M.Tech. Thesis

INVESTIGATIONS FOR IMPROVED CONVERGENCE DURING YAGI-UDA ANTENNA DESIGN OPTIMIZATION USING BBO

Submitted in partial fulfillment of the requirements for the degree of Master of Technology in Electronics & Communication Engineering by

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CERTIFICATE

I, Gagan Sachdeva, hereby declare that the work being presented in this thesis on Investigation in Improved Convergence Performance for Yagi-Uda Antenna Design Optimization using BBO is an authentic record of my own work carried out by me during my course under the supervision of Dr. Satvir Singh Sidhu. This is submitted in the Department of ECE at Shaheed Bhagat Singh State Technical Campus, Ferozepur (affiliated to Punjab Technical University, Jalandhar) as partial fulfillment of requirements for award of the degree of Master of Technology in Electronics and Communication.

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To the best of our/my knowledge, this thesis has not been submitted to Punjab Technical University, Jalandhar or to any other university or institute for award of any degree or diploma. It is, further, understood that by this certificate the undersigned do/does not endorse or approve any statement made, opinion expressed or conclusion drawn therein, however, approve the thesis only for the purpose for which it is submitted.

Dr. Satvir Singh Sidhu [Supervisor(s)]

The M.Tech Viva-Voce Examination of Gagan Sachdeva is held at Department of ECE, SBS State Technical Campus, Ferozepur on ....

External Examiner
Name: ....

Head, Department of ECE
Dr. Satvir Singh

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At this stage of work, as the rather longish work winds up, I am becoming increasingly present to the fact that research can indeed be an enjoyable and rewarding experience, despite the tedium and hardwork involved. This thesis report is truly the culmination of the support, motivation, generous help and teachings of my Guide, **Dr. Satvir Singh Sidhu**, Associate Professor & Head of Department, Department of Electronics & Communication Engineering. I can never forget the cheerful moments of my life when he accepted me as a research scholar. I must record my sincere gratitude to him for not only the great store-houses of knowledge they bestowed upon me but also for the chiseling and grooming. I received in large measure in spheres of academic, professional and personal life. Without his constant chase and help, this work could not have taken this shape. I am pretty sure that his guidance would go a step beyond this project report and would be reflected in a couple of more publications of improved quality and of greater rigor and coverage, which I now look forward to.

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Date: October 13, 2012 Gagan Sachdeva

ABSTRACT

This thesis is intended to present investigations on convergence performance of Biogeography Based Optimization (BBO) algorithms during evolution of optimal designs of Yagi-Uda antenna. BBO is one of recently introduced population based stochastic optimization technique inspired from science of biogeography, i.e., the study of distribution of biological species, over space and time. Similar to other Evolutionary Algorithms (EAs), to evolve optimal solution to any problem, BBO involves two inherent activities, i.e., (a) the exploitation of available solution features (species) is made to happen using process of migrationamong various potential solutions (habitats), (b) the exploration of new solution features occur due to mutation operator. As BBO has shown impressive performance over other EAs in the past research, therefore, is considered here for six-element Yagi-Uda antenna design optimization to maximize gain.

An antenna act as interface between free space radiations and transmitter or receiver. Yagi-Uda antenna introduced in 1926 by H. Yagi and S. Uda as a directional antenna consisting of a driven element (a dipole or folded dipole) and additional parasitic elements (called reflector and directors). The reflector element is slightly longer than the driven dipole, whereas the directors can be more than one in numbers whose lengths decrease in the direction of radiation. Yagi-Uda antenna is one of the most popular antenna designs at VHF to UHF due to its constructional ease and high gain, typically greater than 10 dB.

Yagi-Uda antenna is, however, difficult to design as physical design parameters such as element lengths, spacings between adjacent elements, and diameter bear complex and non-linear relationships for gain, impedance and Side Lobe Level (SLL), etc. This antenna design problem, further, complicates as the number of antenna elements are increased with the objective

of achieving higher directional gain. Therefore, gain maximization of the antenna has always been a catchy problem for researchers. Although, a lot of work is done in this domain, still scope of improvement is visible with modern heuristic of artificial intelligence. Gain of the antenna can be optimized by evolving element lengths and spacings between adjacent elements using recent EAs. To evaluate Yagi-Uda antenna for gain, impedance, etc., a Method of Moments (MoMs) based antenna modeling software, Numerical Electromagnetics Code (NEC2), can be called using system command in to C++ programming environment.

Since the introduction of BBO, in 2008, various BBO variants are reported by many researchers intended towards improved convergence performance. BBO variants can be classified into two categories, i.e., Migration variants and Mutation variants. Till date, three migration variants, viz., (a) Blended migration, (b) Immigration refusal and (c) Enhanced Biogeography-Based Optimization (EBBO), have reported. However, in this thesis, we have experimented three mutation variants from other EAs, viz., (a) Flat mutation, (b) High mutation on mediocre habitats (Standard mutation) and (c) Increasing mutation with iterations, where (a) and (c) are borrowed from GAs. All migration and mutation variants have experimented to optimize gain of six-wire Yagi-Uda antenna design for multiple times.

During simulations, the antenna designs are evolved 10 times using each BBO variant for gain maximization. Averages of all 10 monte-carlo evolutionary runs are presented for fair convergence investigation of stochastic natured BBO algorithms. C++ programming platform is used for coding of BBO algorithms, whereas, NEC2 is used for evaluation of antenna designs for gain. Convergence performance of BBO during gain maximization of Yagi-Uda antenna with all migration variants, i.e., standard migration, blended migration, immigration refusal and EBBO, are investigated with different mutation options, i.e., flat mutation, high mutation on mediocre habitats and increasing mutation. From simulation results, it can be observed that standard migration with standard mutation, immigration refusal with 15% flat mutation rate, blended migration with 10% flat mutation rate and EBBO with 20% flat mutation rate are the best options for faster convergence performance among BBO variants. Maximum gain of Yagi-Uda antenna achieved during optimization using BBO and variants is 13.85 dB, that is better than that of reported in [Singh et al., 2010], i.e., 13.84 dB.

This thesis is outlined as follow: Chapter 1 is devoted to introduction to M.Tech. thesis that includes introduction to research topic, motivation, methodologies, contributions, research findings and organization of thesis. State-of-the-art study of the historical research in optimizing Yagi-Uda antenna using AI and non-AI techniques is represented in Chapter 2. In

Chapter 3, various design parameters of Yagi-Uda antenna and radiation pattern are represented to formulate antenna design problem as optimization problem. Chapter 4 is dedicated to study of biogeography, literature background of BBO, algorithmic flow and BBO variants reported till date. In Chapter 5, firstly, NEC software introduced to carry on simulation and analysis of electromagnetic behavior of various antenna designs. Secondly, implementations flow of BBO in C++ along with NEC2. Simulation results of convergence performance of BBO algorithm and its variants for maximization of gain of Yagi-Uda antenna, are represented in Chapter 6. Lastly, conclusion and future scopes of this research are discussed in Chapter 7.

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ABBREVIATIONS

Abbreviations	Description
ACO	Ant Colony Optimization
AI	Artificial Intelligence
BBO	Biogeography Based Optimization
CLPSO	comprehensive Learning Particle Swarm Optimization
CI	Computational Intelligence
EA	Evolutionary Algorithm
EBBO	Enhanced Biogeography-Based Optimization
GA	Genetic Algorithm
HSI	Habitat Suitability Index
NEC	Numerical Electromagnetics Code
PSO	Particle Swarm OPtimization
SA	Simulated Annealing
SIV	Suitability Index Variable

NOTATIONS

Symbols	Description
μ	Emigration rate
λ	Immigration rate
E	Maximum possible emigration rate
I	Maximum possible immigration rate

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CONTENTS

CHAPTER 1

INTRODUCTION

This thesis presents investigational studies in Biogeography Based Optimization and their use in optimal designing of Yagi-Uda antenna. This introducing chapter presents an overview of thesis. This include introduction to research topic, motivation, methodologies, contributions, research findings and organization of thesis.

1.1 Introduction

An antenna forms the interface between the free space radiations and the transmitter or receiver. The choice of an antenna normally depends on many factors such as gain, bandwidth and directivity, etc. A high gain directional antenna is required where signals need to travel long distance, e.g., satellite-earth link. Our focus on this thesis is on low cost antennas. Since half wave dipole and the folded dipole antennas cannot offer much needed gain and bandwidth, our attention is thus shifted to Yagi-Uda antenna and log-periodic dipole array antennas. Yagi-Uda antenna is difficult to design and optimize due to their numerous parasitic elements. There are no simple formulas for designing Yagi-Uda antennas due to the complex relationships between physical parameters such as element length, spacing, and diameter. So many researchers have proposed different algorithm for the optimized design of Yagi-uda antenna.

Biogeography Based Optimization (BBO) is a recent swarm based stochastic optimization technique inspired from the science of biogeography. In BBO, like of EAs, (a) the exploitation is made to happen using migration of solution features (species) to evolve optimal solution to any problem among various potential solutions (habitats), whereas, (b) the exploration of new solution features occurs due to mutation operator. The same BBO technique is applied on Yagi-Uda antenna to maximize gain by optimizing element-lengths and spacings between antenna elements.

1.1.1 Antenna

An antenna (or aerial) is a device which converts electric signals into electromagnetic waves, and vice-versa. It is used to transmit or receive signals, wirelassly. During transmission electrical signals are modulate at high frequency, amplified and then supplied to antenna to radiate as electromagnetic wave into free space. In reception, antenna intercepts some electromagnetic signal in order to produce a tiny voltage at its terminals. Then small signal is amplified enough to be fed to demodulation sections. An antenna can be used for both transmitting and receiving electromagnetic signals, e.g., RADAR.

1.1.2 Yagi-Uda Antenna

A Yagi-Uda array, commonly known simply as a Yagi antenna, is a directional antenna consisting of a driven element (typically a dipole or folded dipole) and additional parasitic elements (usually a so-called reflector and one or more directors). The reflector element is slightly longer than the driven dipole, whereas the so-called directors are a little bit shorter. This design achieves a very substantial increase in the antenna's directionality and gain compared to a simple dipole. The Yagi-Uda antenna or Yagi Antenna is one of the most brilliant antenna designs. It is simple to construct and has a high gain [Ehrenspeck and Poehler, 1959], typically greater than 10 dB. The Yagi-Uda antennas typically operate in the HF to UHF bands (about 3 MHz to 3 GHz) or a wavelength range 10 meters to 10 centimeters, although their bandwidth is typically small. The Yagi-Uda antenna is named after its inventor S. Uda and H. Yagi (who was UDA's professor). Yagi-Uda antenna is also used for radar and low cost communication at microwave frequencies and millimeter wavelength. Yagi-Uda antenna consist of one driven element plus one or more directors on one side and a reflector on other as shown in Fig. 1.1 which is a six elements antenna. An incoming field sets up resonant currents on all dipole elements. This causes the passive elements to re-radiate signals. These re-radiated fields are then picked by driven element. Hence total current induced in the driven dipole is a combination of direct field striking it and the re-radiates contribution from the directors and reflector. The goal of designer is to obtain a Yagi-Uda antenna which satisfies particular performance criteria like gain,input impedance,side lobe and beam width etc. This can be achieved by varying lengths and spacings of Yagi antenna.

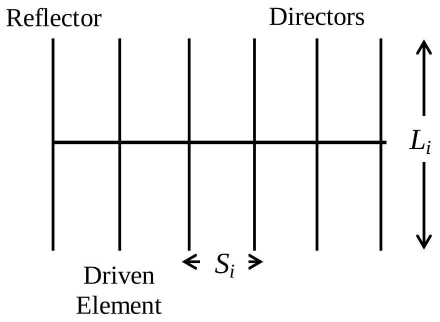

FIGURE 1.1: Six Elements Yagi-Uda antenna

An N-element Yagi-Uda antenna consist of $2N-1$ variables of N-element Yagi-Uda antenna are

$$y = [L_0, L_1, ..., L_{N-1}, S_0, S_1, ..., S_{N-2}] \tag{1.1}$$

1.1.3 Biogeography Based Optimization

Biogeography is the study of distribution of biodiversity over space and time or in simple words it is the study of geographical distribution of biological organism [A.Wallace, 2005]-[Darwin, 1995]. Its main aim to where the organism live and in what abundance.

BBO is an application of biogeography to optimization problems, it is based upon the immigration and emigration of species between the islands [Simon, 2008]. Immigration is the arrival of new species into habitat or population, while Emigration is the act of leaving one's native region.

1.2 Motivation

Artificial Intelligence (AI) is not too old paradigm that presents the scope for better design with non traditional design. BBO is recently introduced population based optimization technique proposed by D. Simon [Simon, 2008]. As it is introduced in 2008 and shows better results than other optimization techniques [Baskar et al., 2005; Jones and Joines, 1997; Rattan et al., 2008; Venkatarayalu and Ray, 2003], scope of better optimization results are viewable with BBO.

Yagi-Uda antenna introduced in 1926 by H. Yagi and S. Uda. Calculation of gain of Yagi-Uda antenna is always become a problem for researchers due to number of element lengths and spacing between them of Yagi-Uda antenna. There is no straight forward formula to calculate gain of Yagi-Uda antenna. A lot of work is already done in this domain still scope of improvement is visible with modern theoretic. If time permits BBO can be investigated for multi-objective and parallel computing as well.

1.3 Objectives

The primary objectives of this research work are summarized as follow :

1. To study parameter characterization of Yagi-Uda antenna for maximum gain that can be obtain for six-element Yagi-Uda antenna.
2. Investigation in BBO algorithm with a application of optimizing Yagi-Uda antenna.
3. Performance comparison of migration variants for Yagi-Uda antenna.
4. Performance comparison of mutation variants for Yagi-Uda antenna.
5. To investigate standard mutation operator for the improved performance.

1.4 Methodology

1. To find out gain and other parameter characterization, Method of Moments (MoM) based software, called Numerical Electromagnetics Code (NEC-2) will be studied.
2. A programming platform of Visual Studio 2008 will be created and reviewed for developing BBO algorithms.
3. The work in the paper Singh et al. Design of Yagi-Uda antenna using BBO will be re-done in C-environment.
4. Then other variants of BBO reported till date in IEEE journals will be studied and implemented in C.

1.5 Contributions

The main contributions of this report are :

1. To study Yagi-Uda antenna for design issues and their performance parameters.
2. To create BBO algorithm on Visual C++ to optimize various parameters of Yagi-Uda antenna.

3. To explore various migration and mutation variants for improved convergence performance.

4. To develop Visual C++ with NEC-2 for optimize designing of Yagi-Uda antenna using BBO.

1.6 Thesis Outline

After the brief introduction to M.Tech. thesis given in Chapter 1, detailed study of the historical research in optimizing Yagi-Uda antenna using AI and non-AI techniques reported till date is represented in Chapter 2.

Chapter 3 devoted understanding of various design parameters of Yagi-Uda antenna. Here, we discuss radiation pattern obtained during simulation results are also represented for better understanding.

Chapter 4 is dedicated to study of biogeography, literature of BBO, BBO algorithms flow and its variants reported till date.

In Chapter 5, firstly, NEC software developed, on basis of Method of Moments (MoMs), for simulation and analysis of electromagnetic behavior of various antenna. Secondly, implementation flow of BBO in C-environment along with NEC-2, a breif introduction to NEC environment also presented in this chapter.

CHAPTER 2

LITERATURE SURVEY

The needed detailed of literature survey, to get preliminary knowledge and search scope of investigation, to design Yagi-Uda antenna for optimization of its various characteristics, i.e., gain, impedance, SLL, etc., is explained in this chapter. Design of Yagi-Uda antenna with traditional methods and modern heuristics theory, i.e. Artificial Intelligence (AI) that occurred till date, in these domain of research are presented in this chapter.

2.1 Introduction

A Yagi-Uda antenna is a widely used antenna design due to its high forward gain, low cost and easy of construction. It is a linear array of parallel elements, one of which excited by voltage or current source and other act as a directors in which currents are induced due to mutual coupling.

Yagi-Uda antenna was invented by H. Yagi and S. Uda in 1926 at Tohoku University in Japan [Uda and Mushiake, 1954], but first published in English in 1928 and it has been extensively used as an end-fire antenna [Yagi, 1928]. The goal of the design process is to develop an antenna that meets some desired performance characteristics. Yagi-Uda antenna is difficult to design and optimize due to their numerous parasitic elements. There are no simple formulas for designing Yagi-Uda antennas due to the complex relationships between physical parameters such as element length, spacing, and diameter. So many researchers have proposed different algorithm for the optimized design of Yagi-uda antenna those can be classified, broadly as :

- Traditional mathematical based
- Artificial Intelligence (AI) based

AI techniques are basically inspired from natural/biological systems, e.g. (1) social behavior of ants, birds and termites, etc, (2) Genetic improvements in species over generations, (3) parallel processing of biological neurons (4) decision making capabilities of human beings from linguistic information, etc. These all techniques are, further, classified as (1) Fuzzy Logic (2) Artificial Neural Networks (3) Evolutionary Algorithms (EAs).

2.1.1 Design of Yagi-Uda antenna with traditional mathematical techniques (non AI techniques)

After the invention of Yagi-Uda antenna, Walkinshaw has proposed the theoretical design treatment of short Yagi-Uda antenna which is consists of a one driven dipole and four identical radiators [Walkinshaw, 1946]. As a result, polar diagrams, power gain and input resistance curves, as a function of the self-reactance of the parasitic radiators, are provided for each array.

In [Fishenden and Wiblin, 1949], Fishenden and Wiblin have proposed the design of Yagi aerials in which the advantages and limitations of Yagi arrays are considered and a simple theoretical explanation of a Yagi aerial is given. But these results are based on theoretical calculations and Yagi-Uda antenna has limited number of elements.

In [Mailloux, 1966], Mailloux has proposed an experimental study of a twenty-element Yagi array by using a King-Sandler theory to drive its results. A set of numerical data of wave theory compare with array theory to obtain a better results.

Researchers target different objectives (characteristics) to optimize design of Yagi-Uda antenna discussed as follow :

2.1.1.1 Maximum gain or directivity of Yagi-Uda antenna

Gain of a Yagi-Uda antenna is always a problem of researchers due to many numbers of input parameters. In [Reid, 1946], Reid has given an expression for power gain of an end-fire array having an infinite number elements and plotted curves show variation of gain with overall length of the array and from the envelope of these curves, the maximum gain for a given length of array is determined. The obtained results are coming from approximation calculations, this may or may not be same as practical results.

In conventional Yagi-Uda antenna design, optimum design requires separate adjustments in a number of parameters, viz. element lengths, diameter, and spacings between elements. Ehrenspec and Poehler have proposed a new method for obtaining maximum gain from Yagi-Uda antennas by demonstrating experimentally the interrelationship between all parameters [Ehrenspeck and Poehler, 1959]. Thus maximum gain for a given length and spacings less than 0.5λ is presented in it.

In [Bojsen et al., 1971], Bojesen *et al.* have proposed numerical optimization techniques to find the maximum gain of Yagi-Uda arrays by optimizing its geometrical parameters. The obtained results show that standard traveling-wave design methods are not optimum.

In [Cheng, 1971], Cheng has proposed optimization techniques for antenna arrays to calculate maximum power gain in which the method of moments technique is applied to the maximization of power gain.

Yagi-Uda antenna operate in single as well as in double band of frequencies and, in [Shen, 1972], Shen has proposed Yagi-Uda array design that operates at two bands of frequency. It is shown that optimum design can be obtained if any two parameters from, (a) bandwidth, ()b directivity and (c) size of antenna array, are specified.

In [Cheng and Chen, 1973], Cheng and Chen have used optimum element spacings to obtain maximum gain of Yagi-Uda arrays using a finite dipole radius and the mutual coupling between the antenna elements. Antenna gain is maximized by repeating iterations which converge the antenna gain rapidly. This method eliminates the need of a previously trail approach or large data collection.

In [Shen and Raffoul, 1974], Shen and Rouffal have proposed how to determine the optimum structure of a Yagi-Uda array of circular loops, which have directional or conical shell beam, by taking directivity into consideration.

In [Korekado et al., 1991], Korekado *et al.* have presented a design method for the Yagi-Uda two-stacked circular-loop array antenna by using the computed and measured antenna currents and a graphical method is given to estimate optimum size of antenna without detailed numerical calculations.

In [Chen and Cheng, 1975], Chen and Cheng have used optimum element lengths for maximum directivity of Yagi-Uda arrays. This method can be combined with previously developed spacing-perturbation method to obtain a maximum directivity.

In [Liang and Cheng, 1983], Liang and Cheng have proposed optimization of directivity by using optimum positions of an antenna elements.

In [Cheng, 1991], Cheng has proposed design procedure for Yagi-Uda antenna for a maximum gain by adjusting element lengths and spacings between elements of the antenna and by which the gain is increased by 80%.

For optimal design of Yagi-Uda antenna, in [Kolundzija and Olcan, 2003], Kolundzija and Olcan have presented a relatively simple and robust optimization algorithm which is based on a combination of random and Nelder-Mead simplex algorithms for finding optimal and near optimal solutions for antenna design and it offers more freedom in research area of antenna design.

In [Lim and Ling, 2007b], Lim and Ling have proposed the design two-element electrically small Yagi antenna which is composed of a spiral dipole and a director. The antenna design has been optimized and measured forward gain of 8.81 dB.

2.1.1.2 SLL reduction in Yagi-Uda antenna

First time, SLL reduction in Yagi-Uda antenna has proposed by Kajfez in 1973 [Kajfez, 1973], he has proposed nonlinear optimization for SLL reduction in which radiation pattern of the antenna is optimized with use of integral equation for current distribution. Several Yagi-Uda antennas are optimized that show gain of the antenna cannot be improved further, however, the side lobes can be reduced by as much as 10 dB.

2.1.1.3 Reduction in size of Yagi-Uda antenna

For reducing the size of Yagi-Uda antenna, in [Shen, 1972], Shen has proposed Yagi array that operate at two frequency bands for obtaining the optimum design of the antenna with constraints on size of the array. It is shown that the antenna array is optimized if any two of the, bandwidth, directivity, or the size of array, parameters are specified.

In [Shen and Raffoul, 1974], Shen and Rouffal have proposed the optimal structure of a Yagi-Uda array of circular loops by taking size of antenna into consideration.

For small size of antenna, in [Lim and Ling, 2007b], Lim and Ling have proposed a two-element electrically small Yagi-Uda antenna which is composed of a spiral-shaped dipole and a director. The design of this antenna has been optimized and achieve maximum gain of 8.81 dB.

2.1.2 Design of Yagi-Uda antenna with AI techniques

There is a large number of proposed electromagnetic radiators designed as wire or Yagi-Uda antennas. To calculate various design parameters of Yagi-Uda antenna, integral equations and various antenna simulators are used which give current distribution on the wires of an antenna and on the basis of these calculations design parameters are obtained. However, using an antenna simulator in conjunction with AI make possible to design an antenna using different optimization techniques.

In [Altshuler and Linden, 1997], Altshuler and Linden have used GA to design wire antennas. In this paper, they design four types of antennas using GA : (1) Monopole antenna with modified driven element operating at 1.6 GHz, (2) Seven-elements wire antenna, (3) Modified Yagii antenna that designed for a broad frequency band and low side lobes at center frequency 235 MHz, and (4) modified Yagi antenna that designed for high gain at single frequency 432 MHz.

In [Sorokin et al., 2002], Sorokin *et al.* have proposed technique for evolutionary design fitness calculation of Yagi-Uda antenna with use of Hallen's integral equation to find current distribution on antenna elements to find optimal antenna designs.

Many researchers have proposed various algorithms for design optimization of Yagi-Uda antenna and are discussed, in brief, below :

2.1.2.1 Maximum gain or directivity of Yagi-Uda antenna

For maximum gain or directivity of Yagi-Uda antenna, in [Jones and Joines, 1997], Jones and Joines have proposed GA to design Yagi-Uda antenna by optimizing element lengths and spacings between them. A method of moments code, Numerical Electromagnetics Code (NEC2), is used to evaluate each of the antenna designs during the optimization process.

In [Austin and Liu, 1999], Austin and Liu have proposed an optimum design of three-element Yagi-Uda array using GA by varying element lengths, angles and spacings between them for maximum gain.

In [Correia et al., 1999], Correia *et al.* have used GA to optimize gain of Yagi-Uda antenna by fix one or more antenna objectives. It can also optimize more than one objectives at the same time.

GAs are of two types: (1) Binary GAs and (2) Continuous (decimal) GAs and only binary GAs are used for optimal Yagi-Uda antenna designs. However, some researchers have investigated the use of continuous GAs. In [Lee et al., 1999], Lee *et al.* have reported similarities and differences between continuous and binary GAs for the antenna design optimization.

In [Lohn et al., 2001], Lohn *et al.* have proposed GA based automated antenna optimization that used for a fixed Yagi-Uda topology and a byte-encoded antenna representation. The method proposed is less complex than previous ones and result shows a excellent gain with very good impedance characteristics of Yagi-Uda antenna.

For comparison of various GAs, in [Orchard and Clark, 2003], Orchad and Clark have presented the comparison of various GA techniques for the optimization of Yagi-Uda and helix antenna design in which various mutation rates and mating techniques are compared. The optimized antenna designs are then compared to theoretical designs and it is found that the optimized designs either matched or exceeded the theoretical design performances.

In [Wang et al., 2003], Wang *et al.* has proposed hierarchical GA for the optimization of Yagi array by optimizing the element spacings and lengths of Yagi-Uda antenna. This technique has the ability of handling single-objective as well as multi-objective functions during numerical optimizing process. Furthermore, this feature enables a design tradeoff between cost and performance without extra computational efforts.

For optimum design of Yagi-Uda antenna, in [Venkatarayalu and Ray, 2004], Venkatarayalu and Ray have introduced a stochastic, zeroth-order optimization algorithm that handles constraints and objectives separately via pareto ranking to design a Yagi-Uda antenna which eliminates the problem of scaling.

In [Zainud-Deen et al., 2004], Zainud *et al.* have used GA for optimum design of Yagi fractal array in which NEC2 and GAs is used to evaluate antenna design and optimize the element spacings and the lengths of Yagi fractal arrays, respectively. As a result, maximum gain between 10-13 dB is achieved with this optimization technique.

After GA, in [Baskar et al., 2005], Baskar *et al.* have used Comprehensive Learning Particle Swarm Optimization (CLPSO) to optimize element spacing and lengths for Yagi-Uda antenna design. Three objectives are considered to optimize: (1) gain, (2) gain and input impedance only, and (3) gain, input impedance and relative sidelobe level (rSLL). These design problems are optimized using three variants of PSO algorithms, the modified PSO, fitness-distance ratio PSO (FDR-PSO), and CLPSO. Then, obtained results are compared with GA, CI and between the variants of PSO and these compared with GA and found that CLPSO give a better results.

In [Zainud-Deen et al., 2005], Zainud-Deen *et al.* have proposed PSO to design six-elements Yagi-Uda antenna by optimize element lengths and spacing between them for high gain and input impedance.

In [Bayraktar et al., 2006], Bayraktar *et al.* have used PSO to design miniature three-element stochastic Yagi-Uda arrays for optimum gain, good front-to-back ratio (FBR). Simulation results of PSO are compared with binary GA and with a conventional three-element Yagi-Uda array design.

In [Li, 2007], Li *et al.* have used Differential Evolution (DE) algorithm for design optimization of Yagi-Uda antenna by determining its geometric parameters using a method of moments code. Simulation results clearly show that the DE is a robust and useful optimization tool for designing antennas.

In [Lim and Ling, 2007a], Lim and Ling have proposed how to design a two-element Yagi antenna to achieve high gain at 900 MHz by using a GA and NEC. The maximum gain of the antenna is found to be 9.5dB.

Simulated Annealing (SA) is another new stochastic, global search and optimization technique that is also used to optimize antenna design. Singh *et al.* [Singh et al., 2007] and Rattan *et al.* [Rattan et al., 2008] have used SA to optimize design of Yagi-Uda antenna by varying element spacing and their lengths and results show that Yagi-Uda antenna have excellent gain and FBR properties.

In [Yan et al., 2010], Yan *et al.* have used DE to design wide band Yagi-Uda antenna with X-shaped driven dipoles with objective of maximum gain, i.e., 12.7 dB and minimum SLL.

In [Khodier and Al-Aqil, 2010], Khodier and Al-Aqil have used PSO for optimization of Yagi-Uda antenna array and compared its evolutionary results with other optimization methods such as GA, SA, PSO, and DE.

In [Singh et al., 2010], Singh *et al.* have proposed Biogeography Based Optimization (BBO) to design Yagi-Uda antenna. BBO is a latest population-based technique, developed on the science of biogeography, that employs migration and mutation operator. Yagi-Uda antenna is optimized for three different design objectives gain, input impedance and SLL. During optimization, NEC2 is used to evaluate antenna design generated by BBO algorithm. The results obtained by BBO are compared with GA, CLPSO and SA.

2.1.2.2 Impedance optimization of Yagi-Uda antenna

For impedance optimization of Yagi-Uda antenna, in [Correia et al., 1999], Correia *et al.* have used GA to optimize gain of Yagi-Uda antenna by fix one or more antenna parameters. It can also optimize more than one parameter at the same time.

In [Zainud-Deen et al., 2004], Zainud *et al.* have used GA for optimum design of Yagi fractal array in which NEC2 is used to evaluate antenna designs where, maximum gain between 10-13 dB is achieved.

After GA, in [Baskar et al., 2005], Baskar *et al.* have proposed CLPSO to optimize antenna element spacing and their lengths where three objectives are considered to optimize: (1) gain, (2) gain and input impedance only, and (3) gain, input impedance and rSLL. These design problems are optimized using three variants of PSO algorithms, viz. the modified PSO, FDR-PSO, and CLPSO. Then, obtained results are compared with GA where CLPSO reported as better choice.

In [Zainud-Deen et al., 2005], Zainud-Deen *et al.* have also used PSO to design six-elements Yagi-Uda antenna by optimizing the element lengths and spacing between them for high gain and input impedance.

In [Singh et al., 2010], Singh *et al.* have used BBO to design Yagi-Uda antenna. Yagi-Uda antenna is optimized for three different design objectives gain, input impedance and SLL. During optimization, NEC2 is used to evaluate antenna design generated by BBO algorithm. The results obtained by BBO are compared with the GA, CLPSO and SA.

2.1.2.3 SLL reduction in Yagi-Uda antenna

To reduce the rSLL, in [Baskar et al., 2005], Baskar *et al.* have used CLPSO along with FDR-PSO, modified PSO and GA to optimize element spacing and lengths of Yagi-Uda antennas. Three objectives are considered to optimize: (1) gain, (2) gain and input impedance only, and (3) gain, input impedance and rSLL.

In [Singh et al., 2010], Singh *et al.* have prposed BBO to design Yagi-Uda antenna with gain, input impedance and SLL as objectives. NEC2 is used to evaluate antenna design generated by BBO algorithm. The results obtained by BBO are compared with the GA, CLPSO and SA.

In [Lu et al., 2000], Lu *et al.* have proposed special corner reflector Yagi-Uda antenna in which Emperor-Selective GA (EMS-GA) is used for antenna design optimization. The obtained results are compared with traditional Yagi antenna and found that the designed antenna has much lower SLL with better immunity to interference.

2.1.2.4 Optimize bandwidth of Yagi-Uda antenna

For bandwidth optimization, in [Correia et al., 1999], Correia *et al.* have used GA to optimize gain of Yagi-Uda antenna by fixing one or more antenna parameters. It can also optimize more than one parameter at the same time.

In [Lohn et al., 2001], Lohn *et al.* have proposed GA-based automated antenna optimization that is used for a fixed Yagi-Uda topology and a byte-encoded antenna representation. The fitness function evaluation give the relationship between power gain and sidelobe/backlobe loss to emerge naturally. This method is less complex than previous proposed methods and result shows a excellent gain with very good impedance characteristics of Yagi-Uda antenna.

In [Rattan et al., 2008], Rattan *et al.* have used SA for the optimization of Yagi-Uda antenna by taking gain as a objective in which NEC2 and SA has been used to evaluate the antenna design and to optimize geometrical parameters of a Yagi-Uda antenna, respectively.

2.1.2.5 Small size Yagi-Uda antenna design

In [Lim and Ling, 2007a], Lim and Ling have proposed how to design a two-element Yagi-Uda antenna to achieve high gain of 9.5 dB at 900 MHz by using GA and NEC.

2.1.2.6 Multiobjective optimization of Yagi-Uda antenna

Investigators has also presented multiobjective optimization of Yagi-Uda antenna using AI techniques. In [Ramos et al., 2003], Romos *et al.* have used real-biased multiobjective GA to design of wire antennas. This procedure leads to better estimates of the Pareto set and is applied to the optimization of a Yagi-Uda antenna in a wide frequency range with several simultaneous performance specifications, providing antenna geometries with good performance.

In [Venkatarayalu and Ray, 2004, 2003], N. V. Venkatarayalu and T. Ray has used computational intelligence for single and multi-objective design of Yagi-Uda antennas. They introduce a population-based, stochastic, zero-order optimization algorithm and use it to solve single and multiobjective Yagi Uda design optimization problems. The algorithm is attractive as it is computationally efficient and does not require additional user inputs to model constraints or objectives.

In [Wang et al., 2003], Wang *et al.* has used hierarchical GA for optimization of Yagi array by optimizing the element spacing and lengths of Yagi-Uda antenna. This scheme has the ability of handling multiobjective functions as well as the discrete constraints in the numerical optimizing process where the technique of Pareto ranking scheme, more than one possible solution can be obtained. Furthermore, this feature also enables a design tradeoff between cost and performance without extra computational effort.

After the evolution in GA, in [Baskar et al., 2005], Baskar *et al.* have used Comprehensive Learning Particle Swarm Optimization (CLPSO) to design Yagi-Uda antenna that is used to optimize the element spacing and lengths of Yagi-Uda antennas. SuperNEC, an object-oriented version of the numerical electromagnetic code (NEC-2) is used to evaluate the performance of various Yagi-Uda antenna designs. The three objectives considered are gain only, gain and input impedance only, and gain, input impedance and relative sidelobe level (rSLL). Each design problem is optimised using three variants of PSO algorithms, namely the modified PSO, fitness-distance ratio PSO (FDR-PSO), and comprehensive learning PSO (CLPSO). For the purpose of comparison genetic algorithm and computational intelligence are taken into an account and the results clearly show that the CLPSO is a robust and useful optimization tool for designing Yagi antennas for the desired target specifications. In particular, this method can solve the multiobjective optimization problem using various Pareto-optimal solutions in an extremely efficient manner.

In [Kuwahara, 2005], Y. Kuwahara has proposed multiobjective optimization design of Yagi-Uda antenna by using Pareto GA, by which various Pareto-optimal solutions for each objective function can be obtained that enables the selection of parameters in accordance with the design requirement. The effectiveness of the Pareto GA is compared with conventional GA and with the values of the design benchmark reference.

In [Varlamos et al., 2005], Varlamos *et al.* have proposed multiobjective genetic optimization to design Yagi-Uda arrays with additional parasitic elements. The genetic algorithms are employed, and various objective functions such as gain, front-to-back ratio and input impedance are examined. Comparisons are made among the modified and conventional Yagi-Uda configurations and the modified Yagi-Uda array give higher performance standards over an extended bandwidth around 2.4 GHz.

In [Lei et al., 2007], Lei *et al.* have used multiobjective optimization design of X-shape driven dipole Yagi-Uda antenna. The effects of the angle that the x-shape driven dipole spread on the performance of the antenna are also studied. The simulated maximum antenna gain across the operating frequency band, obtained from the optimization process, is about 12.1 dBi. A wide-band Yagi-Uda antenna with an x-shape driven dipole for the Meteor Burst Communication (MBC) at the VHF is presented in this paper.

In [Li and Guo, 2009], J. Y. Li and J. L. Guo have used DE algorithm for multiobjective optimization of Yagi-Uda antenna in which method of moments MoM is used to evaluate antenna design and DE is employed to optimize the geometric parameters of Yagi-Uda antenna. The results clearly show that the DE is a robust and useful optimization tool for the optimization of several conflicting objectives such as gain maximization, SLL reduction and input impedance matching. Multi-objective Evolutionary Algorithms (MOEAs) are suitable optimization techniques for solving such problems.

In [Goudos et al., 2010], Goudos *et al.* have proposed Generalized Differential Evolution (GDE3), which is a multi-objective extension of DE to design Pareto optimal Yagi-Uda antenna. Both GDE3 and Nondominated Sorting Genetic Algorithm-II (NSGA-II) are applied to Yagi-Uda antenna design under specified constraints. Three different Yagi-Uda antenna designs are considered and optimized and Pareto fronts are produced for both algorithms. The results indicate the advantages of this approach and the applicability of this design method.

2.1.3 Applications specific Yagi-Uda antenna designs

Investigators has done various changes in design of Yagi-Uda antenna such as microstrip Yagi array, multisector monopole Yagi array, quasi Yagi antenna, membrane supported Yagi-Uda antenna and tridimensional Yagi antenna for specific application. Investigators have proposed various design of Yagi-Uda antennas discussed as follows

2.1.3.1 Microstrip Yagi antenna design

A novel antenna structure formed by combining the Yagi-Uda array concept and the microstrip radiator technique, called microstrip Yagi array. In [Huang and Densmore, 1991], J. Huang and A. C. Densmore have proposed design of microstrip Yagi array antenna for the mobile satellite (MSAT) system as a low-profile, low-cost, and mechanically steered medium-gain land-vehicle antenna. With the antenna's active patches (driven elements) and parasitic patches (reflector and director elements) located on the same horizontal plane. Because of the parasitic patches are not connected to any of the lossy RF power distributing circuit the antenna is an efficient radiating system.

In [Gray et al., 1998] Gray *et al.* have proposed dual-frequency circularly polarized electronically steerable microstrip patch antenna array suitable for land-mobile communications which is based on a four-element Yagi-Uda patch antenna. The main lobe of the array covers the elevation angles from 20 to 70^0 with a peak gain of 8.4 dBi at 1.54 GHz and 11.7 dBi at 1.62 GHz.

In [Kumar and Malathi, 2007], R. Kumar and P. Malathi have proposed design of multi-band fractal Microstrip Yagi Uda Antenna. This antenna has been modeled by incorporating fractal geometry that apply to the conventional Yagi-Uda principle. It has been observed that Yagi - Uda antenna resonant at three frequencies, i.e., 0.370 GHz, 1.795 GHz and 3.665 GHz. The experimental resonant frequencies are in good agreement with simulated resonant frequencies.

2.1.3.2 Quasi Yagi antenna design

In [Qian et al., 1998], Qian *et al.* have proposed microstrip-fed quasi-Yagi antenna with broadband characteristics. The novel Yagi-like printed dipole array antenna is fed by a microstrip-to-coplanar strip transition, and uses the truncated microstrip ground plane as its reflecting element.

In [Kaneda et al., 1999], kaneda *et al.* have used quasi yagi antenna for broadband microstrip to waveguide transition. The compact and single-layered quasi-Yagi antenna fabricated on high dielectric-constant substrate has end-fire radiation patterns. This transition, in addition, achieves very broad bandwidth and relatively low insertion loss.

In [Hang et al., 2001], Hnag *et al.* have used high-efficiency push-pull power amplifier integrated with quasi-Yagi antenna. By using the active integrated antenna concept, this novel circuit eliminates the usage of an ordinary 180 hybrid at the power-amplifier output stage, therefore eliminating the losses associated with the hybrid, resulting in a compact and high-efficiency power-amplifier design with intrinsic second harmonic suppression. At an operating frequency of 4.15 GHz, a maximum measured power-added efficiency (PAE) of 60.9% at an output power of 28.2 dBm has been achieved. The measured PAE is above 50% over a 260-MHz bandwidth.

In [Kaneda et al., 2002], kaneda *et al.* have proposed a broadband planar quasi-Yagi antenna which is based on the classic Yagi-Uda dipole array. This quasi-Yagi antenna achieves a measured 48% bandwidth for VSWR < 2, better than 12 dB front-to-back ratio, smaller than -15 dB cross polarization, 3-5 dB absolute gain and a nominal efficiency of 93% across the operating bandwidth. The excellent radiation properties of this antenna make it ideal as either a stand-alone antenna with a broad pattern or as an array element. The antenna should find wide applications in wireless communication systems, power combining, phased arrays and active arrays, as well as millimeter-wave imaging arrays.

2.1.3.3 Membrane supported Yagi-Uda antenna design

For membrane supported antenna, in [Neculoiu et al., 2003], Neculoiu *et al.* have given design methodology for the millimeter-wave membrane supported antennas. Two types of antenna demonstrators were designed, one is Yagi-Uda antenna and second is double folded slot antenna and the experimental return loss is in a very good agreement with the simulated results.

In [Neculoiu et al., 2004], Neculoiu *et al.* have proposed membrane supported Yagi-Uda antenna for millimetre-wave applications. This paper presents for the first time the design, fabrication and 'on wafer' characterization of membrane supported Yagi-Uda at 45 GHz frequency range. The antennae were fabricated on 1.4 μm thin SiO_2/Si_3N_4 membranes obtained by micromachining of high resistivity silicon, using a backside reactive ion etching process. The antenna structures have shown very good agreement between experimental and simulated results.

In [Neculoiu et al., 2005], Neculoiu *et al.* have used Yagi-Uda antennas fabricated on thin GaAs membrane for millimeter wave applications. Micromachining technology has been proposed for the fabrication of millimeter wave circuits on very thin dielectric membranes. This approach offers many advantages as the Yagi-Uda antenna has become a standard for multi-element antenna arrays in the range from HF to UHF. Experimental results for 45 GHz and 60 GHz antennas are presented. The simulated and measured return loss curves for the 60 GHz antenna show very good agreement.

In [Yoon et al., 2005], Yoon *et al.* have proposed a vertical W-band surface-micromachined Yagi-Uda antenna that stand on a high-k soda-lime glass substrate and fed by a coplanar waveguide. The performance of the vertical Yagi-Uda is to be superior to conventional W-band printed antennas due to minimum substrate wave effects. A successful implementation of the vertical Yagi-Uda structure is demonstrated using high-aspect-ratio surface micromachining fabrication technologies.

In [Neculoiu et al., 2006], Neculoiu *et al.* have proposed design and characterization of a 45 GHz Yagi-Uda antenna receiver fabricated on GaAs micromachined membrane. This design, fabrication and characterization of a GaAs membrane supported millimeter wave receiver that monolithically integrates a Yagi-Uda antenna with a Schottky diode that also includes electromagnetic simulation and modeling.

In [DeJean and Tentzeris, 2007], G. R. DeJean and M. M. Tentzeris have proposed a new high-gain microstrip Yagi array antenna with a high front-to-back (F/B) ratio for WLAN and millimeter-wave applications. The high front-to-back (F/B) ratio is up to 15 dB, the directivity between 9-11.5 dBi and the F/B ratio can be altered to suit the different application.

In [Alhalabi and Rebeiz, 2009], R. A. Alhalabi and G. M. Rebeiz have used to design high-gain Yagi-Uda antennas for millimeter-wave switched-beam systems. The antenna is built on both sides of a teflon substrate which results in an integrated balun for the feed dipole. A 7-element design results in a measured gain of 9-11 dB at 22-26 GHz.

In [Alhalabi and Rebeiz, 2010], R. A. Alhalabi and G. M. Rebeiz have proposed design of differentially-fed millimeter-wave Yagi-Uda antennas with folded dipole. The antennas are built on both sides of a Teflon substrate. A big change in design aspect is the use of a folded dipole feed which increases the input impedance. The differentially-fed Yagi-Uda antenna with folded dipole results in high radiation efficiency is grater than 90% at 22-26 GHz and is suitable for mm-wave point-to-point links communication systems.

2.1.3.4 Tridimensional Yagi-Uda antenna design

In [Brianeze et al., 2009, 2010], Brianeze *et al.* have proposed tridimensional Yagi, which is a novel type of Yagi antenna operating in P band. It is made from two other types of Yagi antennas- Quasi-Yagi and Yagi-Uda as microstrip balun, as in Quasi-Yagi, and its driver and directors are made from metal tubes, as in Yagi-Uda, both integrated to a reflecting plane. The key point of this new antenna model is its asymmetric and reconfigurable radiation pattern and therefore the possibility of a high rejection between bands in a plane.

2.1.3.5 Planar Yagi-Uda antenna design modification

In [Huang and Hsu, 2009], H. C. Huang and P. Hsu have proposed a planar reconfigurable Yagi-Uda antenna with end-fire beam scan which is based on thin dielectric substrate. This design not only can provide the end-fire beam scan with high directivities coverage but also can operate at a fixed frequency without frequency shift when beam scans.

In [Beer et al., 2010], Beer *et al.* have proposed planar Yagi-Uda antenna array for W-band automotive radar applications. The radar antenna concept consists of end-fire antennas and a cylindrical parabolic reflector that can be integrated into the sensor's metal housing that reduces the antenna substrate area while maintaining a small installation depth. The achieved gain of 16 dBi can be increased up to 22 dBi for the 4-element array by an improved power-divider network and even higher if more antenna elements are used.

With some more modifications in design of planar Yagi-Uda antenna, in [Huang and Hsu, 2009], Huang *et al.* has used meandered driven dipole and a concave parabolic reflector to design planar Yagi-Uda antenna. A planar Yagi-Uda antenna with a single director, a meandered driven dipole, and a concave parabolic reflector on a thin dielectric substrate is proposed. The area of this antenna is much smaller than that of the previously proposed.

In [Sun et al., 2010], Sun *et al.* have proposed modified two-element Yagi-Uda antenna with tunable beams. These tunable beams are achieved by simply adjusting the short-circuit position of the transmission line connected to the parasitic element and work on the principle of current relations between the driven and parasitic elements.

Many investigators have proposed different modification in design of Yagi-Uda antenna. In [Maruyama et al., 1996], Maruyama *et al.* have proposed analysis and design of multi-sector monopole Yagi-Uda array (MS-MPYA) mounted on a ground plane. To numerically analyze

MS-MPYA and clarify mutual sectors interaction when the antenna uses multiple sectors, the moment method which combines patch and wire models, is used.

To operate Yagi-Uda antenna at very high frequency, in [Grajek et al., 2004], Grajek *et al.* have proposed a high-gain Yagi-Uda antenna array that operates at 24GHz by added capacitance due to the supporting dielectric substrate. The antenna results in a directivity of 9.3 dB, a front-to-back ratio of 11 dB. The design method presented in this paper is quite straightforward, and can be used to develop low-, medium-, and even high-gain end fire Yagi-Uda antennas.

In [Zheng et al., 2004], Zheng has proposed a modified printed Yagi antenna with a simplified feed mechanism. In this new design, the driver dipole is fed by a transmission line formed by two parallel strips printed on opposite sides of the dielectric substrate, this leads to reduction of the transmission line length and the radiation losses.

In [Juan et al., 2007], Juan *et al.* have used a wide-band Yagi-Uda antenna with an x-shape driven dipole for the Meteor Burst Communication (MBC) at the VHF. Parameters design, multiobjective optimization process and effect of installed height on the performance of antenna are studied.

In [Lei et al., 2008], Lei *et al.* have used a vertically stacked Yagi-Uda antenna array with X-shape driven dipoles for the long range Meteor Burst Communication (MBC) at the VHF. The parameter design and multi-objective optimization process of the compact 6- element antenna array are taken that show good radiations with gain variations less than 1.3 dB and the side lobe level less than -15 dB over the optimized band obtained.

For high input impedance, in [Han et al., 2008], Han *et al.* have proposed a design of tetrahertz Yagi-Uda antenna that operates in the terahertz frequency region and gives a high input resistance of approximately 2600 Omega at the resonance frequency by using a full-wavelength dipole as the driver element instead of a half-wavelength dipole. The output power of this antenna is expected to be appreciably greater than that of existing terahertz photomixer antennas.

In [Mahmoud et al., 2008], Mahmoud *et al.* have presented performance of circular Yagi-Uda arrays (CYUA) for beamforming applications using PSO using the lengths and spacings of a three-element linear Yagi-Uda antenna.

In [Nascimento et al., 2008], Nascimento *et al.* have proposed low cost Yagi monopole array. The goal is achieving a compact, low cost, efficient radiator for GPRS applications.

In [Song et al., 2008], Song *et al.* have proposed simulation and analysis of a kind of cylindrical conformal Yagi-Uda antenna to save the space of aerocraft. The proposed cylindrical conformal Yagi-Uda antenna is composed of five conformal dipoles, which is mounted on the surface of the cylindrical object in order to realize the radiation toward the axis of the cylinder. The radiation performances of the proposed antenna are simulated for two cases, the one case is that the substrate of the dipoles is dielectric and the other case is that the dielectric substrate of the dipoles supported by metallic conductor. The calculation results reveal that the anticipative radiation directivity is obtained and the sum and difference patterns are formed. The simulation and calculation results give the maximum contribution in the field of cylindrical conformal Yagi-Uda antenna.

In [Iigusa et al., 2009], Ligusa *et al.* have proposed design of Yagi-Uda antenna for UHF-ITS mobile terminal. A Yagi-Uda antenna with a small short interelement distance of approximately 0.025 lambda is proposed for use as a UHF-band ITS in-vehicle antenna by placed near the body of a car without any significant deterioration in the gain.

In [Alhalabi et al., 2011], Alhalabi *et al.* have proposed self-shielded high efficiency Yagi-Uda antennas for 60 GHz communication. The antenna is built on a teflon substrate with a thickness of 0.254 mm and this antenna shows excellent performance in free space and in the presence of metal-planes used for shielding purposes. This antenna is ideal for used at complex platforms, such as laptops, for point-to-point communication systems, either as a single element or a switched-beam system.

2.2 Conclusion

In literature survey, there are many opportunities do research on these areas. BBO is a new optimization technique that show better results than other EA's. Problem of designing Of Yagi-Uda antenna solve with MATLAB which shows slow processing performance, to take more faster response Visual Studio is take into consideration. Next chapter tells about problem formulation and about implementation algorithm used to solve the problem of design of Yagi-Uda antenna using BBO.

CHAPTER 3

YAGI-UDA ANTENNA DESIGN

Antenna is a very important component of communication systems. Selection of an antenna is done on its various characteristics, i.e., gain or directivity, input impedance, bandwidth, rSLL and operating frequency. Gain or directivity is a figure of merit for an antenna which tell about the ability of an antenna to transmit and receive a energy in a particular direction. Yagi-Uda antenna introduced by S. Uda and H. Yagi in 1926 which is easy to construct, high gain, typically greater than 10 dB, and operating frequency 3MHz to 3GHz. Yagi-Uda antenna mainly used in TV signal transceiver and its variants are used in modern communication technology.

3.1 Introduction to Yagi-Uda antenna

A Yagi-Uda antenna commonly known as Yagi antenna. Yagi-Uda Antenna design consisting of three types of parasitic elements, viz. driven element, reflector element and director elements. Their features and characteristics are discribed in following subsections :

3.1.1 Driven Element

The driven element of a Yagi-Uda antenna is the feed point where the transmission line is attached to the antenna. There is usually just one driven element. A dipole driven element will be *resonant* when its electrical length is half of the wavelength of the frequency applied to its feed point. It might contain traps so that it resonates on more than one band. The driven element can be either as an electrically separate dipole or together with the boom.

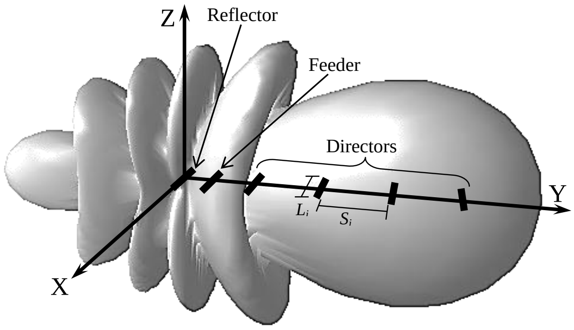

FIGURE 3.1: Six Elements Yagi-Uda antenna

3.1.2 Reflector

The reflector is the element that is placed at the rear of the driven element. It's resonant frequency is lower and its length is approximately 5% longer than the driven element. The length of reflector will depending on the spacing, the element diameter as well as gain, bandwidth, front to Back ratio (F/B ratio), and SLL pattern requirements of the antenna design.

3.1.3 Directors

The directors elements can be one or more in number with different lengths. Those are smaller than feeder and reflector elements. They are resonant slightly higher in frequency than the driven element and its length will be about 5% shorter, progressively than the driven element. The length of directors will depending upon the director spacing, the number of directors used in the antenna, the desired pattern, pattern bandwidth and element diameter. The number of directors that can be used are determined by the physical size or length.

3.2 Radiation Pattern of Yagi-Uda antenna

The radiation or antenna pattern describes the relative strength of radiated field in various directions from the antenna, at a constant distance. The radiation pattern is also called reception pattern as well, since it also describes the receiving properties of the antenna. The radiation pattern is three-dimensional, however, usually the measured radiation patterns are a two dimensional slice of the three-dimensional pattern, in the horizontal and/or vertical planes as shown in Figure. These pattern measurements are presented in either a rectangular or a polar format. A polar format of the gain verses orientation (radiation pattern) is useful when characterizing antennas. Some important features that appears on plot are :

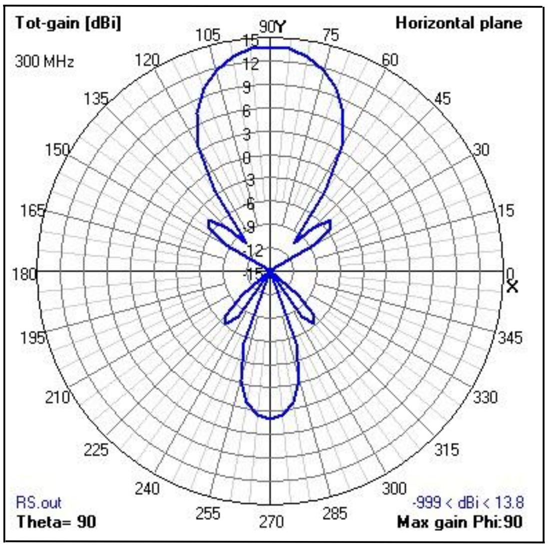

FIGURE 3.2: Horizontal Plane of Radiation Pattern of Yagi-Uda Antenna

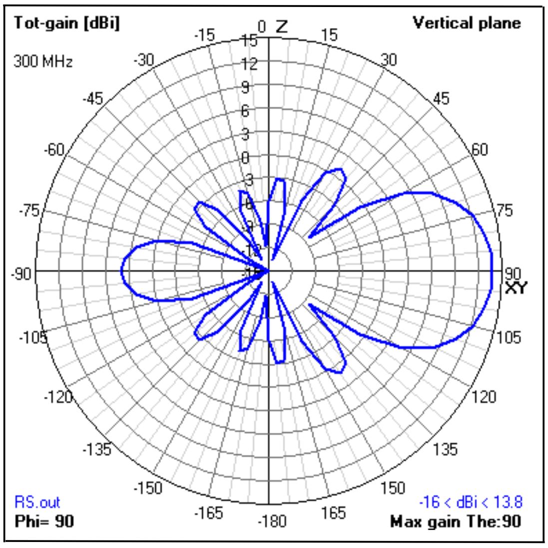

FIGURE 3.3: Vertical Plane of Radiation Pattern of Yagi-Uda Antenna

1. **Forward gain** : Forward gain is the ability of an antenna to focus energy in a particular direction while transmitting receiving energy better from a particular direction. To determine the gain or directivity of an antenna, a reference antenna is used to compare antenna performance. Forward gain is expressed in decibles (dB) relative to an isotropic source or a standard dipole (in direction of maximum gain) represent the improvement in signal lavel to reference antenna. Typically, the higher the gain, more the efficient antenna performance, and longer the range of the antenna will operate. Radiation pattern of six-elements Yagi-Uda antenna, depicted in Figure 3.4, which is used to calculate gain of Yagi-Uda antenna.

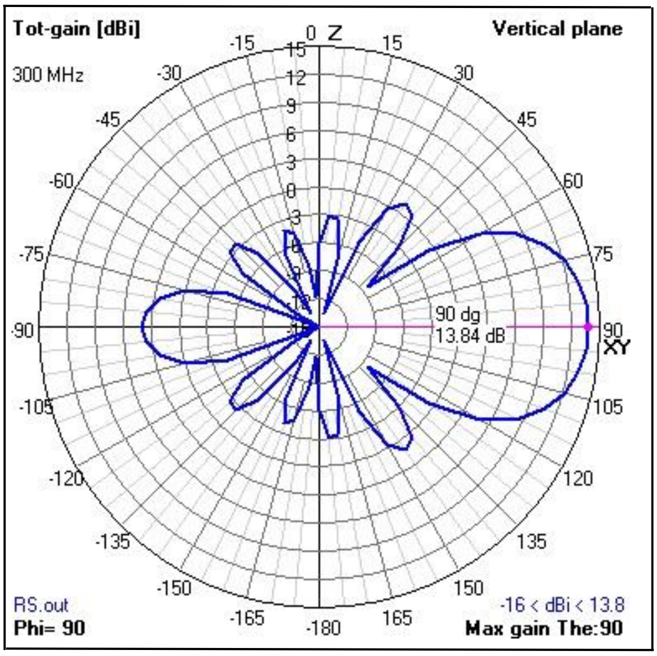

FIGURE 3.4: Gain Radiation Pattern of Yagi-Uda Antenna

2. **Front to Back ratio** : The F/B ratio is used in describing directional radiation patterns for antennas. If an antenna has a unique maximum direction, the F/B ratio is the ratio of the gain in the maximum direction to that in the opposite direction (180 degrees from the specified maximum direction) also expressed in dB as depicted in Figure 3.5.

3. **Beamwidth** : Beamwidth is the angle between directions where the power is the half the value at the direction of maximum gain which is -3dB. It gives a measure a directivity of antenna as depicted in Figure 3.5.

4. **Sidelobes** : Antenna is not able to radiate all the energy in one preferred direction because some part of energy is inevitably radiated in other directions. Sidelobes are unwanted peaks in the gain at angles other than in forward direction, they reduce the amount of useful energy contained in the forward direction. The peaks are referred to as side lobes, as shown in Figure 3.6, commonly specified in dB down from the main lobe.

Other characteristics that do not appear on the polar plot but which are equally important are :

1. **Bandwidth** : Bandwidth is the range of frequency over which the antenna exhibits acceptable characteristics.

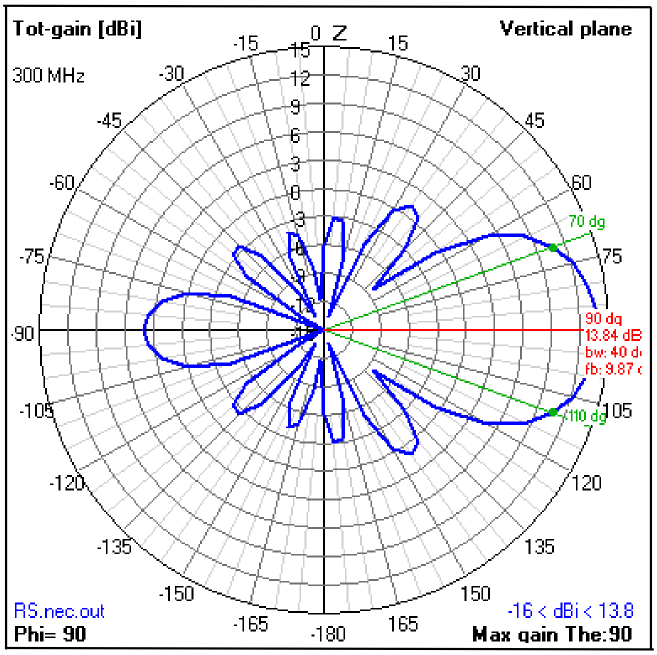

FIGURE 3.5: F/B and Beamwidth Radiation Pattern of Yagi-Uda Antenna

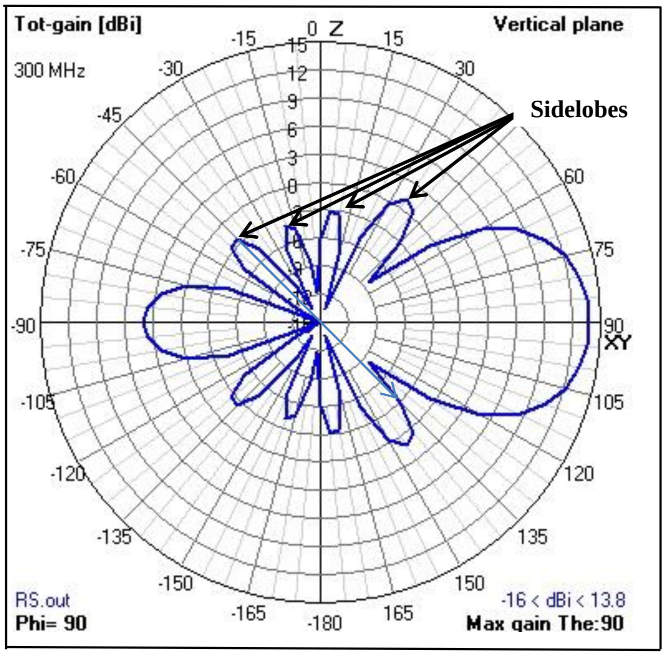

FIGURE 3.6: Sidelobes Radiation Pattern of Yagi-Uda Antenna

2. **Radiative impedance** : For an efficient transfer of energy, the radiative impedance of the antenna and transmission cable connecting them must be the same. Transceivers and their transmission lines are typically designed for 50Ω resistive impedance. If the antenna has an impedance different from 50Ω then there is a mismatch and an impedance matching circuit is required. Radiation resistance is used to match the impedance of antenna to impedance of transmission cable otherwise signal loss and high voltages in the cable may occur.

3.3 Conclusion

In this chapter, various design parameters of Yagi-Uda antenna are discussed to enable reader to have some background knowledge about Yagi-Uda antenna. In this thesis, gain maximization will be target in the coming chapters using biogeography based optimization and its variants. Philosophy and algorithmic flow of BBO are discussed in the next chapter.

CHAPTER 4

BBO AND ITs VARIANTS

In this chapter, the science of biogeography and derived optimization technique is discussed. BBO has two major operators, viz. migration and mutation. Researchers have further proposed variant with the objective of improved performance. This chapter dedicated to all the variants of BBO and the algorithmic flow of these variants.

4.1 Biogeography and BBO terminology

BBO is one of the recently developed population based algorithms which has shown impressive performance over other Evolutionary Algorithms (EAs). As name suggests, BBO is a population based global optimization technique developed on the basis of the science of biogeography, i.e., study of the distribution of animals and plants among different habitats over time and space. BBO results presented by researchers are better than other optimization techniques like Ant Colony Optimization, Particle Swarm Optimization, Genetic Algorithm and Simulated Annealing [Baskar et al., 2005; Jones and Joines, 1997; Rattan et al., 2008; Venkatarayalu and Ray, 2003].

Originally, biogeography was studied by Alfred Wallace [A.Wallace, 2005] and Charles Darwin [Darwin, 1995] mainly as descriptive study. However, in 1967, the work carried out by MacAurthur and Wilson [MacArthur and Wilson, 1967] changed this view point and proposed a mathematical model for biogeography and made it feasible to predict the number of species in a habitat.

4.1.1 BBO Terminology

1. **Habitat** : The habitat is any *Island* that geographical isolated from other islands. Therefore, we use generic term habitat in place of island. In science of biogeography, a habitat is an ecological area that is inhabited or covered by particular plants or animal species. The candidate solutions for problem, in BBO, aer encoded as string as given by (4.1) and termed as habitats.

$$H = [SIV_1, SIV_2, ..., SIV_M] \tag{4.1}$$

2. **Habitat Suitability Index (HSI)** : HSI is a measure of the goodness or fitness of the solution which is represented as a habitat. Some habitats are more suitable for habitation than others.

3. **Suitability Index Variable (SIVs)** : Habitability is related to constituently factors of a habitat such as rainfall, temperature, diversity of vegetation etc. In BBO, there are parameters or variables encoded in a string format(refer 4.1) to make habitats.

4. **Migration** : Migration is a movement of species from one island or habitat to other for better comforts of living. In BBO, immigration and emigration terms are used that related to migration of species from one island to other. Immigration is the act of species passing or coming into a country for the purpose of permanent residence or in other words, immigration is the replacement of an old solution feature in an individual with a new solution feature from another individual. The solution feature comes from the contributing individual by way of emigration, whereas, Emigration is the act of species moving out of a home country or in other words, the sharing of a solution feature in BBO from one individual to another. The emigrating solution feature remains in the emigrating individual.

Following are some features of good habitats over poor habitats.

4.1.2 Features of High HSI habitats

1. Habitat with high HSI tend to have large number of species, while those with low HSI have small number of species.

2. Habitats with high HSI have low immigration rate because they are already nearly saturated with species.

3. They have high emigration rate; large number of species emigrate to neighboring habitats.

4. A good solution represent a habitat with a high HSI. Good solutions have more resistance to change than poor solutions.

4.1.3 Features of Low HSI habitats

1. Habitats with low HSI have high immigration rate and low emigration rate because of their sparse populations.
2. The immigration of new species to low HSI habitats may raise the HSI of the habitat.
3. As, HSI is proportional to biological diversity.
4. Poor solution represent a habitat with a low HSI. Poor solutions are more dynamic and accept a lot of new feature from good solutions.

4.2 BBO Characteristization

BBO characteristics tell about the relationship between immigration and emigration as shown in Fig 4.1. At the initial point, habitats with low HSI tend to have low emigration rate, μ, due to sparse population, however, they will have high immigration rate, λ. Suitability of habitats with low HSI is likely to increase with influx of species from other habitats having high HSI. However, if HSI does not increase and remains low, species in that habitat go extinct that leads to additional immigration. For sake of simplicity, it is safe to assume a linear relationship between HSI (or population) and immigration and emigration rates and same maximum emigration and immigration rates, i.e., $E = I$ as depicted graphically in Figure 4.1. On the other hand, the habitats with a high HSI tend to have a large population of its resident species, that is responsible for more probability of emigration (emigration rate, μ) and less probability of immigration (immigration rate, λ) due to natural random behavior of species. Immigration is the arrival of new species into a habitat or population, while emigration is the act of leaving one's native region.

For k-th habitat, i.e., HSI_k, values of emigration rate and immigration rate are given by (4.2) and (4.3).

$$\mu_k = E \cdot \frac{HSI_k}{HSI_{max} - HSI_{min}} \tag{4.2}$$

$$\lambda_k = I \cdot \left(1 - \frac{HSI_k}{HSI_{max} - HSI_{min}}\right) \tag{4.3}$$

The candidate solutions are referred as habitats and associated HSI is analogous to fitness in other EAs. The immigration of new species from high HSI to low HSI habitats may raise the HSI of poor habitats as good solutions have more resistance to change than poor

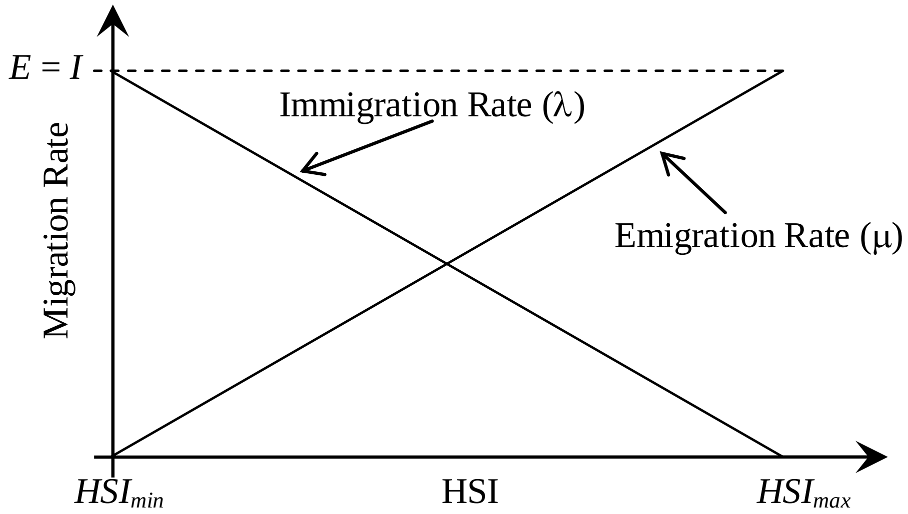

FIGURE 4.1: BBO Characteristics

solutions whereas poor solutions are more dynamic and accept a lot of new features from good solutions.

Each habitat in a population of size NP, in BBO, is represented by M-dimensional vector as H=[$SIV_1, SIV_2, \ldots, SIV_M$] where M is the number of SIVs (features) to be evolved for optimal HSI. HSI is the degree of acceptability that is determined by evaluating the cost/objective function, i.e., $HSI = f(H)$.

4.3 BBO Algorithms

Algorithmic flow of BBO involves two mechanisms, i.e., (i) migration and (ii) mutation, these are discussed in the following subsections.

4.3.1 Migration

Migration is a probabilistic operator that improves HSI of poor habitats by sharing features from good habitats. During Migration, ith habitat, H_i where ($i = 1, 2, \ldots, NP$) use its immigration rate, λ_i, given by (4.3) to probabilistically decide whether to immigrate or not. In case immigration is selected, then the emigrating habitat, H_j, is found probabilistically based on emigration rate, μ_j, given by (4.2). The process of migration is completed by copying values of SIVs from H_j to H_i at random chosen sites, i.e., $H_i(SIV) \leftarrow H_j(SIV)$. The pseudo code of migration is depicted in Algorithm 1.

Migration may lead to same types of habitats because of copying SIVs or features from habitat having high HSI to low HSI habitat. To reduce the number of same types of habitats and

Algorithm 1 Standard Pseudo Code for Migration

```
for i = 1 to NP do
    Select H_i with probability based on λ_i
    if H_i is selected then
        for j = 1 to NP do
            Select H_j with probability based on μ_j
            if H_j is selected
                Randomly select a SIV(s) from H_j
                Copy them SIV(s) in H_i
            end if
        end for
    end if
end for
```

make BBO convergence faster, migration variants are introduced. BBO has three migration variants discussed in following subsections:

1. Immigration Refusal
2. Blended Migration
3. Enhanced Biogeography-Based Optimization

4.3.1.1 Immigration Refusal

In BBO, if a habitat has high emigration rate, i.e, the probability of emigrating to other habitats is high and the probability of immigration from other habitats is low. However, the low probability does not mean that immigration will never happen. Once in a while, a highly fit solution will migrate solution features from a low-fit solution to high-fit solution. This may degrade the high fitness of the habitats which receives the immigrants. If high fitness of solution decrease after receiving the immigrants, then immigrating habitat may refuse the immigrating solution features. This BBO variants with conditional migration is termed as Immigration Refusal [Du et al., 2009] and is depicted in Algorithm 2.

4.3.1.2 Blended Migration

Blended migration operator is a generalization form of the standard BBO migration operator and inspired by blended crossover in GAs [McTavish and Restrepo, 2008]. In blended migration, a solution feature of solution H_i is not simply replaced by a feature from solution H_j that happened in standard BBO migration operator. Instead, a new solution

Algorithm 2 Pseudo Code for Immigration Refusal

```
for i = 1 to NP do
    Select H_i with probability based on λ_i
    if H_i is selected then
        for j = 1 to NP do
            Select H_j with probability based on μ_j
          if H_j is selected
            if ((fitness(H_j ) > (fitness(H_i ))
                apply migration
            end if
          end if
        end for
    end if
end for
```

feature, in blended migration, solution is comprised of two components, the migration of a feature from another solution and the migration of a feature from itself, i.e., $H_i(SIV) \leftarrow \alpha.H_i(SIV) + (1-\alpha).H_j(SIV)$. Where α is a random number between 0 and 1. The pseudo code of blended migration is depicted Algorithm 3.

Algorithm 3 Pseudo Code for Blended Migration

```
for i = 1 to NP do
    Select H_i with probability based on λ_i
    if H_i is selected then
        for j = 1 to NP do
            Select H_j with probability based on μ_j
            if H_j is selected
                H_i(SIV) ← α.H_i + (1 − α).H_J
            end if
        end for
    end if
end for
```

4.3.1.3 Enhanced Biogeography-Based Optimization (EBBO)

Standard BBO migration operator creates the duplicate solutions which decreases the diversity of the algorithm. To prevent the harmful over similarity among the solutions, clear duplicate operator with random mutation is utilized, i.e., EBBO [Pattnaik et al., 2010], depicted in Algorithm 4, increases the exploration ability. In EBBO, clear duplicate operator is integrated in basic BBO for faster convergence.

Algorithm 4 Pseudo Code for Enhanced Biogeography-Based Optimization

```
for i = 1 to NP do
    Select H_i with probability based on λ_i
    if H_i is selected then
      for j = 1 to NP do
          Select H_j with probability based on μ_j
          if H_j is selected
            if ((fitness(H_j ) == (fitness(H_i ))
             eliminate duplicates
            end if
          end if
      end for
    end if
end for
```

4.3.2 Mutation

Mutation is another probabilistic operator that randomly modifies the values of some randomly selected SIVs that is intended for exploration of search space for better solutions by increasing the biological diversity in the population. The pseudo code of migration is depicted in Algorithm 5.

Algorithm 5 Pseudo Code for Mutation

```
for n = 1 to NP do
   for j = 1 to M do
        Select H_j(SIV) with mRate
        If H_j(SIV) is selected then
            Replace H_j(SIV) with randomly generated SIV
        end if
   end for
end for
```

In this thesis, following three mutation operators, are experimented for performance of BBO algorithm.

4.3.2.1 Flat Mutation Rate

In this case of mutation all SIVs of all habitats is considered as one pool where we randomly pick some percent of SIVs and modify their values. Here, no specific considerations have been paid to poor performing and good performing habitats. BBO is a swarm based stochastic search algorithm where mutation is responsible for the new search locations in the hyper search-space. However, no mutation is experimented that leads to premature convergence where all the habitats convergence to same SIVs and HSI, after some iterations, due to lack of exploration of new search locations. Five cases viz., 0%, 5%, 10%, 15% and 20% mutation rates are investigated for over all performance and progress of BBO as depicted in Algorithm 6.

Algorithm 6 Pseudo Code for Flat Mutation

```
switch (Mutation Rate)
    case 1: mRate = 0%
    case 2: mRate = 5%
    case 3: mRate = 10%
    case 4: mRate = 15%
    case 5: mRate = 20%
end switch

for n = 1 to NP do
  for j = 1 to M do
      Select H_j(SIV) with mRate
      If H_j(SIV) is selected then
         Replace H_j(SIV) with randomly generated SIV
      end if
  end for
end for
```

4.3.2.2 High Mutation on Mediocre Habitats

Habitats with high HSI are emigrating towards habitats with low HSI, i.e., habitats having high and low HSI, participate, probabilistically more in migration as compare to habitats with mediocre HSI. Here, increased mutation rate is investigated on habitats those are, probabilistically, participating less in migration. The mutation rate, $mRate$, for k-th habitats is calculated as (4.4)

$$mRate_k = C \cdot min(\mu_k, \lambda_k) \tag{4.4}$$

Where C is the constant that is experimented with four values, i.e., 1, 2, 3 and 4 results are presented as depicted in Algorithm 7.

Algorithm 7 Pseudo Code for High Mutation on Mediocre Habitats

$mRate_k = C \cdot \min(\mu_k, \lambda_k)$ where C = 1, 2, 3, 4

```
for n = 1 to NP do
   for j = 1 to M do
        Select Hj(SIV) with mRate_k
        If Hj(SIV) is selected then
           Replace Hj(SIV) with randomly generated SIV
        end if
   end for
end for
```

4.3.2.3 Increasing Mutation Rate with Iterations

The increasing mutation rate for investigation is also considered, with the objective of exploring search space in smaller step sizes during initial stage and bigger step sizes during ending iterations as depicted in Algorithm 8.

Algorithm 8 Pseudo Code for Increasing Mutation Rate with Iterations

$$mRate = \frac{Iteration\ No.}{Maximum\ Iterations}$$

```
for n = 1 to NP do
   for j = 1 to M do
        Select Hj(SIV) with mRate
        If Hj(SIV) is selected then
           Replace Hj(SIV) with randomly generated SIV
        end if
   end for
end for
```

4.4 Conclusion

Here, in this chapter, philosophy of biogeography and inspired algorithms with different variant are discussed. These migration variants along with different mutation operators are experimented in convergence on application on optimizing Yagi-Uda antenna design.

CHAPTER 5

IMPLEMENTATION

5.1 Introduction

Designing a Yagi-Uda antenna is a complex optimization problem. The goal of the design process is to determine constructional detail of the antenna that meets some desired performance characteristics. A few of the characteristics that define an antenna performance are SLL, beamwidth, bandwidth, F/B ratio, size, gain, and input impedance. There are no simple formulas for designing Yagi-Uda antennas due to the complex relationships between physical parameters such as element length, spacing, and diameter, and performance characteristics such as gain and input impedance. With an N element Yagi-Uda antenna, there are $2N - 1$ parameters, i.e., N wire lengths and $N - 1$ spacings. To evolve optimal antenna design BBO and variants are experimented and investigated for faster convergence. Visual Studio is used as to create BBO algorithms in C++, whereas NEC2 is used to evaluate all antenna designs for gain, impedance, etc.

5.2 Implementational Requirements

To evolve the design of Yagi-Uda antenna using BBO requires Visual Studio for C++ programming and NEC2 to evaluate antenna design based on method of moments. Their brief introduction present in following subsections :

5.2.1 Visual Studio

Visual Studio is a complete set of development tools for building ASP.NET Web applications, XML Web Services, desktop applications, and mobile applications. Visual Basic, Visual C++, Visual C ♯, all use the same integrated development environment (IDE), which allows them to share tools and facilitates in the creation of mixed-language solutions. In addition, these languages leverage the functionality of the .NET Framework, which provides access to key technologies that simplify the development of ASP Web applications and XML Web Services.

Visual studio has following features :

1. It consists of three sets of tools:
   (a) Inter operability support
   (b) Programming tools support
   (c) Automated conversion from Java language source code to C ♯
2. Integrated IE Browser
3. HTML/XML Editors
4. Macros/Macro Explorer.
5. Solution Explorer
6. Tabbed Documents
7. Dynamic Help
8. Common Forms Editor
   (a) VB.NET
   (b) Visual C++
   (c) Visual C ♯

Visual C++ programming interface is used from visual studio to create BBO algorithms. Here, *system* command is used to call nec2.exe into C++ programming environment.

5.2.2 Numerical Electromagnetics Code

The old version of Numerical Electromagnetics code, i.e., NEC-2 is a computer code that runs through command line for analyzing the electromagnetic response of an arbitrary structure consisting of wires and surfaces in free space or over a ground plane. The analysis is accomplished by the numerical solution of integral equations for induced currents. The excitation may be an incident plane wave or a voltage source on a wire, while the output may include current and charge density, electric or magnetic field in the vicinity of the structure, and radiated fields.

The Numerical Electromagnetics Code (NEC-2) is a user-oriented computer code for analysis of the electromagnetic response of antennas and other metal structures. It is built around the numerical solution of integral equations for the currents induced on the structure by sources or incident fields. This approach avoids many of the simplifying assumptions required by other solution methods and provides a highly accurate and versatile tool for electromagnetic analysis.

5.2.3 How to use NEC

First of all, create a text file with *.nec* extension and write commands with parameters to create geometry and radiation pattern of antenna. Commands to create geometry and radiation pattern of antenna are as follow :

1. **Comment Cards (CM, CE)** : The data-card deck for a run must begin with one or more comment cards which can contain a brief description and structure parameters for the run. The cards are printed at the beginning of the output of the run for identification only and have no effect on the computation. Any alphabetic and numeric characters can be punched on these cards.

2. **Scale Structure Dimensions (GS)** : It is used to scale all dimensions of a structure by a constant.

3. **Wire Specification (GW)** : It is used to a string of segments to represent a straight wire.

4. **End of Run (EN)** : It is used to indicate to the program the end of all execution.

5. **Excitation (EX)** : It is used to specify the excitation for the structure. The excitation can be voltage sources on the structure, an elementary current source, or a plane wave incident on the structure.

6. **Frequency (FR)** : specify the frequency (frequencies) in Mega Hertz (MHZ).

7. **Ground Parameters (GN)** : It is used to specify the relative dielectric constant and conductivity of ground in the vicinity of the antenna. In addition, a second set of ground parameters for a second medium can be specified, or a radial wire ground screen can be modeled using a reflection coefficient approximation.

8. **Radiation Pattern (RP)** : It is used to specify radiation pattern sampling parameters and to cause program execution. Options for a field computation include a radial wire ground screen, a cliff, or surface-wave fields.

After create a text file, it passes through the NEC2.exe as a input file. Then it create a output text file with .OUT extension contains all characteristics of antenna like frequency, wavelength, input impedance, gain and run time.

5.3 Implementation Algorithm

Design of Yagi-Uda antenna is done in two algorithm, first is Fitness Algorithm to design an antenna without any optimization technique and second is BBO algorithm that used to apply BBO technique for optimized design of Yagi-Uda antenna.

5.3.1 Fitness Algorithm

Followings are to step for fitness evaluation in NEC and C++ programming environment.

1. In first step, create a input text file with .nec extension.

2. In second step, add all commands and parameters to design particular antenna with specific parameters.

3. If file is created, then input file with .nec extension pass to nec2.exe, otherwise create correct input file as shown in fitness algorithm flow chart Fig 5.1 .

4. In next step, output text file is generated with .out extension.

5. Read all characteristics of an antenna that is required for optimization.

5.3.2 BBO Algorithm

Algorithmic flow for BBO described below step wise.

1. In first step, identify SIVs and their universe of discourse (UODs).

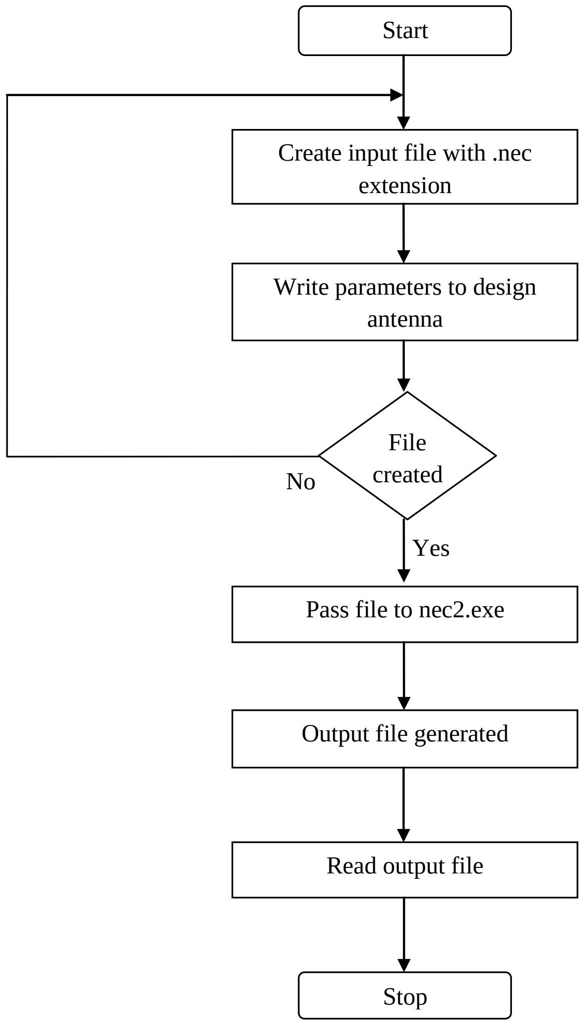

FIGURE 5.1: Flow Chart of Fitness Algorithm

2. In next step, create a habitat (string) as shown in flow chart of BBO algorithm in Fig 5.2.

3. Then generate a random population.

4. After create a random population, check maximum iteration is done or not. If yes, select a best habitat and stop the BBO algorithm. If no, then evaluate fitness.

5. If fitness is achieved then select a best habitat and stop the BBO algorithm. If no, then apply migration process of BBO.

6. If fitness is achieved then select a best habitat and stop the BBO algorithm. If no, then apply mutation process of BBO.

7. If fitness is achieved then select a best habitat and stop the BBO algorithm. If no, then repeat the process from maximum iteration as shown in Fig 5.2.

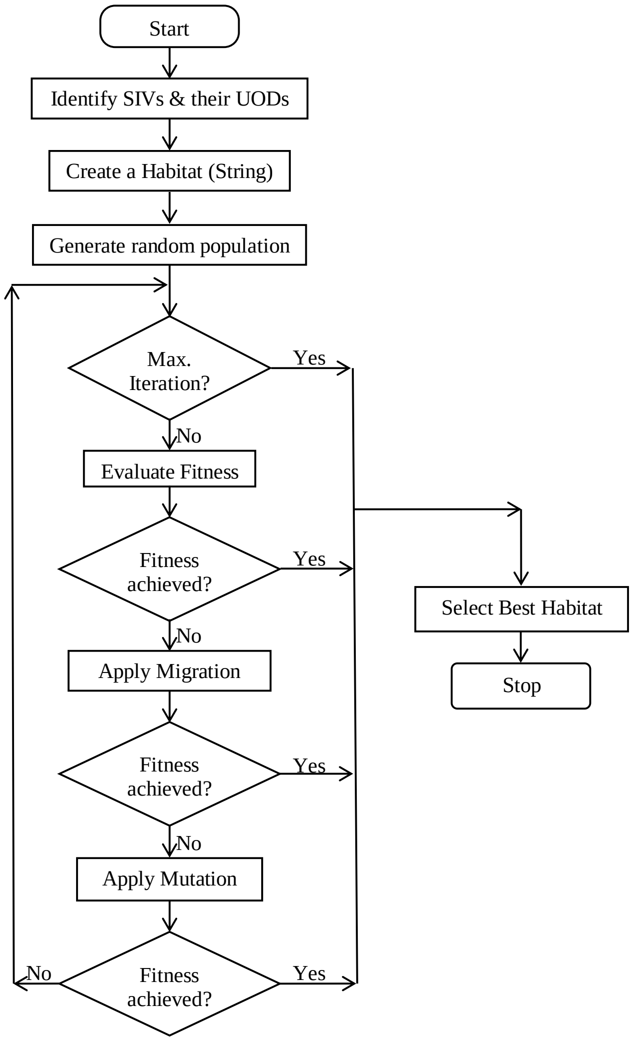

FIGURE 5.2: Flow Chart of BBO Algorithm

5.4 Conclusion

To design Yagi-Uda antenna Visual C++ and NEC-2 is very useful and BBO optimization technique is used to create optimized design of Yagi-Uda antenna with migration and mutation process.

CHAPTER 6

SIMULATION RESULTS

As already discussed, design of Yagi-Uda antenna is not a easy task due to large number of geometrical parameters, i.e., wire lengths and spacings in between them, and their complex relationship for gain, impedance and SLL, etc. Here, we use C++ programming platform for coding of BBO algorithms and NEC2, antenna modeling software, to determine antenna characteristics like gain and impedance etc. This chapter presents average simulation results of 10 monte-carlo evolutionary run to conclude convergence performance of stochastic BBO algorithms.

6.1 Introduction

BBO is one of stochastic search algorithms therefore, require multiple run to present fair analysis. Here, BBO and its variants are made to run for 200 iterations with 30 habitats in each case. Every habitats involves 11 SIVs for evolution of six-wire Yagi-Uda antenna.

6.2 Simulation Platform

Here, Six-wire Yagi-Uda antenna designs are optimized for gain using BBO and variants. Average of 10 monte-carlo evolutionary runs for each migration and mutation operators are presented here for fair comparative study of stochastic algorithm variants.

The C++ programming platform is used for coding of BBO algorithm, whereas, a NEC2 [Burke and Poggio, 1981] is used for evaluation of antenna designs based on method of moments. Each potential solution in BBO is encoded as vector with 11 SIVs as given by (1.1). The universe of discourse for the search of optimum values of wire lengths and wire spacings are $0.40\lambda - 0.50\lambda$ and $0.10\lambda - 0.45\lambda$, respectively, however, cross sectional radius and segment sizes are kept same for all elements, i.e., 0.003397λ and 0.1λ respectively, where λ is the wavelength corresponding to frequency of operation, i.e, 300 MHz. Excitation is applied to the middle segment of driven element and location of middle segment of the reflector element is always kept at $x = 0$.

In this chapter, Convergence performance of BBO to optimize gain of Yagi-Uda antenna with migration variants, i.e., standard migration, blended migration, immigration refusal and EBBO are investigated with different mutation options, i.e., flat mutation, high mutation on mediocre habitats and increasing mutation.

In flat mutation rate, 0%, 5%, 10%, 15% and 20% mutation rate are experimented by each migration variants. High mutation on mediocre habitats with $C = 1, 2, 3, 4$ are experimented by standard migration and its variants.

6.3 Simulation Results

The evolutionary simulation results for convergence performance are presented, systematically, one by one as follows:

6.3.1 Standard Migration

Standard migration is experimented with mutation operators, i.e. flat mutation, high mutation on mediocre habitats and increasing mutation, and convergence performance discussed as follows:

6.3.1.1 Flat Mutation

Standard migration are experimented with 0%, 5%, 10%, 15% and 20% flat mutation rate. Without mutation rate, i.e., 0%, means there is no mutation, only standard migration participate in convergence performance and give constant performance as shown in Figure 6.1. It can be observed that with standard migration, flat mutation with 15% and 20% give best convergence performance over other mutation rates.

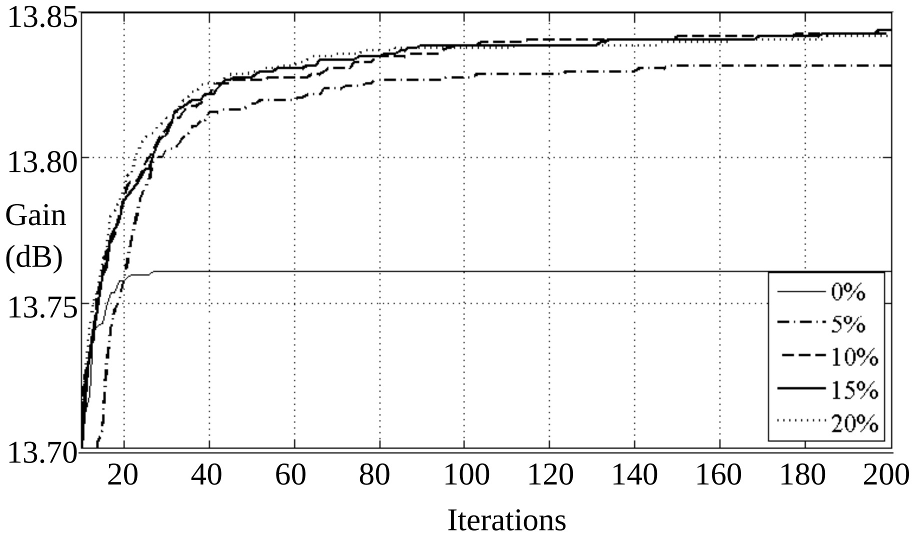

FIGURE 6.1: Convergence Performance of Standard Migration with Flat Mutation

6.3.1.2 High Mutation on Mediocre Habitats

Habitats either with high HSI or low HSI are actively involved in migration, however, habitats with mediocre HSI are comparatively less participating in migration. In this section, convergence performance of standard migration is investigated with high mutation on mediocre habitats, i.e., $C = 1, 2, 3, 4$. Here, $C = 3$ give the best convergence performance than other options and $C = 2$ give mediocre performance between $C = 3$ and $C = 1$, as depicted in Figure 6.2.

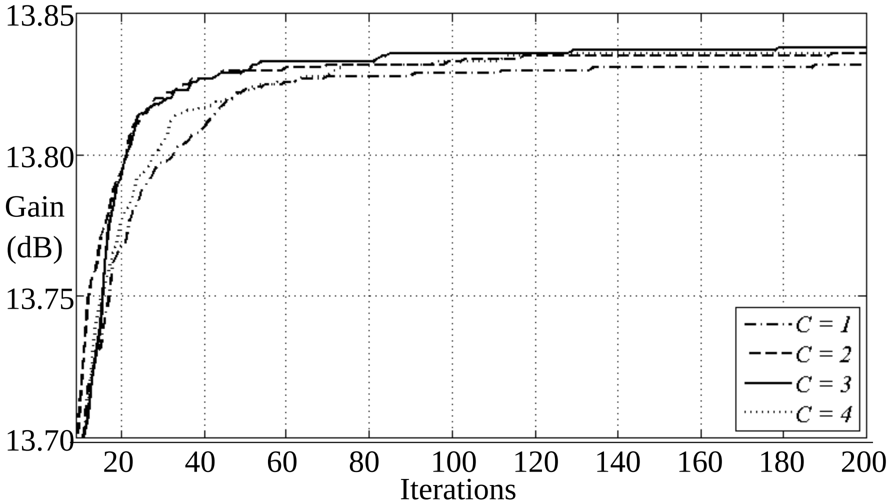

FIGURE 6.2: Convergence Performance of Standard Migration with High Mutation on Mediocre Habitats

6.3.1.3 Overall Comparison Among Best Mutation Options

In overall convergence performance of standard migration, best convergence performance in flat mutation, high mutation on mediocre habitats and increasing mutation, discussed in section 6.3.1.1 and 6.3.1.2, are depicted in Figure 6.3

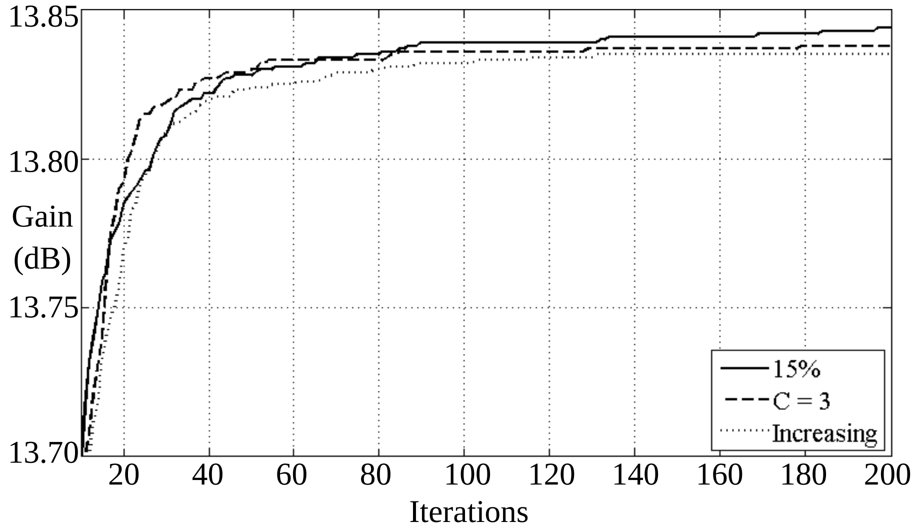

FIGURE 6.3: Overall Convergence Progress of Standard Migration among Best Mutation Options

6.3.2 Immigration Refusal

Sometimes, SIVs from poor habitat tend to migrate to habitat with high HSI. This may lead to degradation of better performing habitat. In Immigration Refusal variant [Du et al., 2009] of BBO, such immigration are refused to prevent degradation of good habitat. This modification into original BBO algorithm has shown improved performance and, therefore, experimented here with different mutation options. These are discussed below one by one.

6.3.2.1 Flat Mutation Rates

Convergence performance of immigration refusal are investigated with 0%, 5%, 10%, 15% and 20% flat mutation rate. Mutation rate of 15% and 20% give comparatively better convergence performance among other flat mutation options, as depicted in Figure 6.4.

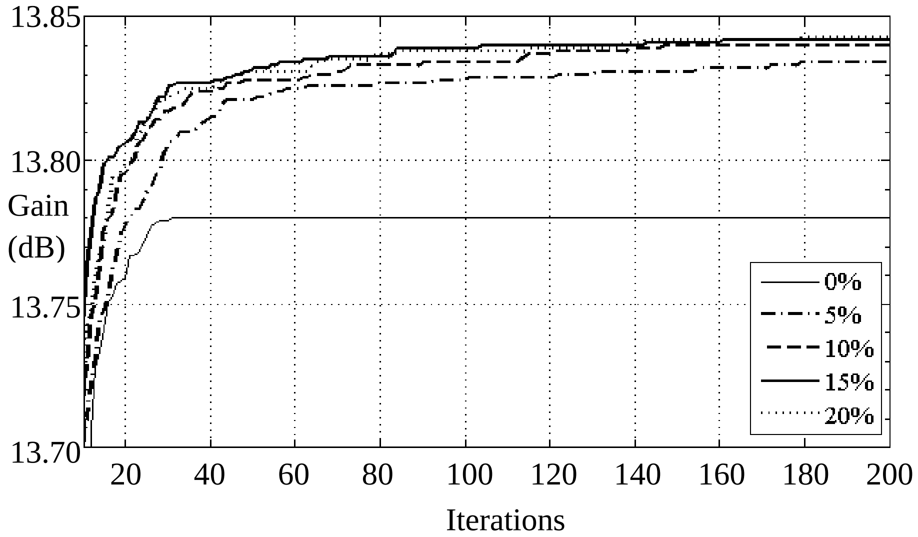

FIGURE 6.4: Convergence Performance of Immigration Refusal with Flat Mutation

6.3.2.2 High Mutation on Mediocre Habitats

Here, convergence performance of immigration refusal is investigated higher mutation rates on mediocre habitats ($C = 1, 2, 3, 4$), those are probabilistically less participating in migration, i.e., exploiting available search space. Mutation rate determined using 4.4 with $C = 4$ give best convergence performance among all mutation options, as depicted in Figure 6.5.

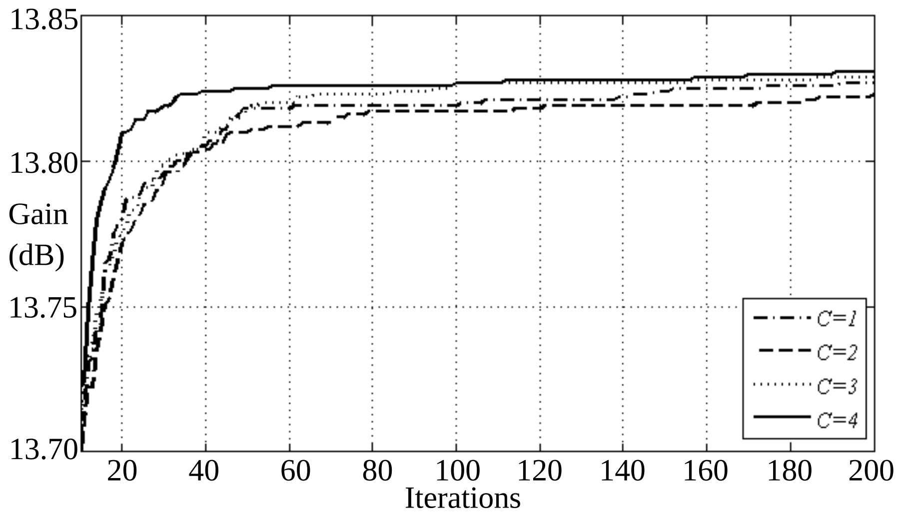

FIGURE 6.5: Convergence Performance of Immigration Refusal with High Mutation on Mediocre Habitats

6.3.2.3 Overall Comparison among Best Mutation Operators

In this section, best best performing mutation with immigration refusal, i.e., flat mutation of 15% and high mutation on mediocre habitats, i.e., $C = 4$ are compared with increasing mutation rates(borrowed from GA) for overall evaluation. It can be observed form Figure 6.6 that immigration refusal with 15% flat mutation rate give the best convergence performance among all mutation option, along with immigration refusal variant of BBO.

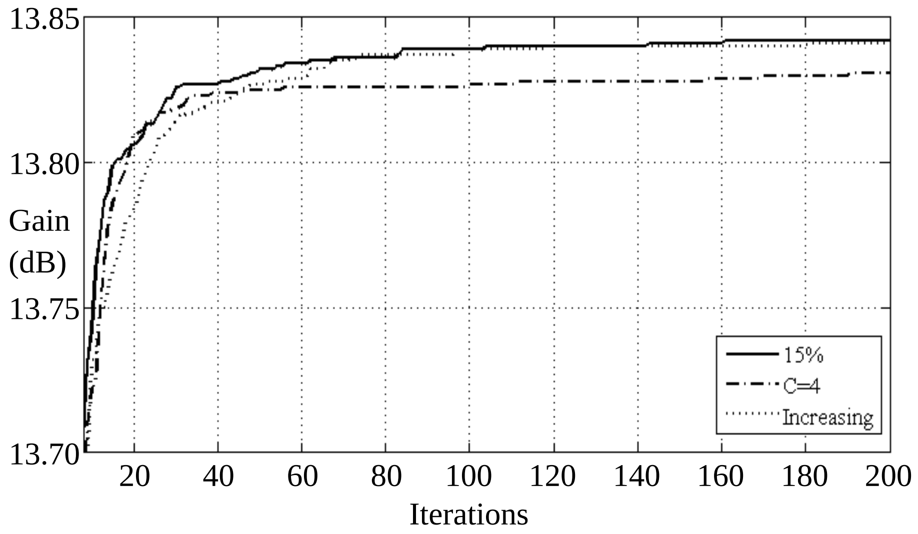

FIGURE 6.6: Overall Convergence Progress of Immigration Refusal among Best Mutation Options

6.3.3 Blended Migration

Blended migration is inspired form crossover operator in GAs in which a solution feature of immigrating solution is not simply replaced by a feature from emigrating solution that happened in standard BBO migration operator. However, a new solution feature, in blended migration, solution is comprised of two components, the migration of a feature from another solution and the migration of a feature from itself, given by 6.1.

$$H_i(SIV) \leftarrow \alpha.H_i(SIV) + (1-\alpha).H_j(SIV) \tag{6.1}$$

Blended migration is experimented here with flat mutation, high mutation on mediocre habitats and increasing mutation, discussed as follows :

6.3.3.1 Flat Mutation

Convergence performance of blended migration is experimented with flat mutation rate of 0%, 5%, 10%, 15% and 20%. Blended migration with 10% flat mutation rate depicts best convergence performance among other mutation options. Mutation rate of 0% leads to poorest performance as no exploration of new solution feature occurs. Mutation rate 5% and 15% initially give slow convergence and , however, give better results as the iteration number increases, depicted in Figure 6.7.

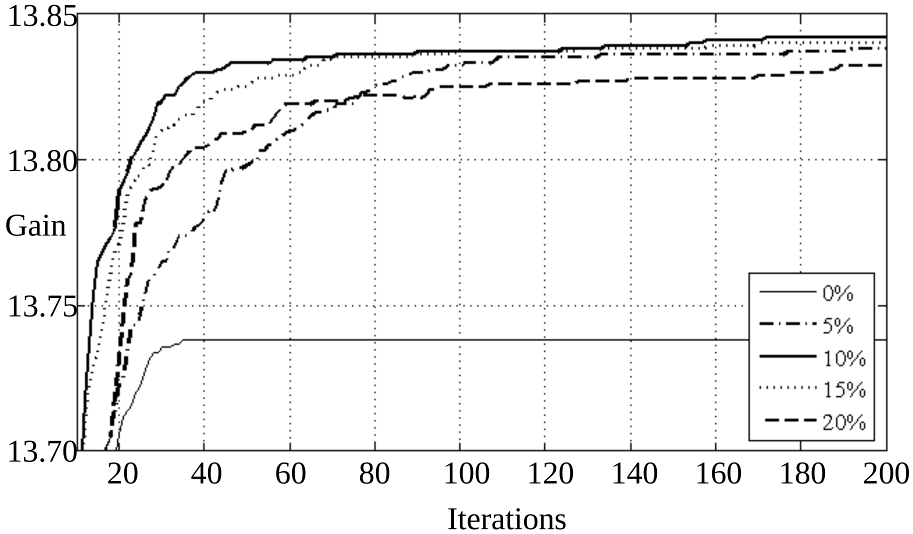

FIGURE 6.7: Convergence Performance of Blended Migration with Flat Mutation

6.3.3.2 High Mutation on Mediocre Habitats

High mutation on mediocre habitats given by 4.4, for $C = 1, 2, 3$ and 4 with blended migration operator is experimented here. With high number of iteration all are performing very close to each other. Simulation results shows (refer Figure 6.8) that mutation rate with $C = 3$ and $C = 4$ give comparatively better convergence performance, however, $C = 4$ shows slow convergence at initial stage.

6.3.3.3 Overall Comparison among Best Mutation Operators

Here best performing flat mutation rate of 10%, high mutation on mediocre habitats, i.e., $C = 3$ is plotted in Figure 6.9 along with increasing mutation rate. Blended migration with 10% flat mutation rate give marginally better convergence performance, whereas, mutation with $C = 3$ and increasing mutation give comparative and almost equal convergence performances.

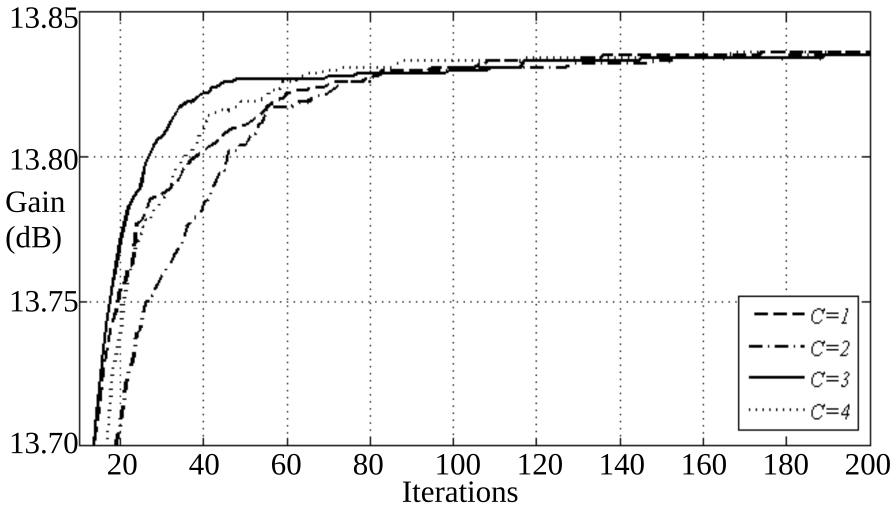

FIGURE 6.8: Convergence Performance of Blended Migration with High Mutation on Mediocre Habitats

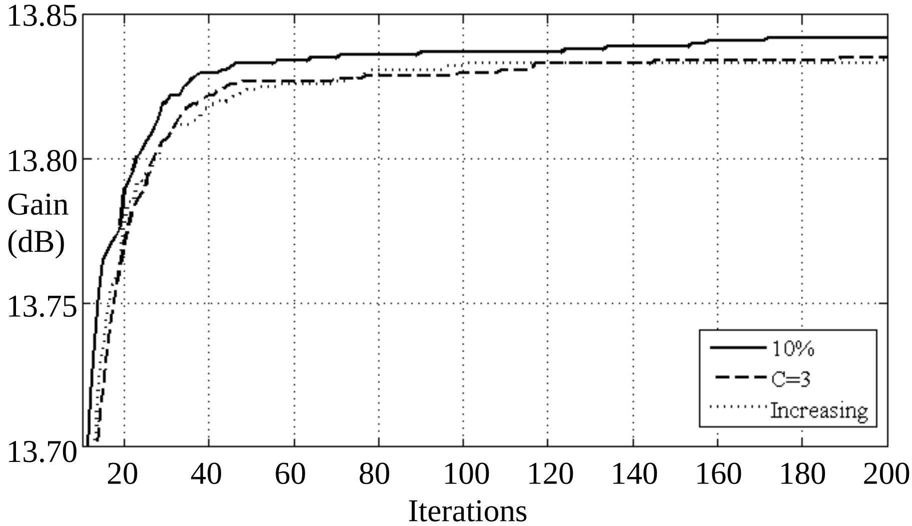

FIGURE 6.9: Overall Convergence Progress of Blended Migration among Best Mutation Options

6.3.4 Enhanced Biogeography-Based Optimization

Standard BBO migration operator creates duplicate solutions which decreases diversity among solutions and consequently leads to prematured convergence. To prevent this duplicate solutions are replaced with new randomly generated solutions. This BBO variant has shown performance improvement and known as Enhanced BBO, in short, EBBO. Convergence performance of EBBO also is investigated with flat mutation, high mutation on mediocre habitats and increasing mutation.

6.3.4.1 Flat Mutation

EBBO is experimented with 0%, 5%, 10%, 15% and 20% flat mutation rate. EBBO with 20% mutation rate give fast convergence in initial iterations, however, 5% flat mutation yields poor solution initially and laterally it improves significantly as shown in Figure 6.10. EBBO without mutation also give better result as compared to 0% mutation in all migration options due to duplicate solutions are randomly mutate that increase the diversity of the algorithm, as depicted in Figure 6.10.

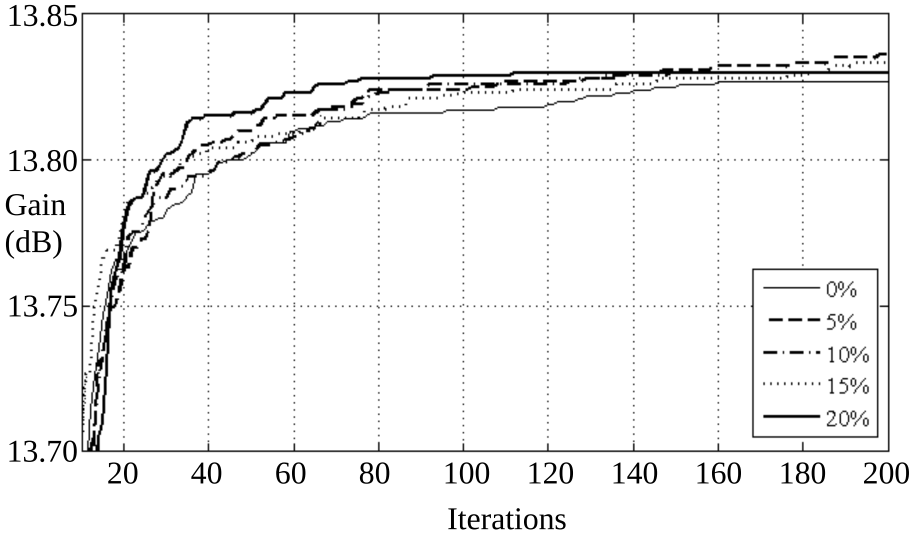

FIGURE 6.10: Convergence Performance of EBBO with Flat Mutation

6.3.4.2 High Mutation on Mediocre Habitats

EBBO is experimented here with high mutation on mediocre habitats, i.e., $C = 1, 2, 3, 4$. All mutation options are performing very close to each other at initial stage. With increase of number of iterations, simulation result shows that $C = 4$ give marginally better performance over others, as depicted in Figure 6.11.

6.3.4.3 Overall Comparison among Best Mutation Options

Here, EBBO with best performing flat mutation rate of 20%, high mutation on mediocre habitats, i.e., $C = 4$ is plotted in Figure 6.12 along with increasing mutation rate. Flat mutation rate of 20% give better convergence performance during initial iterations, as number of iterations increased, $C = 4$ converge faster as compare to flat mutation of 20%. Increasing mutation rate ,initially, bear poor performance and give better results, as number of iterations increased.

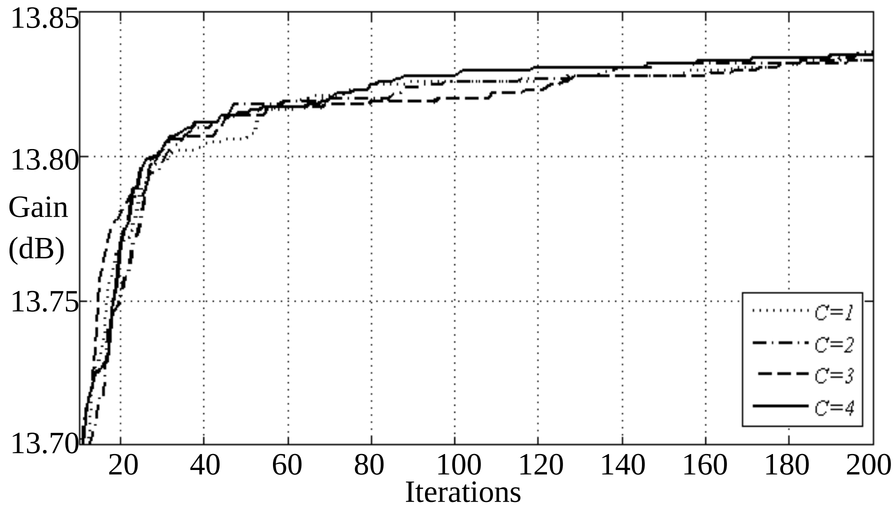

FIGURE 6.11: Convergence Performance of EBBO with High Mutation on Mediocre Habitats

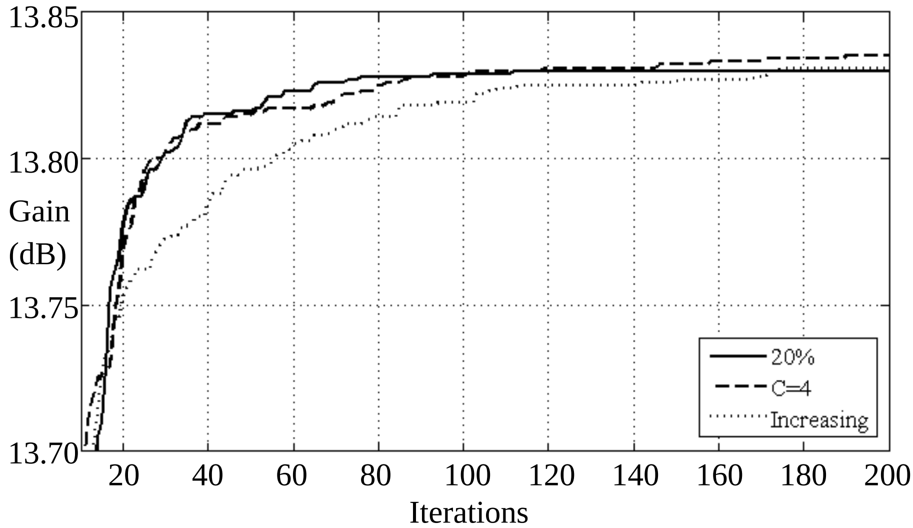

FIGURE 6.12: Overall Convergence Progress of EBBO among Best Mutation Options

6.3.5 Simulation Result Table

During simulations, migration variants, i.e., standard migration, immigration refusal, blended migration and EBBO are experimented with mutation variants, i.e., flat mutation rete, high mutation on mediocre habitats and increasing mutation rate to optimize gain of Yagi-Uda antenna. Average gain of Yagi-Uda antenna obtained during simulations are tabulated in Table 6.1. Standard migration is experimented with mutation variant, flat mutation rate of 15% and $C = 4$ give best average gain of 13.844 dB, however, $C = 3$ give better convergence performance. Immigration refusal migration variant is experimented with mutation variant, flat mutation rate of 15% give better convergence performance over other mutation options, whereas, flat mutation rate of 20% give best average gain of 13.843 dB. Convergence performance of blended migration is investigated with mutation variant and flat mutation rate of 10% give better performance and best average gain of 13.842 dB among all mutation options. EBBO is experimented with mutation variant, flat mutation rate of 20% give better convergence results, however, flat mutation rate of 5% and $C = 2$ give best average gain of 13.836 dB, as tabulated in Table 6.1.

TABLE 6.1: The best average gain obtained during simulations

Migration	Flat Mutation Rate					High Mutation on Mediocre Habitats				Increasing Mutation Rate
	0%	5%	10%	15%	20%	C=1	C=2	C=3	C=4	
Standard Migration	13.762	13.832	13.843	**13.844**	13.842	13.762	13.832	13.843	**13.844**	13.842
Immigration Refusal	13.780	13.834	13.840	13.842	**13.843**	13.827	13.823	13.829	13.831	13.841
Blended Migration	13.738	13.838	**13.842**	13.840	13.832	13.836	13.835	13.835	13.836	13.834
Enhanced BBO	13.827	**13.836**	13.830	13.833	13.830	13.833	**13.836**	13.833	13.835	13.831

6.4 Conclusion

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

7.1 Introduction

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