ_k=I.(-k/n).............(3)

Good solutions (habitats with high HSI) are more resistant to change than poor solutions (habitats with low HSI) whereas poor solutions are more dynamic in nature and accept a lot of new features from good solutions. This addition of new features to low HSI solutions from high HSI solutions may raise the quality of those solutions.

In a global optimization problem with number of possible solutions, each habitat or a solution in a population of size NP is represented by M-dimensional integer vector as H = [SIV1; SIV2; : : : ; SIVM] where M is the number of SIVs (features) to be evolved for optimal HSI. HSI is the fitness criteria that is determined by evaluating the cost/objective function, i.e., HSI = f(H). BBO consists of mainly two mechanisms: (A) Migration and (B) Mutation, these are discussed in the following subsections.

3.1 Migration

Migration is a probabilistic operator that improves HSI of poor habitats by sharing information from good habitats. During Mi-gration, immigrating habitat, ImHbt, use its immigration rate, , given by (3), to probabilistically decide whether to immigrate or not. In case immigration is selected, then the emigrating habitat, EmHbt, is found probabilistically based on emigration rate, , given by (2). The process of migration is completed by copying values of SIVs from EmHbt to ImHbt at random chosen sites. BBO employing above mentioned migration scheme is termed as the standard BBO. The migration operator may lead to same types of habitats in large number after few iterations. Different migration variants are proposed to increase the diversity in the population, with objective of improved performance of BBO algorithm, whose pseudo codes are given in Algorithm 1

Algorithm 1 Standard Pseudo Code for Migration

```
for i = 1 to NP do
    Select Hi with probability based on λi
    if Hi is selected then
       for j = 1 to NP do
          Select Hj with probability based on μj
          if Hj is selected
             Randomly select a SIV(s) from Hj
             Copy them SIV(s) in Hi
          end if
       end for
    end if
end for
```

Best Antenna Designs Obtained during Optimization								
	Six-Element [21]		Six-Element [20]		Nine-Element [36]		Eighteen-Element	
Element	Length	Spacing	Length	Spacing	Length	Spacing	Length	Spacing
1(λ)	0.4838	-	0.4872	-	0.4796	-	0.4786	-
2(λ)	0.4690	0.1722	0.4947	0.1540	0.4539	0.2658	0.4585	0.3578
3(λ)	0.4450	0.2193	0.4407	0.2554	0.4424	0.2007	0.4453	0.1649
4(λ)	0.4226	0.4406	0.4244	0.4001	0.4206	0.4245	0.4257	0.4167
5(λ)	0.4218	0.3954	0.4217	0.4048	0.4170	0.4261	0.4148	0.4053
6(λ)	0.4286	0.3754	0.4277	0.3775	0.4146	0.4002	0.4115	0.442
7(λ)	-	-	-	-	0.4108	0.4592	0.4088	0.4521
8(λ)	-	-	-	-	0.4174	0.3923	0.4059	0.4043
9(λ)	-	-	-	-	0.4159	0.4546	0.4002	0.3898
10(λ)	-	-	-	-	-	-	0.4036	0.3215
11(λ)	-	-	-	-	-	-	0.4004	0.3018
12(λ)	-	-	-	-	-	-	0.4002	0.7611
13(λ)	-	-	-	-	-	-	0.4002	0.4354
14(λ)	-	-	-	-	-	-	0.4008	0.427
15(λ)	-	-	-	-	-	-	0.3998	0.3588
16(λ)	-	-	-	-	-	-	0.4009	0.3224
17(λ)	-	-	-	-	-	-	0.4098	0.3044
18(λ)	-	-	-	-	-	-	0.4128	0.4516
Gain(dBi)	**13.84**		**13.85**		**15.89**		**18.38**	
Z(Ω)	**3.229+j23.42**		**4.45+j63.20**		**4.68+j1.80**		**4.8+j7.62**	

3.2 Mutation

Mutation is another probabilistic operator that alters the values of randomly selected SIVs of some habitats that are intended for exploration of search space for better solutions by increasing the biological diversity in the population. Here, higher mutation rates are investigated on habitats those are, probabilistically, par-ticipating less in migration process. Elitism approach is generally used along with mutation to preserve features of the best habitat. The mutation rate, mRate, for k-th habitat is calculated as (5)

$$mRate = C \ \min(\lambda_k, \mu_k) \qquad \text{.......................(5)}$$

where μ_k and λ_k are emigration and immigration rates, respec-tively, given by (2) and (3). Here C is a scaling constant and its value is equal to 1. The pseudo code of mutation operator is given in Algorithm 2.

Algorithm 2 Standard Pseudo Code for Mutation

$mRate = C \times \min(\mu_k, \lambda_k)$ where $C = 1$
for $i = 1$ to NP **do**
  for $j = 1$ to length(H) **do**
    Select H_j(SIV) with *mRat*
    If H_j(SIV) **is selected then**
      Replace H_j(SIV) with randomly generated SIV
    end if
  end for
end for

IV. SIMULATION RESULTS

18-ElementsYagi-Uda antenna designs are optimized for maximum gain using BBO with different migration variants, discussed in Section 3.1, and standard mutation operator. Each design is optimized with 20 habitats and 200 iterations. The C++ programming platform is used for coding of BBO algorithm, whereas, a NEC2 [6] is used for evaluation of antenna designs based on method of moments. Each potential solution in BBO is encoded as vector with 35 SIVs as given by (1). The universe of discourse for the search of optimum values of wire-lengths and wire-spacings are 0.4-0.5λ and 0.1-0.4λ respectively, however, cross sectional radius 0.003397λ and segment sizes 0.1λ are kept same for all elements, i.e., and respectively, where is the wavelength corresponding to frequency of operation, i.e, 300 MHz. Typically, the best antenna designs obtained during process of optimization are tabulated in Table 1.

V. CONCLUSION AND FUTURE SCOPE

In this paper, BBO algorithm is applied to optimize 18-ElementYagi-Uda antenna designs for gain maximization. As perobservations, the gain obtained with BBO, in this paper, is higher as comparedto other optimization techniques. Results show that BBO is a robust optimization technique foroptimizing Yagi-Uda antenna. Investigation of Yagi-Uda antennadesigns with different migration and mutation variants for betterconvergence performance is next on our agenda.

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