A STUDY ON NATURE BASED SEARCH ALGORITHMS FOR SOLVING OPTIMIZATION PROBLEMS WITH EMPHASIS ON APPLICATION TO ELECTROMAGNETIC ANTENNA ARRAYS

CHAPTER 1

INTRODUCTION

1.1. INTRODUCTION TO THE SUBJECT

1.1.1 OPTIMIZATION TECHNIQUE:

Optimization has been interpreted in many ways. According to Rao, “optimization is the act of obtaining the best result under given circumstances”. [1.1]. In Bronson’s words, optimization problem “is one in which the aim is to maximize or minimize a specific quantity, called the objective, which depends on a finite number of input variables. These variables may be independent of each other, or may be related through one or more constraints" [1.2]. Hill has described optimization as the process of “finding the best solution (least expensive or most efficient) by asking ‘what if’ and exploring all possibilities.” [1.3]. Irrespective of technique or approach used, the ultimate goal of optimization has always been to either maximize the desired result or minimize the effort required. This has lead to optimization becoming a full-fledged mathematical discipline that concerns with the finding of minima or maxima of functions, subject to constraints.

Mathematically speaking, optimization is a way of finding a set of values of \( \{x_1, x_2, x_3, \ldots\} \) which provides, minimum / maximum value of an objective function, \( y = f(x_1, x_2, x_3, \ldots) \).

For a typical System shown in Fig.1.1, optimization problem can be formulated as [1.4],
Maximize / Minimize, $\xi = \{ Q[A(Z)] \}$, \hspace{1cm} (1.1)

Q : Performance criteria of the system, being monitored
Z : set of design variables of the system, each within limit S
A : Operator expressing the relationship between Q and Z
$\xi$ : Numeric representative of system performance Q

Optimization approach of the problem will generally depend on the relational operator A. When A is a differentiable function and the derivatives are continuous, classical analytical methods based on differential calculus can be used for finding the unconstrained maxima and minima of the function, even if it contains several variables.

When the nature of the relational operator A is linear, Linear Programming (LP) techniques are useful. LP technique was first recognized by economists in 1930’s for optimum allocation of resources. Since then LP techniques have seen a revolutionary development and find good number of applications in operational research areas.

The problems where A is nonlinear can be tackled by using Non Linear Programming (NLP) techniques. Deterministic techniques can be used when a clear relationship exists between characteristics of possible solutions and their utility. When such a relationship is not definable, stochastic techniques are useful.

1.1.2 OPTIMIZATION TECHNIQUES AND SEARCH ALGORITHMS

In many practical situations, the optimization problem may lead to a number of possible solutions, and one may have to use discretion in choosing the right solution depending on situational application. Finding such a solution can prove quite difficult, even with powerful computing. In this context, optimization implies finding many solutions and then selecting the best one, based on the needs / constraints.

Searching for the right solution would tend to make the whole process slow, and hence requires application of proper algorithm. Depending on the type of problem taken for optimization, the underlying methodology of the search algorithm may vary from the
basic brute force search technique to sophisticated techniques based on different forms of heuristics. [1.5]

Some heuristic techniques improve quality of candidate solution iteratively by exploiting partial knowledge about structure of the space using probability rules, working in an “oriented random” manner. These are generally referred as Stochastic Optimization Techniques (SOT) and use only information from the objective function, not requiring knowledge of its derivatives or possible discontinuities.

1.1.3 NATURE BASED SEARCH ALGORITHMS (NBSA)

Many of the stochastic techniques have been evolved by imitating natural processes. Complexities involved in natural processes do not follow any simplistic or ordered methodology and hence are often modeled as random events. Systems where output-input relationship is complex and does not follow an easily-orderable methodology is considered akin to natural systems. It is presumed that the more complex the output-input relationship appears, the more likely that a random process may lead to the solution. This is the logic in using random methods for obtaining solutions in complex optimization problems.

Stochastic techniques which have taken inspiration from Nature are called Nature Based Search Algorithms (NBSA). They make few or no assumptions about the problem being optimized and can search very large spaces of candidate solutions. They can work efficiently even when the number of variables are large i.e., the solution space is large and multi-dimensional.

NBSA use population based random solutions, which are scored based upon their fitness to the desired solution and then are improved in the future by exploiting the previous solution which performed the best. At each moment in time a random population of potential optimal solutions is created and fitness to the desired solution is evaluated to direct the algorithm towards the optimal solution.
NBSA do not follow the computational cost surfaces like gradient based methods, but they possess the ability to jump around the computational space and leap from the trappings of local minima to converge to a practically acceptable solution.

Some popular NBS Algorithms are Genetic Algorithms (GA), Particle swarm optimization (PSO) and Ant colony organization (ACO). GA is modeled after the Darwin’s theory of evolution. PSO draws its inspiration from a group of birds flocking together and ACO is based on the foraging behavior of ant colonies. All of them are inspired from nature, and work on a set of population of solutions rather than from a single solution.

1.2 INTRODUCTION TO PRESENT INVESTIGATION

The present investigation is on applying NBSA for solving optimization problems related to electromagnetic antenna arrays.

1.2.1 ELECTROMAGNETIC ANTENNA ARRAYS (EAA)

Electro-Magnetics (EM), in general, refers to the usage of frequencies of the order of a few hundreds of Mega-Hertz (MHz). James Clark Maxwell’s generalisation and prediction of the existence of electromagnetic waves in the late nineteenth century has laid the foundation for modern microwaves and millimetre wave communication engineering. Most of the modern Communication and Radar systems operate in these frequency bands. In particular, microwave (about 1 GHz and above) and millimetric wave bands (about 30GHz and above) are becoming important due to the very large channel capacity that these systems can provide for communications. Also, most of the military radar systems operate in these frequency bands, since it is possible to design systems with high resolution and sensitivity at microwave and millimetric bands.

Antennas have been around for a long time as the organ of touch or feeling in animals, birds and insects. But for the past more than hundred years, antennas have become indispensable part of most electronic devices. They have acquired a new significance as the connecting link between the free space and the electronic device. They have become
an integral part of most of the modern day electronic devices right from the hand-held mobile phone to the most complex communication system.

Although available in a large variety, all antennas operate according to the same basic principles of electromagnetics. In addition to receiving or transmitting energy, an antenna is required to optimize the radiation energy in some directions and suppress it in others. Thus, it must act as a directional device.

Whereas a simple device like the mobile phone may be able to function with a single antenna, many systems would require radiation characteristics that may not be achievable by a single antenna element alone. In such cases, an array of similar antennas is used to get the desired characteristics. These are called Electromagnetic Antenna Arrays (EAA). The number of elements and method of their working differ based on application. For instance, the base-station of a mobile communication system may have just 4 or 8 antenna elements only, but a sophisticated electronic scanning antenna of a missile-tracking radar system can deploy up to tens of thousands of antenna elements. A pictorial view of a large EAA as part of a phased array radar is shown in Figure. 1.2

1.2.2 OPTIMIZATION IN EAA

Optimization in the context of EAA generally refers to its design to meet certain requirements of radiation pattern, including its gain, beam width, side lobe level, shape etc. In certain specific systems, optimization would also involve meeting requirements in respect of size, weight, power consumption, heat dissipation, cost, complexity etc. Most of these aspects have been well researched and analytical and other methods are well documented. [1.6-1.19]

In case of systems involving very large number of antenna elements, an interesting aspect of the design involves ‘thinning’ the array. Thinning involves reducing total number of active elements in an antenna array without causing major degradation in system performance. Need for such approach arises in large arrays because the antenna subsystems include a large numbers of sensitive RF components such as switches, phase shifters, electronic attenuators, limiters and other components apart from the basic
radiating elements. These components are very sensitive to thermal variations. Also in order to avoid unwanted ‘grating lobes’, the antenna subsystems have to be necessarily packed into a very dense environment. Spacing between two elements in case of typical radar operating at 10 GHz would be of the order of 1 cm only. Such tight packing would cause severe heat dissipation problems, especially when thousands of them are operating together in a battlefield environment. Also, most of the antennas are mounted at such locations on vehicles where they get exposed to severe weather conditions, which pose a design challenge to thermal management, power dissipation and reliability of the antenna subsystem in these radars. Thinning is a technique by which these problems can be mitigated.

Typical antenna head without and with thinning is shown in Figure 1.3(a) and (b). The total number of active elements in a thinned array is far less as compared to an antenna without thinning. The key factor in the design of thinned array is to optimally choose appropriate elements which can be electronically deactivated from the antenna head without significantly affecting the system performance.

It is this problem which is proposed to be studied in the present investigation.

1.2.3 RELEVANCE OF NBSA FOR THE OPTIMIZATION PROBLEM

As explained above, optimum thinning of an antenna array requires finding a strategic subset of antenna elements for its optimum performance. From a mathematical perspective this is a nonlinear, multi-dimensional problem with multiple objectives and many constraints. Solution for such problem cannot be obtained by classical analytical techniques.

It will be required to employ some type of search algorithm which can lead to a practical solution in an optimal way. A cursory study shows that the size of the feasible solution space through which the search algorithm has to navigate and find solution would be extremely large due to the large number of antenna elements. Thus it is impossible to deploy brute force technique of exhaustive search. Essentially the search and
optimization technique should aim at reducing the search time and computational resources.

In view of the above, present investigation plans to explore the possibility of using Nature Based Search Algorithms (NBSA) for solving the EAA thinning problem. Since these algorithms are capable of searching through large multi-dimensional solution space, they seem to be ideal for this investigation.

1.3 PRESENT WORK

1.3.1 SUMMARY OF OBJECTIVES

Following are some of the objectives of the present work:

- Understand the implications of thinning in an antenna array and formulating it as an optimization problem.
- Study representative NBSA algorithms with a view of applying them for solving the thinning problem in antenna arrays.
- Identifying problems related to scaling and other issues related to thinning of large antenna arrays.
- Investigating solutions for these problems and verifying the solutions through appropriate simulation studies.
- Examine suitability of NBSA approach for real-time dynamic thinning.
- Documentation so that further investigations can be carried out by other interested researchers.

1.3.2 MOTIVATION FOR THE PRESENT WORK:

Motivation for the present work has come from the following aspects:

- Very limited work has been reported on thinning of large scale Electromagnetic Antenna Arrays
- NBSA is an emerging field of study with enormous scope for application-oriented research
• Proposed activity is an inter-disciplinary work involving Artificial Intelligence, biological systems and electronics; Thus opportunities exist for learning and understanding new disciplines

• Being an inter-disciplinary activity, scope exists for taking up exciting challenges.

• Results of the proposed study are of practical utility, and are useful for design of systems which has relevance to National security and other applications.

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Figure 1.3 (a) A typical antenna head with around 4000 elements (b) Thinned array with a 4000-element grid containing only 900 elements

REFERENCES


