People's Democratic Republic of Algeria

Ministry of Higher Education and Scientific Research

University M'Hamed BOUGARA – Boumerdes

Institute of Electrical and Electronic Engineering

Department of Electronics

Final Year Project Report Presented in Partial Fulfilment of the Requirements for the Degree of

MASTER

In **Telecommunication**

Option: **Telecommunications**

Title:

Design of Elliptic Antenna arrays using Gray wolf optimization

Presented by:

- **TRAIKIA Oussama**

Supervisor:

Dr.A.RECIOUI

Registration Number:………../2018

ABSTRACT

In this work, Grey Wolf Optimization (GWO) is applied to the elliptical and concentric elliptical antenna arrays to minimize the Side lobe and to improve the directivity. GWO is a nature-inspired meta-heuristic algorithm inspired by the social hierarchy and hunting behavior of grey wolves. The obtained optimal values result in a good reduction of the side lobe level for the elliptical and concentric elliptical antenna arrays with an enhancement in the directivity. This makes the designed arrays of practical use in the communication systems.

DEDICATION

First and foremost, we thank ALLAH, for helping us to finish this modest work. It is our belief in him that helped us persevere at times when it seemed impossible to go on.

I would like to dedicate this work:

To My Mother and Father,

To my brothers and sister

And

All dear friends

Whoever helped to achieve this work.

ACKNOWLEDGMENT

I would like to thank Mr. A. Recioui for all the help he offered to me though the project until it was finished.

TABLE OF CONTENTS

GENERAL INTRODUCTION……………………………………………………………1

CHAPTER ONE: GENERALITIES ABOUT ANTENNA ……………………....3

1.1.Introduction 3

1.2. Definition of antenna 3

1.3. Antenna Glossary: 4

1.3.1. The radiation pattern 4

1.3.2. Directivity 5

1.3.3. Beam width 6

1.3.4. Polarization 6

1.3.5. Gain 7

1.3.6. Antenna efficiency 7

1.4. Types of antennas 8

1.5. Antenna arrays 8

1.5.1. Types of antenna arrays 9

1.5.2. Elliptic antenna array 10

1.5.3. Concentric Elliptic antenna array 11

1.6. Conclusion………………..………………………………..……………………11

CHAPTER TWO: GRAY WOLF OPTIMIZATION ……………………………12

2.1. History of Optimization 12

2.2. Optimization 12

2.2.1. The Optimization Problem 13

Objective Function 13

Variables 13

Statement of an optimization problem 13

2.3. Classification of Optimization Problems 14

2.3.1. Based on existence of constraints 14

2.3.2. Based on the nature of the equations involved 14

2.3.3. Based on the number of objective functions 15

2.4. Advanced Optimization Techniques 15

TABLE OF CONTENTS

2.4.1. The genetic algorithms 15
2.4.2. The Simulated annealing 15
2.4.3. The particle swarm optimization 16
2.4.4. Ant colony optimization 16
2.4.5. Neural-network-based methods 16
2.5. Grey Wolf Optimizer (GWO) 17
2.5.1. Inspiration 17
2.5.2. Mathematical model and algorithm 19
Social hierarchy 19
Encircling prey 19
Hunting 19
Attacking prey (exploitation) 20
Search for prey (exploration) 20
2.5.3. Flowchart of main GWO Algorithm 23
2.6. Algorithm Testing with Benchmark Functions 24
2.6.1. De Jong's function 1 24
2.6.2. Rotated hyper-ellipsoid function 25
2.6.3. Function Three 25
2.7. Conclusion 26
CHAPTER THREE: ELLIPTIC ANTENNA ANALYSIS 27
3.1. Problem specifications 27
3.2. The effect of eccentricity 27
3.2.1.Case one 28
3.2.2.Case two 28
3.2.3.Case three 29
3.2.4 Results and Discussion 30
3.3. GWO algorithm 30
3.3.1. Problem Formulation 30
3.3.2. Parameter variations 30
3.3.3. Optimization of simple elliptic antenna array 31
Optimization of SLL only 31
Optimization of DIR only 32

TABLE OF CONTENTS

Optimization of both SLL and DIR 32

3.3.4. Results and Discussion ……………………………………………………….33

3.4. Conclusion.. 34

CHAPTER FOUR: CONCENTRIC ELLIPTIC ANTENNA ANALYSIS…….35

4.1. Introduction 35

4.2. GWO algorithm.. 35

4.2.1Parameter variations 35

4.2.2 Problem Formulation 36

4.3. Concentric Elliptic antenna array.. 36

Optimization of only SLL... 36

Optimization of only DIR... 37

Optimization of both SLL and DIR 38

4.4. Results and discussion.. 38

4.5. Comparison.. 39

Comment.. 39

4.6. Conclusion... 39

GENERAL CONCLUSION………...40

References…………………………………………………………………………41

LIST OF FIGURES

Figure 1.1: A simplified model of an antenna 4
Figure 2.2: Coordinate system for antenna pattern analysis... 5
Figure 1.3: Geometry of an elliptical antenna array (EAA) with isotropic radiators...10
Figure 1.4: Geometry of concentric elliptic array……………..………..……....…11
Figure 2.1: Hierarchy of grey wolf (dominance decreases from top down). 17
Figure 2.2: Attacking prey versus searching for prey. 21
Figure 3.3: Flowchart of the grey wolf optimization algorithm. 23
Figure 2.4: convergence to the global minima after 500 iterations. 24
Figure 2.5: convergence to the global minima after 500 iterations. 25
Figure 2.6: convergence to the global minima after 500 iterations. 26
Figure 3.1: pattern of EAA with eccentricity e=0.5. 28
Figure 3.2: pattern of EAA with eccentricity e=0.86. 29
Figure 3.3: pattern of EAA with eccentricity e=0.94. 29
Figure 3.4: pattern of EAA when optimizing only SLL. 31
Figure 3.5: pattern of EAA when optimizing only directivity. 32
Figure 3.6: pattern of EAA when optimizing SLL and Directivity. 33
Figure 4.1: pattern of CEAA when optimizing only SLL. 37
Figure 4.2: pattern of CEA when optimizing only directivity. 37
Figure 4.3: pattern of CEA when optimizing SLL and directivity……..………….. ..38

LIST OF TABLES

Table 4.1: the directivity and the side lobe level for each case……………………….....30
Table 3.2: the result of the optimization of simple EAA……………………………...33
Table 4.1: the result of the optimization of CEA…………………………………….38
Table 4.2: comparison between elliptic and concentric elliptic array………………...39

ABRIVIATIONS

GA: Genetic Algorithm 2
PSO: Particle Swarm Optimization 2
ACO: Ant Colony Optimization.. ..2
DE: Differential Evolution ……………..………..……....………………………..2
CLONALG: Clonal Selection Algorithm. 2
CMA-ES: Covariance Matrix Adaptation Evolutionary Strategy. 2
GWO: Gray wolf Optimization 2
SLLs:side lobe levels 2
EAA: elliptical antenna array 10
CEAA:Concentric elliptic antenna array. 11

LIST OF TABLES

Table 4.1: the directivity and the side lobe level for each case………………………....30

Table 3.2: the result of the optimization of simple EAA……………………………..33

Table 4.1: the result of the optimization of CEA…………………………………….38

Table 4.2: comparison between elliptic and concentric elliptic array………………..39

GENERAL INTRODUCTION

An antenna is an essential part of any electronic system which transmits or receives electromagnetic energy in a wireless fashion. A radiating source of electromagnetic energy may take different forms. It may be a piece of conducting wire, a dielectric rod, a metallic horn, or a slot on the side of a waveguide. The radiation pattern of a single element is fixed for a given frequency of excitation and contains, in general, a main beam and a number of smaller side lobes. In practical applications there is quite often a need for either improving the directive properties or controlling the side lobe structure of the radiation pattern. Two methods are available for this purpose: one method is to use an appropriately shaped reflector or lens fed by a radiating element, and the other is to employ a number of radiating elements properly arranged in space to form an antenna array.

In long distance communication, there is great need for very directive antennas with very high gain due to the radiation pattern limitations of a single antenna; several single antenna elements can be combined to form an array. Arrays of antennas are used to direct radiated power towards a desired angular sector. The number, geometrical arrangement, and relative amplitudes and phases of the array elements depend on the angular pattern that must be achieved. Once an array has been designed to focus towards a particular direction, it becomes a simple matter to steer it towards some other direction by changing the relative phase of the array elements.

The designed array should allow signals from a desired direction to add constructively while simultaneously adding destructively in the undesired directions, hence an array may be regarded as a spatial filter with high gain in the desired signal direction and low gain elsewhere. Theoretically, the array should be designed with a maximum directivity and minimum side lobe level so as to achieve maximum signal to noise plus interference ratio at the output of the array antenna. However, this is only true if the interferences are evenly distributed, or assume certain distribution patterns over the whole spatial domain, the maximum directivity design may not be the best design. Therefore, if the designer of the array does not know the distribution of the directions of the interferences, an alternative design such as side-lobe level reduction may be preferred.

GENERAL INTRODUCTION

In this project we concentrated on designing directivity and side-lobe levels of uniformly and non-uniformly distributed antenna elements along an elliptic and concentric elliptic by varying the amplitude and the eccentricity(varying the ratio b/a).

Various optimization techniques have been developed in recent past by harnessing nature's activities. Since the early 1970s, various nature-inspired optimization algorithms have emerged starting with the Genetic Algorithm (GA), some of which have proven to be very efficient global optimization methods. Along with the GA, Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO) , Differential Evolution (DE), Clonal Selection Algorithm (CLONALG) , Covariance Matrix Adaptation Evolutionary Strategy (CMA-ES) and recently proposed gray wolf Optimization (GWO), In essence, GWO is a new nature-inspired meta-heuristic algorithm inspired by the social hierarchy and hunting behavior of grey wolves. It has potential to exhibit high performance in solving not only unconstrained but also constrained optimization problems.

In this project address the problem of finding the optimum that is the minimum SLL and maximum Directivity using Gray wolf Optimization (GWO).

The remainder of this report is structured as follows:

Chapter 1: Generalities about Antennas, where a more detailed information and explanation about antennas.

Chapter 2: we talk about optimization and its classification then we give an overview about the most known modern optimization techniques, then we explain what the GWO (gray wolf optimization) are and we look at the rules that control their dynamics.

In *Chapter 3* and *Chapter 4*, results about the elliptic and the concentric elliptic antenna arrays are discussed. As well as, a comparison of the different obtained results, from the optimization preformation, between SLLs and Directivity of the uniform and the non-uniform antenna with varied excitation amplitude and eccentricity. At last but not least, a general conclusion is drawn.

CHAPTER I

GENERALITIES ABOUT ANTENNAS

1. 1. Introduction

communication antennas are all around us and a major part of the way we live our lives. Antennas go back to the mid-1800s and much evolution has occurred since. The first experiments with wireless communication are on record in 1867 but little details are available. A major breakthrough is noted for Guglielmo Marconi with a wireless call that traveled to boats across the Atlantic Ocean.

The next breakthrough was in 1916 when operators at Radio Arlington were able to transmit the sound of a human voice up and down the Atlantic coast.

This sparked an interest in radio and during the mid-1920s many citizens were putting wire array antennas on their roofs to talk to other people nearby. The frequencies used by citizens were in the high frequency range lower than 200 meters wavelength. Because of this people who use this band are known and shortwave or “ham” operators. People quickly realized that the shorter the wave the further it propagates through space. Therefore people operating in the range below 50 meters were able to make contact around the world in the early 1920s [1].

1. 2. Definition of Antenna

Antennas are the parts of transmitting or receiving systems that can radiate or receive electromagnetic waves [2]. Usually, antenna characteristics are described in the frequency domain. The concept of antenna radiation can be illustrated with the simplified model shown in Figure (1.1). A signal source V_s launches voltage and current waves. (V_{inc},I_{inc}) that propagate along a lossless transmission line. The transmission line has real characteristic impedance Z_c that may depend on the frequency f [3].

An ideal antenna should accept all the incident waves. (V_{inc},I_{inc}) that is, the reflected waves. (V_{ref},I_{ref}) back to the source should be zero, and convert all the accepted waves to electromagnetic waves. (E, H) in a surrounding medium with intrinsic impedance.

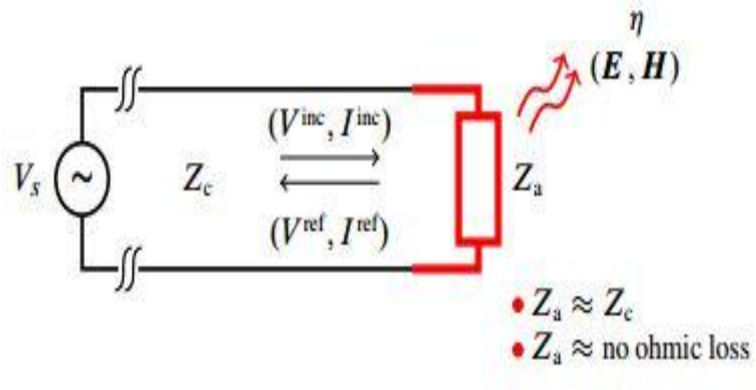

Figure 1.1*: A simplified model of an antenna. [2]*

1. 3. Antenna Glossary:

Before we talk about specific antennas, there are a few common terms that must be defined and explained:

1.3. 1. The Radiation Pattern

The radiation pattern of an antenna is a graphic representation of the radiation properties of an antenna, and could include information on the energy distribution, phase, and Polarization of the radiated field. [4]

Often this radiation pattern is determined in the far field region and represented as a function of the directional coordinates, there can be field pattern (magnitude of the electric or magnetic field) or a power pattern (square or magnitude of the electric or magnetic field), this radiation pattern is often normalized with respect to their maximum value, a radiation patterns are conveniently represented in spherical coordinates. [4]

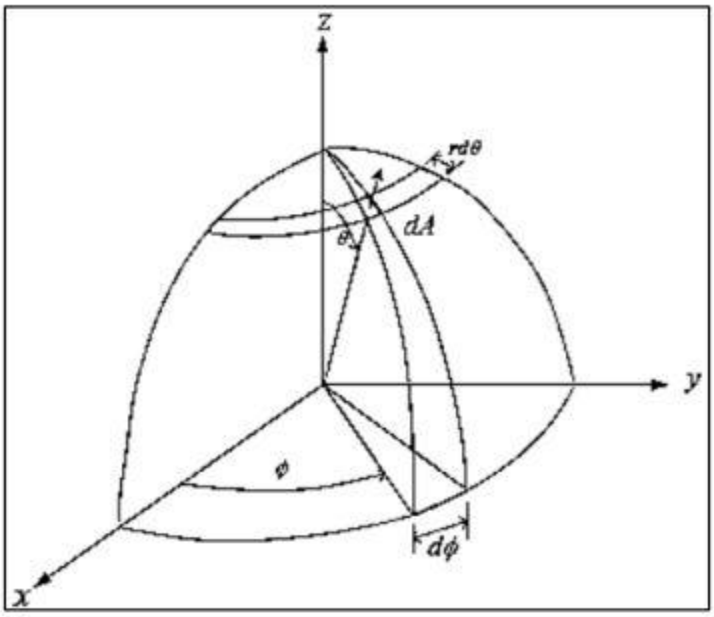

Figure 1.2: *Coordinate system for antenna pattern analysis. [4]*

1.3. 2. Directivity

Directivity is the ability of an antenna to focus energy in a particular direction when transmitting, or to receive energy better from a particular direction when receiving. In a static situation, it is possible to use the antenna directivity to concentrate the radiation beam in the wanted direction. However in a dynamic system where the transceiver is not fixed, the antenna should radiate equally in all directions, and this is known as an Omni-directional antenna. The ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. [5]

- The average radiation intensity: total power radiated by the antenna divided by 4π.
- Stated more simply, the directivity of a no isotropic source is equal to the ratio of its radiation intensity in a given direction over that of an isotropic source.

$$D = \frac{U}{U0} = \frac{4\pi U}{Prad} \tag{1.1}$$

If the direction is not specified, the direction of maximum radiation intensity is implied.

$$Dmax = \frac{U}{U0} = \frac{Umax}{U0} = \frac{4\pi Umax}{Prad} = D_0 \qquad (1.2)$$

- D = directivity (dimensionless).
- D_0= maximum directivity (dimensionless).
- U = U (µ, Á) = radiation intensity (W/S_r).
- U_{max} = maximum radiation intensity (W/S_r).
- U_0= radiation intensity of isotropic source (W/S_r).
- P_{rad}= total radiated power (W).

1.3. 3. Beamwidth

An antenna's beamwidth is usually understood to mean the half-power beam width. The peak radiation intensity is found and then the points on either side of the peak which represent half the power of the peak intensity are located. The angular distance between the half power points is defined as the beam width. Half the power expressed in decibels is –3dB, so the half power beam width is sometimes referred to as the 3dB beam width. Both horizontal and vertical beam widths are usually considered. Assuming that most of the radiated power is not divided into side lobes, and then the directive gain is inversely proportional to the beam width: as the Beam width decreases, the directives gain increases.

1.3. 4. Polarization

Polarization is defined as the orientation of the electric field of an electromagnetic wave. Polarization is in general described by an ellipse. Two special cases of elliptical polarization are linear polarization and circular polarization. The initial polarization of a radio wave is determined by the antenna. [9]

- Polarization is classified as linear, circular, or elliptical.
- If the vector that describes the electric field at a point in space as a function of time is always directed along a line, the field is said to be linearly polarized.
- In general, the figure that the electric field traces is an ellipse, and the field is said to be elliptically polarized.

1.3. 5. The Gain

Another useful measure describing the performance of an antenna is the gain. It takes into account not only the directivity properties but also the efficiency (so the losses) of that antenna.

Absolute gain of antenna (in a given direction) is defined as the ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna radiated isotropically.

$$gain = \frac{4\pi U(\theta,\phi)}{Pin} \qquad (1.3)$$

In most cases we deal with relative gain, which is defined as “the ratio of the power gain in a given direction to the power gain of a reference antenna in its referenced direction. The power input must be the same for both antennas. [5]

1.3. 6. Antenna Efficiency

The total antenna efficiency e_0 is used to take into account losses at the input terminals and within the antenna. Such losses may be due:

- Reflections because of the mismatch between the transmission line and the antenna.
- Conductor and dielectric lossesI^2R.

In general $e_{0=}e_r e_c e_d$ (1.4)

e_r: Reflection efficiency.

e_c: Conductor efficiency.

e_d: Dielectric efficiency.

e_rMay be found using $e_r = (1 - |\Gamma|^2)$, with $\Gamma = \frac{Zin-Z0}{Zin+z0}$is the reflection coefficient at the input of the antenna, while Z_{in} and Z_0 are, respectively, the antenna input impedanceand the transmission line characteristic impedance. Generally $e_c$and $e_d$are difficult to calculate. However, they can be determined experimentally but in associated manner. [5]

1.4. Types of Antennas

- Wire Antennas: Short Dipole Antenna, Dipole Antenna, Wave Dipole Broadband

Dipoles Monopole Antenna Folded Dipole Antenna Loop Antenna, Cloverleaf Antenna

- Travelling Wave Antennas: Helical Antennas, Yagi-Uda Antennas, Spiral Antennas
- Reflector Antennas: Corner Reflector, Parabolic Reflector (Dish Antenna)
- Micro strip Antennas: Rectangular Micro strip (Patch) Antennas, Planar Inverted Antennas.
- Log-Periodic Antennas: Bow Tie Antennas, Log-Periodic Antennas, Log Periodic Dipole.
- Aperture Antennas: Slot Antenna, Cavity-Backed Slot Antenna, Inverted-F

Antenna, Slotted Waveguide Antenna, Horn Antenna, Vivaldi Antenna, Telescopes. [6]

1.4.1. Antenna Arrays

An array of antenna elements is a spatially extended collection of N similar radiators or elements, where N is a countable number bigger than 1, and the term "similar radiators" means that all the elements have the same polar radiation patterns, oriented in the same direction in 3-d space. The elements don't have to be spaced on a regular grid, neither do they have to have the same terminal voltages, but it is assumed that they are all fed with the same frequency and that one can define a fixed amplitude and phase angle for the drive voltage of each element.

Introduction of short wave radio equipment in 1920s made the use of reasonably sized arrays, thereby providing a convenient way to achieve a directive radiation pattern for radio communications. During World War II UHF and microwave array antennas were introduced for use in radar systems. A class of arrays which is just emerging is that of conformal arrays. In these applications the array element locations must conform to some non-planar surface such that found on an aircraft or missile.

Arrays can take many geometrical configurations. Linear array results when the centers of the array elements lie along a straight line. Planar array is obtained by positioning the array elements on a plane. Examples of planar arrays are circular, rectangular and elliptic arrays. [5]

The radiated field strength at a certain point in space, assumed to be in the far field, is calculated by adding the contributions of each element to the total radiated fields. In an array of identical elements, there are five controls that can be used to shape the overall pattern of the antenna. [5]

These are:

- The type of the individual element (or the relative pattern of the individual elements).
- The geometrical configuration of the array (linear, planar, etc.).
- The excitation amplitude of the individual elements.
- The excitation phase of the individual elements.
- The orientations and positions of the elements.

1.4.1.1. Types of Antenna Arrays

Antenna arrays a configuration of multiple antennas (elements) arranged to achieve
A given radiation pattern it can be:

- Linear array: antenna elements arranged along a straight line.
- Circular array: antenna elements arranged around a circular ring.
- Planar array: antenna elements arranged over some planar surface (example – rectangular and elliptic array).
- Conformal array: antenna elements arranged to conform to some non-planar Surface (such as an aircraft skin).

a. Elliptic Antenna Array

The geometry of an elliptical antenna array (EAA) whose N antenna elements lie on an ellipse in the x–y plane is shown in Figure (1.3). The origin is considered to be the center of an ellipse. In free space, the array factor for this elliptical array is given by [7.8]:

$$AF(\theta,\Phi) = \sum_{n=1}^{N} In \exp(j[k\ sin(\theta)(a\cos(\Phi n)\cos(\Phi) + bsin(\Phi n)\sin(\Phi)) + \alpha_n]) \quad (1.5)$$

Where:

$$k = \frac{2\pi}{\lambda} \quad (1.6)$$

$$\Phi_n = \frac{2\pi(n-1)}{N} \quad (1.7)$$

In the above equations, I_n and α_n represent the excitation amplitude and phase of the nth element.

Φ_n Is the angular position of the element in the x–y plane, Φ is the azimuth angle measured from the positive x axis, θ is the elevation angle measured from the positive z axis.

To direct the peak of the main beam in the (θ_0,Φ_0) direction, the excitation phase is chosen to be:α_n=-ksin$(\theta_0\ )(a\cos(\Phi_0)\cos(\ \Phi_n)$+b $\sin(\Phi_n)\sin(\Phi_0))$ (1.8)

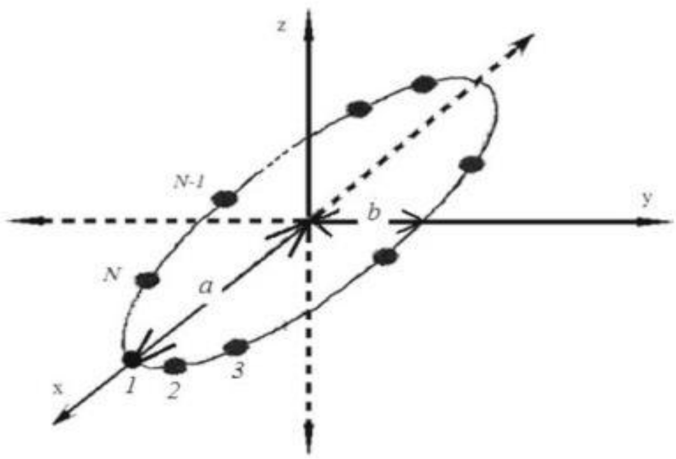

Figure 1.3: *Geometry of an elliptical antenna array (EAA).*

b. Concentric Elliptic Antenna Array

if N is the number of antenna elements lie on ellipses and M is the number of concentric ellipses, then the total array factor of the concentric elliptical array arrangement of isotropic elements is expressed as [20,21]:

$$AF(\theta,\Phi) = \sum_{m=1}^{M}\sum_{n=1}^{N} B_{mn}\exp(j[k\, sin(\theta)(a_m \cos(\Phi n)\cos(\Phi) + b_m sin(\Phi n)\sin(\Phi))]) \quad (1.9)$$

B_{mn} is the amplitude of excitation current, a_m and b_m are semi major axis and semi-minor axis of m-th elliptical array, respectively. If "a" is the smallest semi-major axis and "d" is the spacing between ellipses Figure (1.4), then

$$\mathrm{a_m = a + (m-1)d} \quad (1.10)$$

$$b_m = a_m\sqrt{1-e^2} \quad (1.11)$$

e= $\sqrt{1-\frac{b^2}{a^2}}$ where a, b are the semi-major and semi-minor axis of the elliptic antenna respectively.

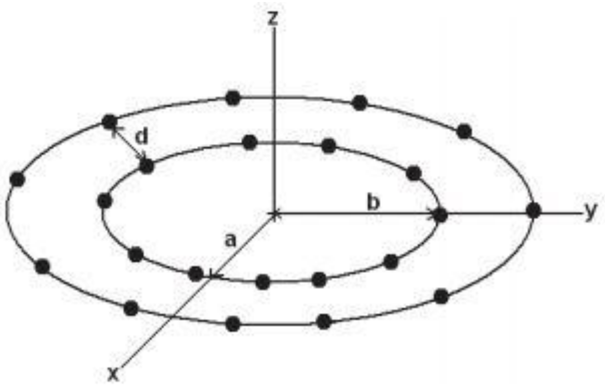

Figure 1.4: *Geometry of concentric elliptic array(CEAA).*

1.5. Conclusion

We have seen in this chapter glossary about antenna and antenna array and some charachteristic of antenna array, in addition to detailed description of the elliptic and concentric elliptic anntenna arrays which are the intersting part of this work.

CHAPTER II

GRAY WOLF OPTIMIZATION

2.1. History of Optimization

In its most basic terms, Optimization is a mathematical discipline that concerns the finding of the extreme (minima and maxima) of numbers, functions, or systems. The great ancient philosophers and mathematicians created its foundations by defining the optimum (as an extreme, maximum, or minimum) over several fundamental domains. This era started with Pythagoras of Samos (569 BC to 475 BC), a Greek philosopher who made important developments in mathematics.

Euclid of Alexandria (325 BC to 265 BC) was the most prominent antique Greek mathematician best known for his work on geometry, The Elements, which not only makes him the leading mathematician of all times but also one who influenced the development of Western mathematics for more than 2,000 years [10].

Further developments in algebra were made by the Arabic mathematician Al-Karaji (953–1029) in his treatise Al-Fakhri, where he extends the methodology to incorporate integer powers and integer roots of unknown quantities. The historian of mathematics, Woepcke in [11], credits him as the first who introduced the theory of algebraic calculus. This was truly one of the cornerstone developments for the area of optimization as it is one of the uses of calculus in the real world.

By the twentieth century, this same method could be implemented in an easier and a faster way due to the emergence of high speed computers and this again, made the implementation of other more complex methods possible, this was followed by producing a massive literature on optimization techniques which made the emergence of several well defined new areas in optimization theory possible today.

2.2. Optimization

Optimization is the act of finding the best possible result under certain circumstances and in its simplest case; it consists of finding the minimum cost possible for the solution or the maximum efficiency possible to our solution. The effort or the benefit can be usually expressed as a function of certain design variables.

Hence, we can mathematically define optimization as the process of finding the conditions that give the maximum or the minimum value of a function.

Most of optimization algorithms are designed to only find the minimum but if a point ‘x’ corresponds to the minimum value of a function f(x),the same point corresponds to the maximum value of the function −f(x) [12], Thus, optimization always can be taken to be minimization.

2.2.1. The Optimization Problem

The main components of an optimization problem are:

a- Objective Function

An objective function expresses one or more quantities which are to be minimized or maximized. The optimization problems may have a single objective function or more objective functions. Usually the different objectives are not compatible. The variables that optimize one objective may be far from optimal for the others. The problem with multi-objectives can be reformulated as single objective problems by either forming a weighted combination of the different objectives or by treating some of the objectives as constraints.

b- Variables

A set of unknowns, which are essential are called variables. The variables are used to define the objective function and constraints. One cannot choose design variable arbitrarily, they have to satisfy certain specified functional and other requirements. The design variables can be continuous, discrete or Boolean.

c- Statement of an optimization problem

An optimization problem can be stated as follows: To find x=$\begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix}$, which minimizes or maximizes$f(x)$; Subject to the constraints

$g_i(x) \leq 0$;$i = 1,2,3 \cdots$ m.

$h_i(x) = 0$;$j = 1,2,3 \cdots$ p.

Where x is an n-dimensional vector called design variable,$f(x)$ is called the objective function, $g_i(x)$ and $h_i(x)$ are known as inequality and equality constraints respectively. This type of problem is called constrained optimization problem.

This problem can be represented in the following way:

Function $f: A \rightarrow R$(from some set A to set R)

Sought: an elements x_0 in A such that $f(x_0) \leq f(x)$ for all x in A ("minimization") or such that $f(x_0) \geq f(x)$) for all x in A ("maximization").

2.3. Classification of Optimization Problems

Optimization problems can be classified based on the type of constraints, nature of design variables, nature of the equations involved and type & number of objective functions. These classifications are briefly discussed below.

2.3.1. Based on Existence of Constraints

A problem is called constrained optimization problem if it is subject to one or more constraints otherwise it is called unconstrained.

2.3.2. Based on the Nature of the Equations Involved

Based on the nature of equations for the objective function and the constraints, optimization problems can be classified as linear and nonlinear programming problems. The classification is very useful from a computational point of view since many predefined special methods are available for effective solution of a particular type of problem. We can consider those methods as classical methods [13]:

- Linear programming: studies the case in which the objective function 'f 'is linear and the set of design variable space is specified using only linear equalities and inequalities.
- Integer programming:studies linear programs in which some or all variables are Constrained to take on integer values.
- Quadratic programming: allows the objective function to have quadratic terms, while the set of design variables must be specified with linear equalities and inequalities.
- Nonlinear programming: studies the general case in which the objective function or the constraints or both contain nonlinear parts.
- Stochastic programming: studies the case in which some of the constraints depend on random variables.
- Dynamic programming: studies the case in which the optimization strategy is based on splitting the problem into smaller sub-problems.

- Combinatorial optimization: is concerned with problems where the set of feasible solutions is discrete or can be reduced to a discrete one.
- Infinite-dimensional optimization: studies the case when the set of feasible solutions is a subset of an infinite-dimensional space, such as a space of functions.
- Constraint satisfaction: studies the case in which the objective function f is constant (this is used in artificial intelligence, particularly in automated reasoning).

2.3.3. Based On the Number of Objective Functions

Under this classification, objective functions can be classified as single-objective and multi-objective programming problems.

2.4. Advanced Optimization Techniques

In recent years, some optimization methods that are conceptually different from the traditional mathematical programming techniques have been developed. These methods are labeled as modern or nontraditional methods of optimization. Most of these methods are based on certain characteristics and behavior of biological, molecular, swarm of insects, and neurobiological systems. these methods have been developed only in recent years and are emerging as popular methods for the solution of complex engineering problems. Most require only the function values (and not the derivatives).

2.4.1. The Genetic Algorithms: they are based on the principles of natural genetics and natural selection. And it is a general method for solving "search for solutions" problems as many other evolutions inspire techniques and its simple form it works by choosing some candidates solution and then systematically perform the mutation process until finding the best fitness [14, 13].

2.4.2. The Simulated Annealing: It is based on the simulation of thermal annealing of critically heated solids. Both genetic algorithms and simulated annealing are stochastic methods that can find the global minimum with a high probability and are naturally applicable for the solution of discrete optimization problems [17, 13].

2.4.3. The Particle Swarm Optimization: is based on the behavior of a colony of living things, such as a swarm of insects, a flock of birds, or a school of fish, just like other algorithms it tries to improve candidate solutions iteratively with regard to a given measure of quality, works by putting a population of candidates solution as particles and move them around in the search space according a formula of position and velocity and this is supposed to move the swarm into a better solution in the search space till getting to the best one [15, 13].

2.4.4. Ant Colony Optimization: is based on the cooperative behavior of real ant colonies, which are able to find the shortest path from their nest to a food source and in many practical systems, the objective function, constraints, and the design data are known only in vague and linguistic terms. Fuzzy optimization methods have been developed for solving such problems [16, 13].

2.4.5. Neural-Network-Based Methods: In this method the problem is modeled as a network consisting of several neurons, and the network is trained suitably to solve the optimization problem efficiently [13].

2.5. Gray Wolf Optimizer (GWO)

In this section the inspiration of the proposed method is first discussed. Then, the mathematical model is provided.

2.5.1. Inspiration

Grey wolf (Canis lupus) belongs to Canidae family. Grey wolves are considered as apex predators, meaning that they are at the top of the food chain. Grey wolves mostly prefer to live in a pack. The group size is 5–12 on average. Of particular interest is that they have a very strict social dominant hierarchy as shown in Fig (2.1).

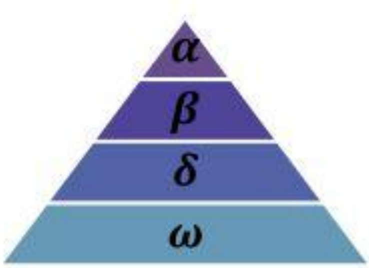

Figure 2.1: *Hierarchy of grey wolf (dominance decreases from top down).*

The leaders are a male and a female, called alpha. The alpha is mostly responsible for making decisions about hunting, sleeping place, time to wake, and so on. The alpha's decisions are dictated to the pack. However, some kind of democratic behavior has also been observed, in which an alpha follows the other wolves in the pack. In gatherings, the entire pack acknowledges the alpha by holding their tails down. The alpha wolf is also called the dominant wolf since his/her orders should be followed by the pack [22]. The alpha wolves are only allowed to mate in the pack. Interestingly, the alpha is not necessarily the strongest member of the pack but the best in terms of managing the pack. This shows that the organization and discipline of a pack is much more important than its strength.

The second level in the hierarchy of grey wolves is beta. The betas are subordinate wolves that help the alpha in decision-making or other pack activities. The beta wolf can be either male or female, and he/she is probably the best candidate to be the alpha in case one of the alpha wolves passes away or becomes very old.

The beta wolf should respect the alpha, but commands the other lower-level wolves as well. It plays the role of an advisor to the alpha and discipliner for the pack.

The beta reinforces the alpha's commands throughout the pack and gives feedback to the alpha.

The lowest ranking grey wolf is omega. The omega plays the role of scapegoat. Omega wolves always have to submit to all the other dominant wolves. They are the last wolves that are allowed to eat. It may seem the omega is not an important individual in the pack, but it has been observed that the whole pack face internal fighting and problems in case of losing the omega. This is due to the venting of violence and frustration of all wolves by the omega(s). This assists satisfying the entire pack and maintaining the dominance structure. In some cases the omega is also the babysitters in the pack.

If a wolf is not an alpha, beta, or omega, he/she is called subordinate (or delta in some references). Delta wolves have to submit to alphas and betas, but they dominate the omega. Scouts, sentinels, elders, hunters, and caretakers belong to this category. Scouts are responsible for watching the boundaries of the territory and warning the pack in case of any danger. Sentinels protect and guarantee the safety of the pack. Elders are the experienced wolves who used to be alpha or beta. Hunters help the alphas and betas when hunting prey and providing food for the pack. Finally, the caretakers are responsible for caring for the weak, ill, and wounded wolves in the pack.

In addition to the social hierarchy of wolves, group hunting is another interesting social behavior of grey wolves. According to Muro et al. [18] the main phases of grey wolf hunting are as follows:

- Tracking, chasing, and approaching the prey.
- Pursuing, encircling, and harassing the prey until it stops moving.
- Attack towards the prey.

2.5. 2. Mathematical Model and Algorithm

In this subsection the mathematical models of the social hierarchy, tracking, encircling, and attacking prey are provided. Then the GWO algorithm is outlined.

a- Social Hierarchy

In order to mathematically model the social hierarchy of wolves when designing GWO, we consider the fittest solution as the alpha (α). Consequently, the second and third best solutions are named beta (β) and delta (δ) respectively. The rest of the candidate solutions are assumed to be omega (ω). In the GWO algorithm the hunting (optimization) is guided by α, β, and δ. The ω wolves follow these three wolves.

b- Encircling Prey

As mentioned above, grey wolves encircle prey during the hunt. In order to mathematically model encircling behavior the following equations are proposed [19]:

$$\vec{D}=\left|\vec{C}.\vec{X}_p(t)-\vec{X}(t)\right| \tag{2.1}$$

$$\vec{X}(t+1)=\vec{X}_p(t)-\vec{A}.\vec{D} \tag{2.2}$$

Where t indicates the current iteration, $\vec{A}$and $\vec{C}$ is coefficient vectors, $\vec{X}_p$is the position vector of the prey, and $\vec{X}$indicates the position vector of a grey wolf.
The vectors$\vec{A}$and $\vec{C}$ are calculated as follows:

$$\vec{A}=2\ c.\vec{r}_1-\vec{a} \tag{2.3}$$

$$\vec{C}=2\vec{a}.\vec{r}_2 \tag{2.4}$$

Where components of $\vec{a}$ are linearly decreased from 2 to 0 over the course of iterations and $\vec{r}_1$,$\vec{r}_2$are random vectors in [0, 1].

c- Hunting

Grey wolves have the ability to recognize the location of prey and encircle them. The hunt is usually guided by the alpha. The beta and delta might also participate in hunting occasionally.

However, in an abstract search space we have no idea about the location of the optimum (prey). In order to mathematically simulate the hunting behavior of grey wolves, we suppose that the alpha (best candidate solution) beta and delta have better knowledge about the potential location of prey. Therefore, we save the first three best solutions obtained so far and oblige the other search agents (including the omegas) to update their positions according to the position of the best search agents. The following formulas are proposed in this regard [19].

$$\vec{D}_\alpha=\left|\vec{C}_1.\vec{X}_\alpha-\vec{X}\right|,\ \vec{D}_\beta=\left|\vec{C}_2.\vec{X}_\beta-\vec{X}\right|,\ \vec{D}_\delta=\left|\vec{C}_3.\vec{X}_\delta-\vec{X}\right| \tag{2.5}$$

$$\vec{X}_1=\vec{X}_\alpha-\vec{A}_1.(\vec{D}_\alpha),\vec{X}_2=\vec{X}_\beta-\vec{A}_2.(\vec{D}_\beta),\vec{X}_3=\vec{X}_\delta-\vec{A}_3.(\vec{D}_\delta) \tag{2.6}$$

$$\vec{X}(t+1)=\frac{\vec{X}_1+\vec{X}_2+\vec{X}_3}{3} \tag{2.7}$$

d- Attacking Prey

The grey wolves finish the hunt by attacking the prey when it stops moving. In order to mathematically model approaching the prey we decrease the value of $\vec{a}$. Note that the fluctuation range of $\vec{A}$is also decreased by$\vec{a}$. In other words$\vec{A}$is a random value in the interval [-2a, 2a] where a, is decreased from 2 to 0 over the course of iterations. When random values of$\vec{A}$are in [-1, 1], the next position of a search agent can be in any position between its current position and the position of the prey. Fig (2.2 (a)) shows that $|A| < 1$ forces the wolves to attack towards the prey.

With the operators proposed so far, the GWO algorithm allows its search agents to update their position based on the location of the alpha, beta, and delta; and attack towards the prey. However, the GWO algorithm is prone to stagnation in local solutions with these operators. It is true that the encircling mechanism proposed shows exploration to some extent, but GWO needs more operators to emphasize exploration.

e- Search for Prey

Grey wolves mostly search according to the position of the alpha, beta, and delta. They diverge from each other to search for prey and converge to attack prey.

In order to mathematically model divergence, we utilize $\vec{A}$with random values greater than 1 or less than -1 to oblige the search agent to diverge from the prey. This emphasizes exploration and allows the GWO algorithm to search globally.

Fig (2.2 (b)) also shows that |A| > 1 forces the grey wolves to diverge from the prey to hopefully find a fitter prey.

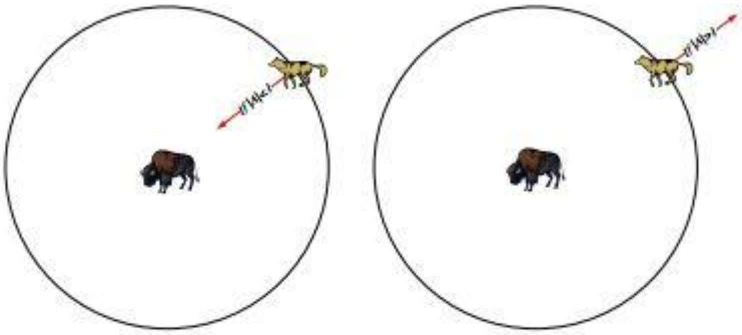

Figure 2.2: *Attacking prey versus searching for prey.*

Another component of GWO that favors exploration is$\vec{C}$. As may be seen in Eq.(2.4), the $\vec{C}$vector contains random values in [0, 2].This component provides random weights for prey in order to stochastically emphasize (C> 1) or deemphasize (C< 1) the effect of prey in defining the distance in Eq.(2.1). This assists GWO to show a more random behavior throughout optimization, favoring exploration and local optima avoidance. It is worth mentioning here that C is not linearly decreased in contrast to A. We deliberately require C to provide random values at all times in order to emphasize exploration not only during initial iterations but also final iterations. This component is very helpful in case of local optima stagnation, especially in the final iterations.

The C vector can be also considered as the effect of obstacles to approaching prey in nature. Generally speaking, the obstacles in nature appear in the hunting paths of wolves and in fact prevent them from quickly and conveniently approaching prey. This is exactly what the vector C does. Depending on the position of a wolf, it can randomly give the prey a weight and make it harder and farther to reach for wolves, or vice versa.

To sum up, the search process starts with creating a random population of grey wolves (candidate solutions) in the GWO algorithm. Over the course of iterations, alpha, beta, and delta wolves estimate the probable position of the prey.

Each candidate solution updates its distance from the prey. The parameter a is decreased from 2 to 0 in order to emphasize exploration and exploitation, respectively. Candidate solutions tend to diverge from the prey when $|\vec{A}|$>1 and converge towards the prey when $|\vec{A}|<1$. Finally, the GWO algorithm is terminated by the satisfaction of an end criterion.

To see how GWO is theoretically able to solve optimization problems, some points may be noted:

- The proposed social hierarchy assists GWO to save the best solutions obtained so far over the course of iteration.
- The proposed encircling mechanism defines a circle-shaped neighborhood around the solutions which can be extended to higher dimensions as a hyper-sphere.
- The random parameters A and C assist candidate solutions to have hyper-spheres with different random radii.
- The proposed hunting method allows candidate solutions to locate the probable position of the prey.
- Exploration and exploitation are guaranteed by the adaptive values of a and A.
- The adaptive values of parameters a and A allow GWO to smoothly transition between exploration and exploitation.
- With decreasing A, half of the iterations are devoted to exploration ($|A|\geq1$) and the other half are dedicated to exploitation n ($|A| < 1$).
- The GWO has only two main parameters to be adjusted (a and C).

2.5.3. Flowchart of Main GWO Algorithm

The following figure is a flowchart that describes the simplified algorithm of the GWO. The algorithm starts by initialize the grey wolf population and maximum number of iterations then the parameters.

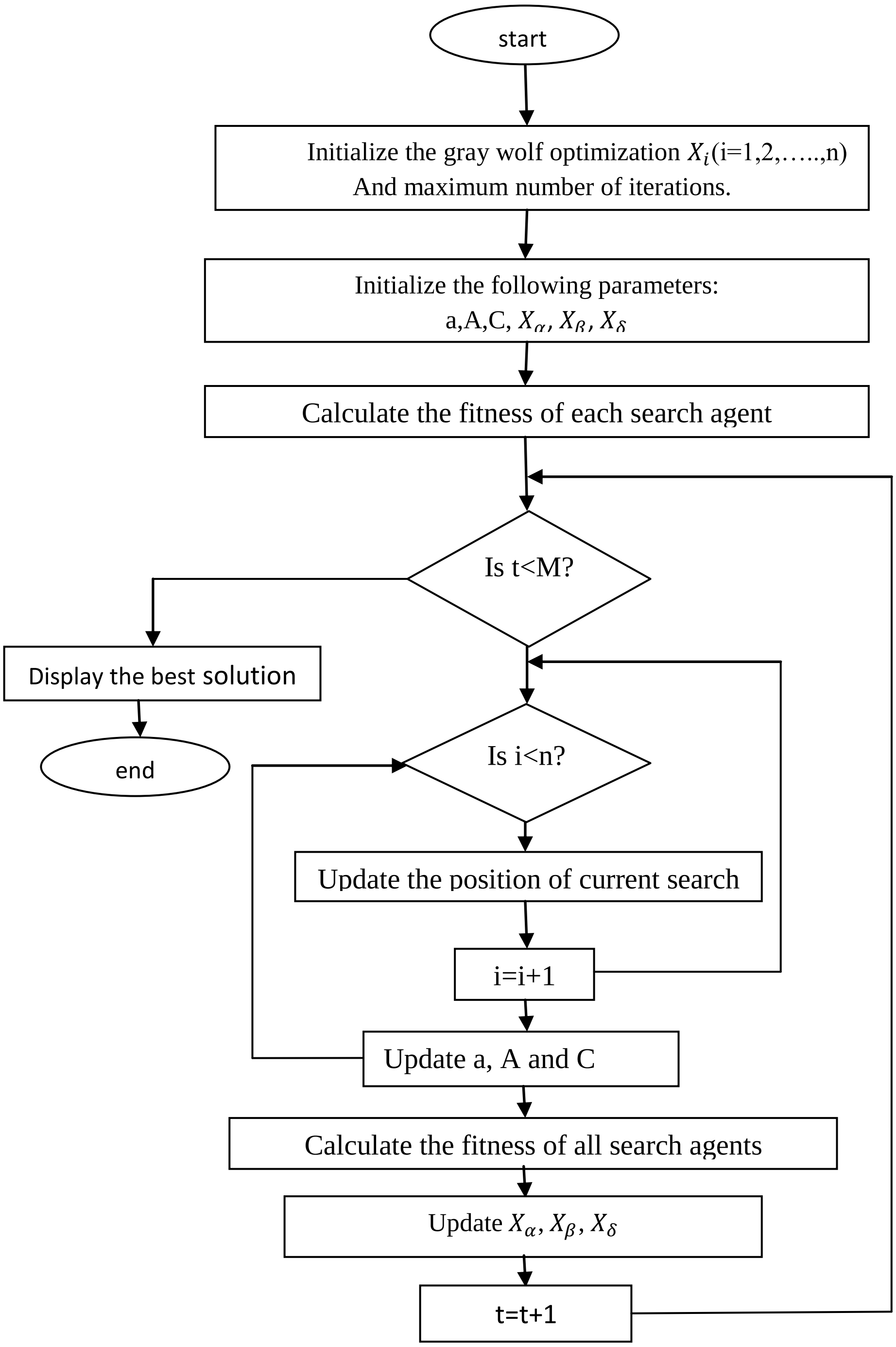

Figure 2.3: *Flowchart of the grey wolf optimization algorithm. [19]*

2.6. Algorithm Testing with Benchmark Functions

A small simulation of the GWO will be performed with a certain benchmark functions to ensure its functionality.

2.6.1. De Jong's Function One

The simplest test function is De Jong's function 1. It is also known as sphere model. It is continuous, convex and unimodal.

Global minimum: f_1 (0, … ., 0) = 0

$$f_1(\mathrm{x})=\sum_{i=1}^{n} x_i^2 \quad (2.8)$$

While n is the dimension and for our simulation test we took n=30.

The best optimal value of the objective function found by GWO is: 2.7899e-28.

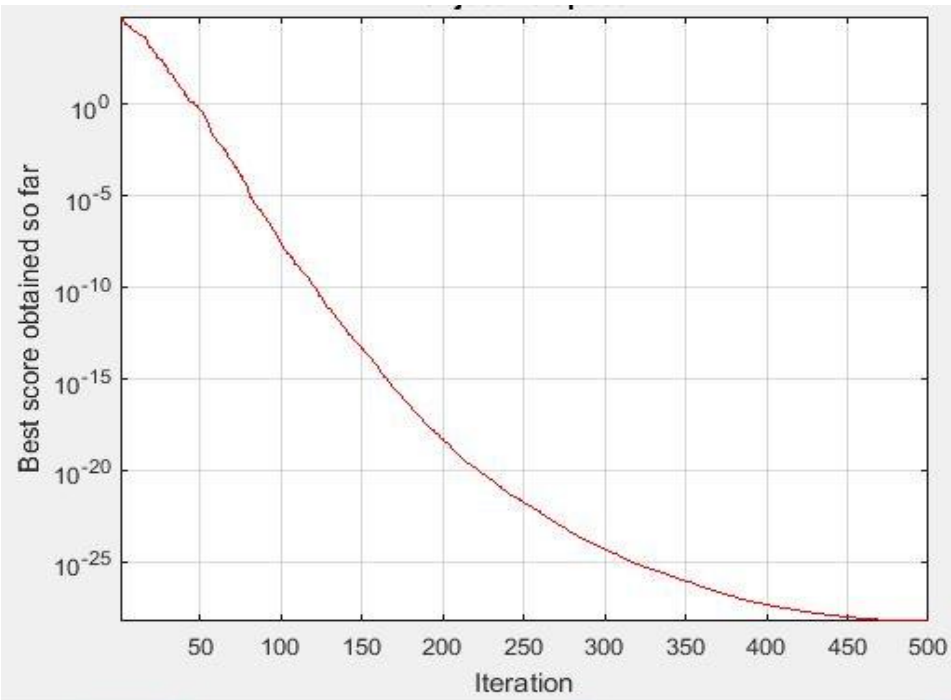

Figure 2.4: *convergence to the global minima after 500 iterations.*

2.6.2. Rotated Hyper-Ellipsoid Function

Global minimum: f_2 (0, … ., 0) = 0

$$f_2(x)=\sum_{i=1}^{n}(\sum_{j=1}^{i} x_j)^2 \qquad (2.9)$$

While n is the dimension and for our simulation test we took n=30.

The best optimal value of the objective function found by GWO is: 4.2738e-07.

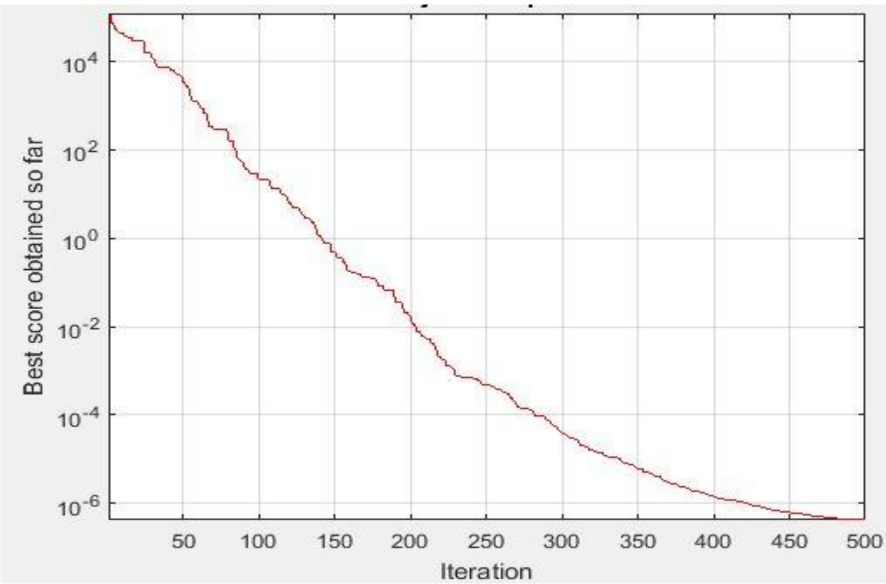

Figure 2.5: *convergence to the global minima after 500 iterations.*

2.6.3. Function Three

Global minimum: f_3 (0, … ., 0)=0;

$$f_3(x)=\sum_{i=1}^{n}|x_i|+\prod_{i=1}^{n}|x_i| \qquad (2.10)$$

While n is the dimension and for our simulation test we took n=30.

The best optimal value of the objective function found by GWO is: 8.1116e-17.

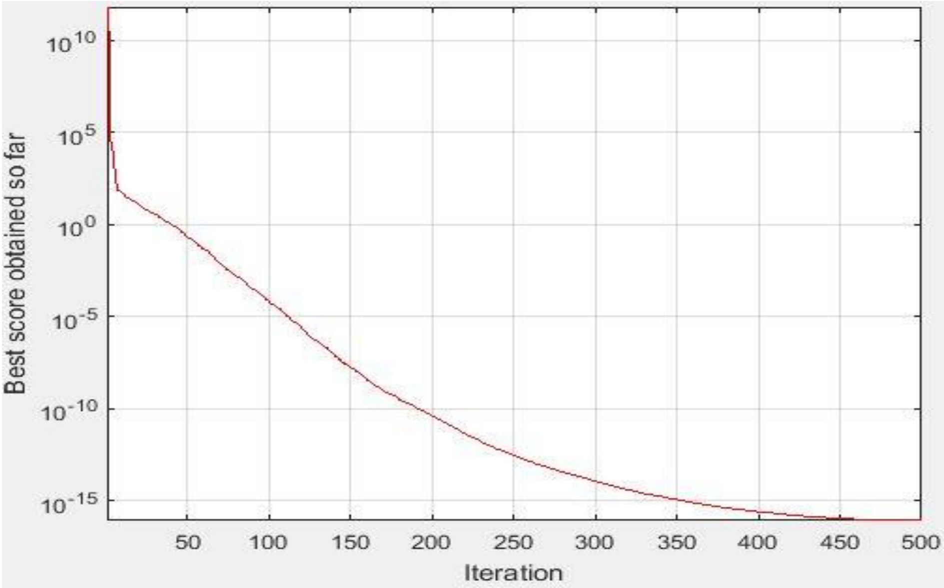

Figure 2.6: *convergence to the global minima after 500 iterations.*

2.7. Conclusion

We have seen in this chapter, a global idea about optimization and classification of optimization problem, after that we have a look at new nature-inspired metaheuristic algorithm inspired by the social hierarchy and hunting behavior of grey wolves (GWO).We also made a simulation with Matlab software to test the algorithm with certain benchmark functions, and in the next chapter we will use this algorithm in our side lobes reduction and directivity improvement problem.

CHAPTER III

ELLIPTIC ANTENNA ARRAY ANALYSIS

3.1. Problem Specifications

In this chapter, firstly we will see the effect of eccentricity on the both of side lobe level and the directivity of elliptical antenna array by changing in the ratio of b /a, secondly the grey wolf optimization algorithm which is explained in the previous chapter is used to reduce the side lobe level and to optimize only the directivity and both of the directivity and the side lobe level of the elliptical antenna array factor.

Remark: The all results of the simulation are obtained by using matlab programming.

The expression of elliptic array factor and its parameters are given by:

$AF(\theta,\Phi) = \sum_{n=1}^{N} In \exp(j[k\, sin(\theta)(a\cos(\Phi n)\cos(\Phi) + bsin(\Phi n)\sin(\Phi)) + \alpha_n])$ (3.1)

Where:

$$k = \frac{2\pi}{\lambda} \quad (3.2)$$

$$\Phi_n = \frac{2\pi(n-1)}{N} \quad (3.3)$$

$$\alpha_n = -\mathrm{k}\sin(\theta_0)(a\cos(\Phi_0)\cos(\Phi_n) + \mathrm{b}\sin(\Phi_n)\sin(\Phi_0)) \quad (3.4)$$

During the simulation in this chapter the following EAAF parameters has been used:

- $-\pi/2 < \theta < \pi/2$.
- $-\pi < \Phi < \pi$.
- N=20, where N is the number of element laying along the x-y plane.
- The excitation phase which is used to direct the peak of the main beam in the (θ_0,Φ_0) direction in our problem θ_0 and Φ_0 are chosen to be 90° and 0°, respectively.
- $\Phi_n = \frac{2\pi(n-1)}{N}$.

3.2. The Effect of Eccentricity

The eccentricity formula of elliptic antenna array can be defined as follows:

e= $\sqrt{1-\frac{b^2}{a^2}}$ where a, b are the semi-major and semi-minor axis of the elliptic antenna respectively.

In this part we have:

- Uniform excited amplitude I_n=1 for all element.
- Changing in eccentricity for each case.

3.2.1. Case One

By setting the eccentricity e=0.5, and the parameters presented above, we see from figure (3.1) that the side lobes level and the Directivity of the uniform array are -8.107dB, 35.8203dB respectively.

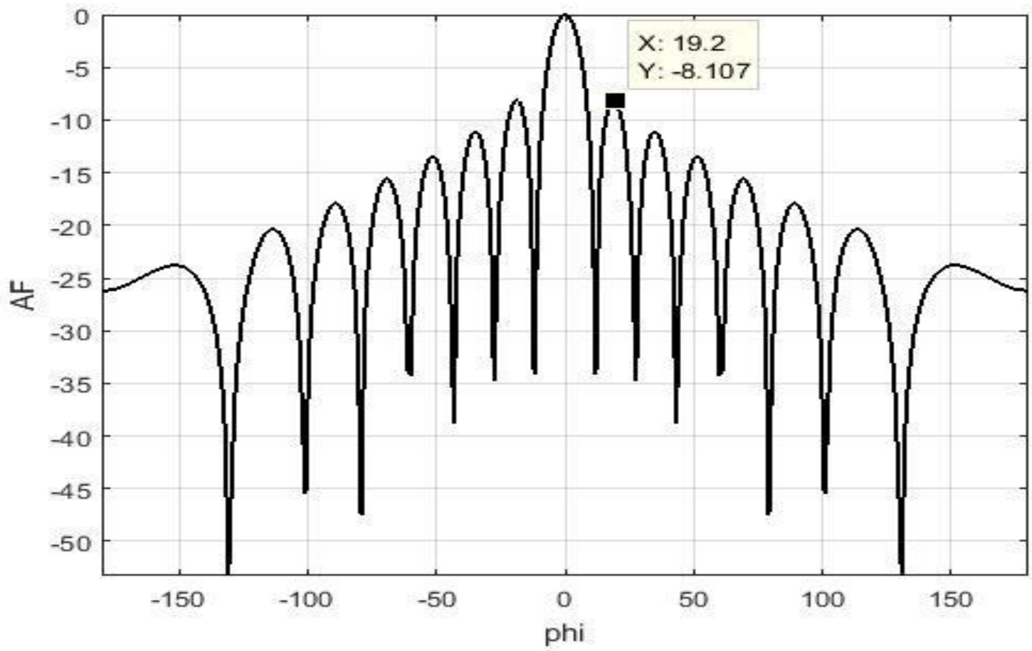

Figure 3.1: pattern of EAA with eccentricity e=0.5.

3.2.2. Case Two

For the eccentricity e=0.86, we see from figure (3.2) that the side lobes level and the Directivity of the uniform array are -11.6dB, 35.001dBrespectively.

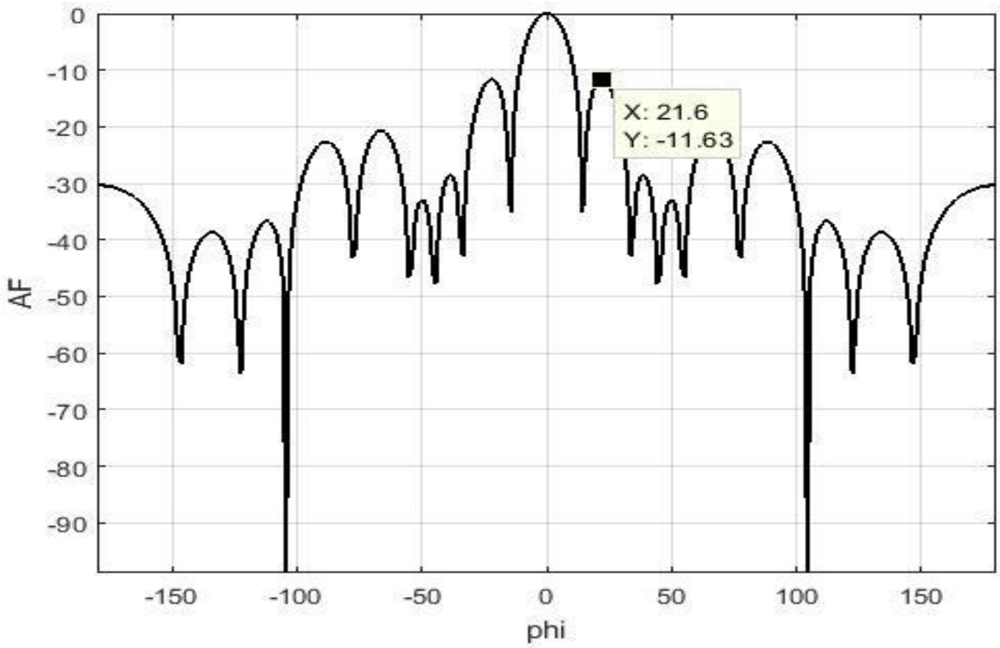

Figure 3.2: *pattern of EAA with eccentricity e=0.86.*

3.2.3. Case three

We have used the eccentricity e=0.94, we see from figure (3.3) that the side lobes level and the Directivity of the uniform array are –16.37dB, 34.96dB respectively.

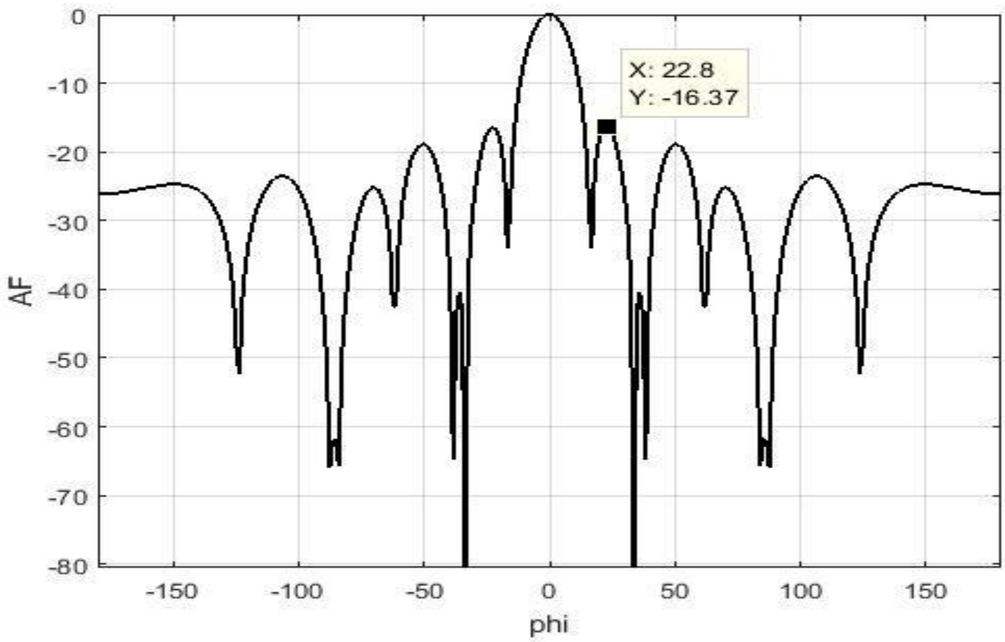

Figure 3.3: *pattern of EAA with eccentricity e=0.94.*

3.2.4. Results and Discussion

We can summarize our result in the following table 3.1:

Table 3.1: *the directivity and the side lobe level for each case.*

e	0.5	0.86	0.94
Side lobe level	-8.107dB	-11.6dB	-16.37dB
Directivity	35.82dB	35.001dB	34.96dB

From this table we can conclude that the Elliptic arrangement has one extra parameter 'eccentricity', because of this parameter; it is possible to reduce side lobe level, but with degrading in the directivity.

3.3. GWO Algorithm

3.3.1. Problem Formulation

The problem formulation of the objective function which is to be optimized follows from Chapter 2 and the array factor of the elliptic array is presented in the beginning of this chapter by the equation (3.1).

So the fitness functions for the three objectives of optimization are: SLL and Directivity optimized separately and optimizing both as given in equations (3.5), (3.6) and (3.7), respectively:

$$Fitness_{SLL} = SLL = \left\{20 * log_{10} \left|\frac{AF(\Phi)}{\max(AF(\Phi))}\right|\right\} \tag{3.5}$$

$$Fitness_{DIR} = -DIR = -\ (41253/\mathrm{BW}) \tag{3.6}$$

$$Fitness_{SLL\&DIR} = SLL - DIR \tag{3.7}$$

3.3.2. Parameter Variations

For non-uniform case, the variations of the excitation amplitude and the eccentricity were provided by the GWO in the following way:

- Amplitude (I): It varies in the interval [0, 1].
- The ratio b/a or the eccentricity: It varies in the interval [0, 1].

3.3.3. Optimization of Simple Elliptic Antenna Array

We are going to use a 20 elements laying along the x-y plane, with the parameters which mentioned in the beginning of this chapter.

- For the **uniform case**(the ellipse eccentricity is fixed in all elliptical array (e=0.5) and I=1)the following result are obtained:

SLL =-8.107dB and a Directivity of 35.82dB.

- For the **non-uniform case** we deal the variation of the excitation Amplitude and the eccentricity to optimize only SLL then only Directivity then both of them.

a- Optimization of SLL Only

by setting the parameters presented above and optimizing only for the SLL we see from figure (3-4) that the side lobes level is reduced to –15.95dB followed by a reduction Directivity to 34.22dB.

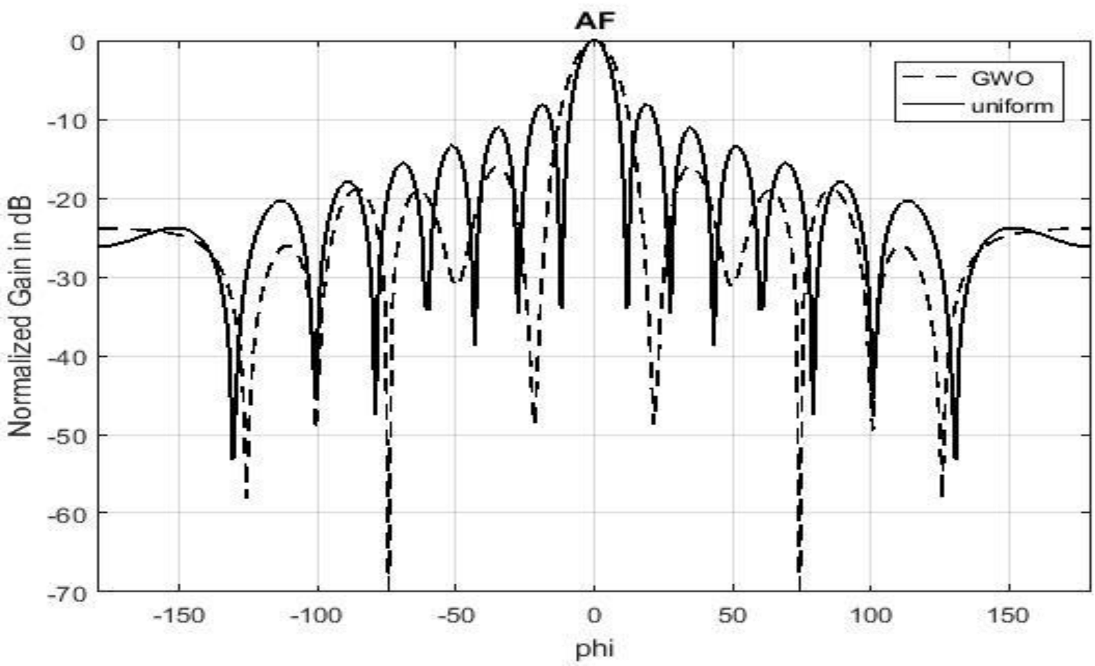

Figure 3.4: *pattern of EAA when optimizing only SLL.*

b- Optimization of DIR Only

Figure (3-5) shows the pattern of the array factor when optimizing the directivity; the directivity is enhanced from 35.8203dB to 38.3730dB but with an increasing side lobe level from –8.107dB to –7.89dB.

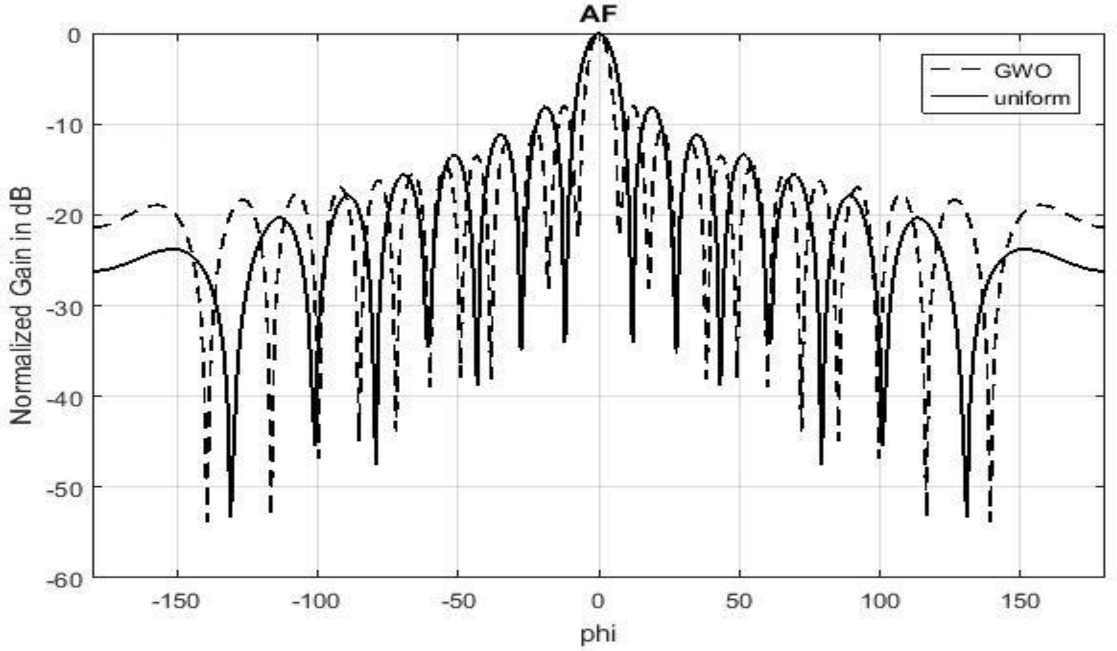

Figure 3.5: *pattern of EAA when optimizing only directivity.*

c- Optimization of Both SLL and DIR

Figure (3-6) show the pattern of the array factor when optimizing for both SLL and Directivity, the absolute value of SLL-DIR for the optimized case is more considerable than the uniform case (optimizing case =44.70dB, Uniform case = 43.92dB).

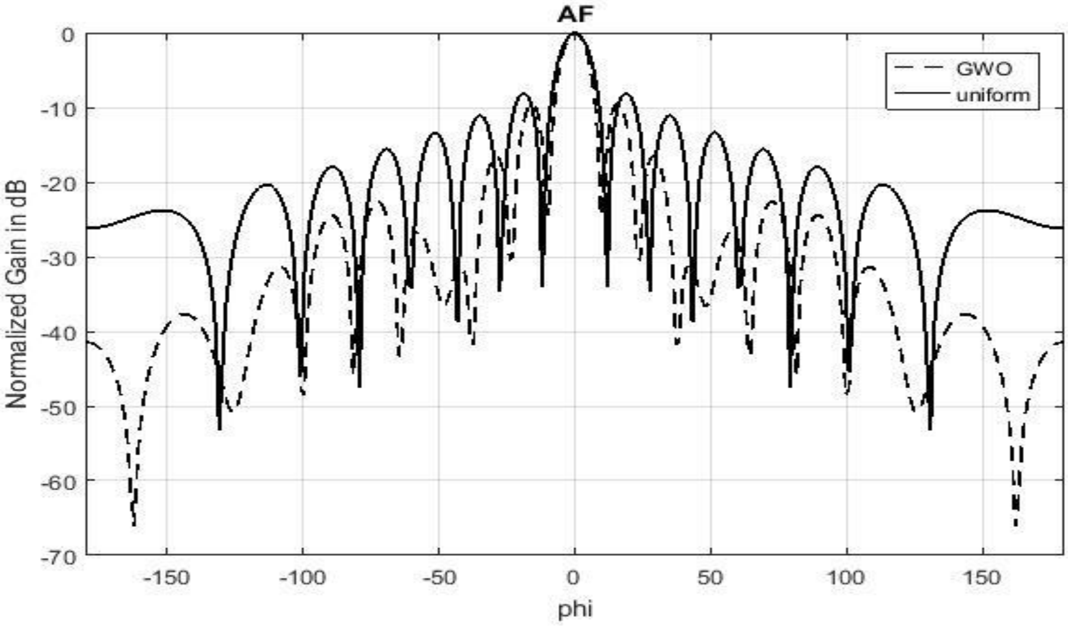

Figure 3.6: *pattern of EAA when optimizing SLL and Directivity.*

3.3.4. Results and Discussion

Table 3.2: *The Result of the Optimization of Simple EAA.*

	SLL	DIR	Ratio($\left\|\frac{DIR}{SLL}\right\|$)
Uniform	–8.107dB	35.82dB	4.41
Optimizing SLL	–15.95dB	34.22dB	2.15
Optimizing DIR	–7.89dB	38.37dB	4.86
Optimizing both	–8.88dB	35.82dB	4.03

From the table above, we see that the best SLL and directivity obtained are –15.95dB and 38.37dB respectively, and we can noticed that no directivity enhancement while optimizing side lobe level and vice versa.

For the uniform one has the absolute value SLL–DIRof43.92dB, we have optimized it to44.70dBwhich means that the directivity it is approximately the same as the uniform case, the side lobe level is slightly optimized.

3.4. Conclusion

As conclusion for this third chapter, and from the result obtained it is visibly that GWO has successfully generates the values of the amplitude and eccentricity for a better SLL suppression and enhancement for the directivity for the shape that we have applied on.

CHAPTER IV

CONCENTRIC ELLIPTIC ANTENNA ARRAY ANALYSIS

4.1. Introduction

In this chapter, the grey wolf optimization algorithm is used to reduce the side lobe level and to optimize only the directivity and both of the directivity and the side lobe level of the concentric elliptic antenna array.

Remark: The all results of the simulation are obtained by using matlab programming.

4.2. GWO Algorithm

4.2.1. Parameter Variations

The expression of concentric elliptic array factor and its parameters can be given by:

$$AF(\theta,\Phi) = \sum_{m=1}^{M}\sum_{n=1}^{N} B_{mn}\exp(j[k\, sin(\theta)(a_m\cos(\Phi n)\cos(\Phi) + b_m sin(\Phi n)\sin(\Phi))]) \quad (4.1)$$

$$\mathrm{a_m = a + (m-1)d} \quad (4.2)$$

$$b_m = a_m\sqrt{1-e^2} \quad (4.3)$$

- $B_{mn}$is the amplitude of excitation current.
- $a_m$and b_m are semi major axis and semi-minor axis of m-th elliptical array, respectively.
- "a" is the smallest semi-major axis.
- "d" is the spacing between ellipses.

During the simulation in this chapter the following CEA parameters has been used:

- $-\pi/2<\theta<\pi/2$.
- $-\pi < \Phi < \pi$.
- N=20, N is the number of antenna elements lie on ellipses.
- M=3, where M is the number of concentric ellipses.
- $\Phi_n = \frac{2\pi(n-1)}{N}$.
- Amplitude (B_{mn}): It varies in the interval [0, 1].
- The ratio$\frac{b_m}{a_m}$: It varies in the interval [0, 1].

4.2.2 Problem Formulation

The fitness functions for the three objectives of optimization are: SLL and Directivity optimized separately and optimizing both as given in equations (4.4), (4.5) and (4.6), respectively:

$$Fitness_{SLL} = SLL = \left\{20 * log_{10} \left|\frac{AF(\Phi)}{\max(AF(\Phi))}\right|\right\} \quad (4.4)$$

$$Fitness_{DIR} = -DIR = -\ (41253/\mathrm{BW}) \quad (4.5)$$

$$Fitness_{SLL\&DIR} = SLL - DIR \quad (4.6)$$

4.3. Concentric Elliptic Antenna Array

We have three ellipses for each ellipse we are going to use a 20 elements laying along the x-y plane, with the parameters which mentioned in the previous title.

- For the **uniform case**(the ellipse eccentricity is fixed in all elliptical array (e=0.5) and B_{mn}=1)the following result are obtained:

SLL = –9.917dB and a Directivity of 34.9488dB.

- For the **non-uniform case** we deal the variation of the excitation Amplitude and the eccentricity to optimize only SLL then only Directivity then both of them.

a- Optimization of Only SLL

by setting the parameters presented in the beginning of the previous chapter and optimizing only for the SLL we see from figure (4.1) that the side lobes level is reduced to –31.56dB followed by a reduction in Directivity to 33.93dB.

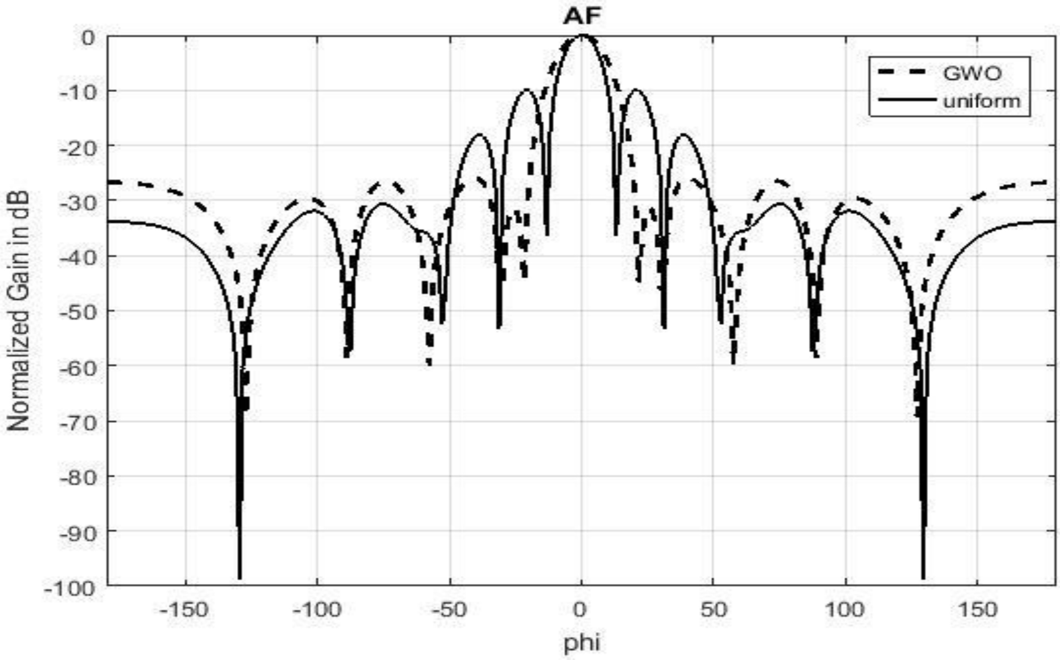

Figure 4.1: *pattern of CEAA when optimizing only SLL.*

b- Optimization of only DIR

Figure (4.2) shows the pattern of the array factor when optimizing the directivity; the directivity is optimized to 38.23 dB but we have increasing in the side lobe level from –9.917dB to –7.89dB.

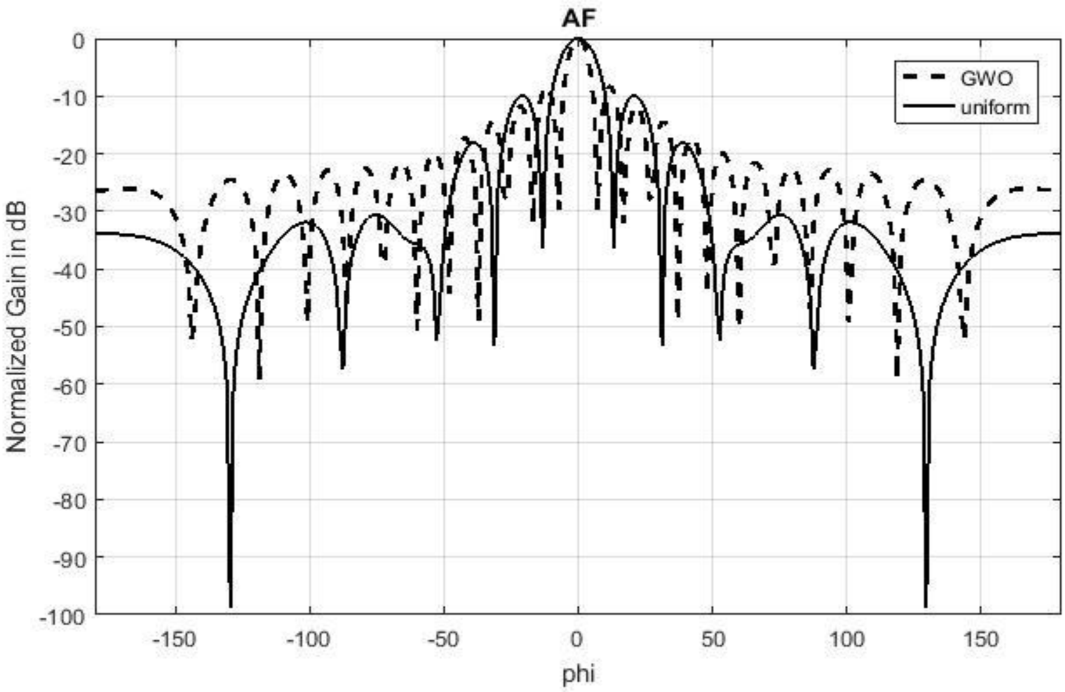

Figure 4.2: pattern of CEA when optimizing only directivity.

c- Optimization of Both SLL and DIR

Figure (4.3) show the pattern of the array factor when optimizing for both SLL and Directivity, the absolute value of SLL–DIR for the optimized case is more considerable than the uniform case (optimizing case =47.53,Uniform case =44.86).

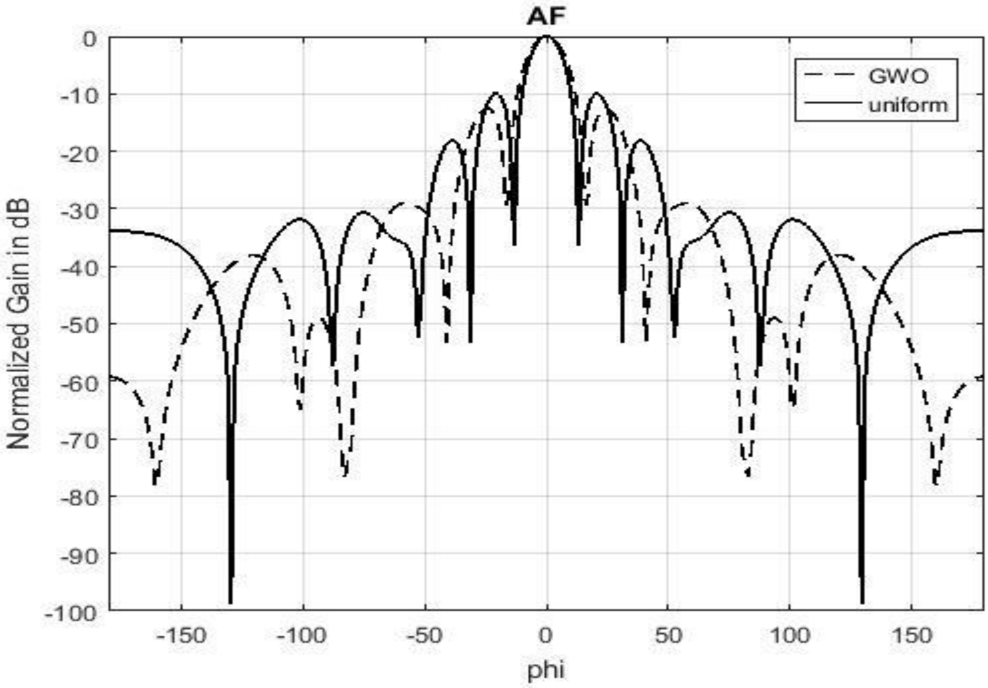

Figure 4.3: *pattern of CEA when optimizing SLL and directivity.*

4.4. Results and Discussion

Table 4.1.*The Results of the Optimization of CEA.*

	SLL	DIR	Ratio($\left\|\frac{DIR}{SLL}\right\|$)
Uniform	−9.917dB	34.95dB	3.52
Optimizing SLL	−31.56dB	33.93dB	1.075
Optimizing DIR	−7.89dB	38.23dB	4.86
Optimizing both	−12.59dB	34.94dB	2.77

From the table, we see that the best SLL and directivity are –31.56dB and 38.23 dB respectively, and we can remark that no directivity improvement while optimizing the side lobe level and vice versa.

For the uniform one has the absolute value of SLL–DIR equal to 44.8656dB, we have optimized it to47.53dB which means that the directivity it is approximately the same as the uniform case, the side lobe level is optimized from –9.917dB to –12.69dB.

4.5. Comparison

Table 4.2: Comparison between Elliptic and Concentric Elliptic Array.

	Elliptic antenna array		**Concentric elliptic array**	
	SLL	**Directivity**	**SLL**	**Directivity**
Uniform	–8.107dB	35.82dB	–9.917dB	34.95dB
Non-uniform	–15.95dB	38.3730dB	–31.56dB	38.23dB
Improvement (%)	96.74	7.12	218.24	9.38

Comment: We see that the optimized side lobe level and the optimized directivity are much better than the SLL and the directivity of uniform one for both antennas, from the percentage of the optimization we see that the concentric elliptic array is much optimized and get a better SLL comparing to elliptic array.

4.6. Conclusion

Gray wolf optimization is a new technique in electromagnetics optimization. It was applied on the optimization of concentric elliptical antenna array, and from the result obtained, it is clear that GWO has successfully generates the values of the amplitude and eccentricity for a reducing SLL and improving the directivity for the CEAA.

GENERAL CONCLUSION

In this report, a new nature-inspired global optimization technique, called Grey wolf optimization (GWO) is used for the optimization of simple elliptic and concentric elliptic antenna arrays. GWO is a new nature-inspired meta-heuristic algorithm inspired by the social hierarchy and hunting behavior of grey wolves. In the GWO algorithm, the hunting (optimization) is guided by α, β, and where alpha (α) is the fittest solution, (β) and delta (δ) are the second and third best solutions. The rest of the candidate solutions are assumed to be omega (ω).

The GWO algorithm generates the non-uniform excitation amplitude for the elliptical and concentric elliptical arrays in question with a set of dimension, minimum and maximum boundaries. The performance of the antennas arrays was optimized in term of side lobe level and directivity. Another parameter has been found to affect the performance of the arrays is the eccentricity factor that has been embedded into the optimization problem along with the element excitations. The simulated results reveal that the optimal design offers a considerable SLL reduction along with an improvement in Directivity compared to the corresponding uniform arrays.

Furthermore for a future research GWO can be focused upon exploration of other parameters like gain, beam width, first null, by varying more parameter like spacing.

REFERENCES

[1]. An Introduction to Communication Antennas' Proceedings Paper for Engineering 302 Spring 2004.

[2] IEEE Standard for Definitions of Terms for Antennas, IEEE Std 145-2013, 2014.

[3] C. A. Balanis, Advanced Engineering Electromagnetics. John Wiley & Sons, 1989.

[4] Handbook_of_Antennas_in_Wireless_Communications_(CRC-2002).

[5] Antenna courses by Dr.A.AZRAR

[6] “Antenna-Theory.com” Copyright 2009-2016.

[7]. Neyestanak, A.; Ghiamy, M.; Moghaddasi, M.; Saadeghzadeh, R.: An investigation of hybrid elliptical antenna arrays. IET Microw Antennas Propag.2(1), 28–34 (2008).

[8]. Ahmidi, N.; Neyestanak, A.; Dawes, R.: Elliptical array antenna design based on particle swarm method using fuzzy decision rules.In: 24th Biennial Symposium on Communications, Kingston, ON,pp. 352–355 (2008).

[9] banalis.

[10]. The MacTutor History of Mathematics archive.http://turnbull.dcs.st-and.ac.uk/history/(978…..).

[11]. F. Woepcke, Extrait du Fakhri, traité d’Algèbre par Abou Bekr Mohammed Ben Alhacan Alkarkhi(1853) (978…..).

[12] IEEE, "IEEE Standard Definitions of Terms for Antennas," IEEE, pp. 0-1, February 1983.

[13] Engineering Optimization: Theory and Practice, Fourth Edition, July 2009.

[14] - Yan, K. K. and Y. L. Lu, Side lobe reduction in array pattern synthesis using genetic algorithm," IEEE Trans. Antennas Propagat., Vol. 45, 1117 -1122, 1997.

[15] Khodier, M. M. and C. G. Christodoulou, Linear array geometry synthesis with minimum side lobe level and null control using particle swarm optimization," IEEE Trans. on Antennas Propagate, Vol. 53, No. 8, 2674-2679, August 2005.

[16] Akdagli, A., K. Guney, and D. Karaboga, Touring ant colony optimization algorithm for shaped-beam pattern synthesis of linear antenna arrays," Electromagnetics, Vol. 26, 615-628, 2006.

REFERENCES

[17] Ferreira, J. A. and F. Ares, \Pattern synthesis of conformal arrays by the simulated nnealing technique," Electron. Lett, Vol. 33, No. 14, 1187{1189, July 3, 1997.

[18] Muro C, Escobedo R, Spector L, Coppinger R. Wolf-pack (Canis lupus) hunting strategies emerge from simple rules in computational simulations. Behav Process 2011; 88:192–7.

[19] S.Mirjalili, s.M.mirjalili, and A.lewis,"grey wolf optimizer", advances in engineering software, vol.69, pp.46-61, 2014.

[20] R. A. Sadeghzadeh, A. L. Neyestanak, M. Naser-Moghadasiand M. Ghiamy, "A Comparison of Various Hybrid Elliptical Antenna Arrays," Iranian Journal of Electrical and Computer Engineering, vol. 7, no. 2, pp. 98-106, 2008.

[21] A. A. Lotfi, M. Ghiamy, M. N. Moghaddasi and R. A. Sadeghzadeh, "An Investigation of Hybrid Elliptical Antenna Arrays," IET Microwaves, Antennas & Propagation, vol. 2, no.1, pp. 28-34, Jan. 2008.

[22]MechLD.Alphastatus,dominance,and division of labor in wolf packs.Can J Zool 1999,77:1196-203.