Multi-Objective Optimization of a Switched Parasitic Array Antenna

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Abstract

This paper examines the approximated trade-off surface of an adaptive directional antenna in terms of antenna size and directional gain using a Multi-Objective Particle Swarm Algorithm.

1. Introduction

An antenna system providing a directional radiation lobe has many associated advantages in a wireless communication link, in particular the minimization of multi-path fading effects, a phenomenon encountered when arriving signal have phase variations due to different travel paths subsequently causing destructive interference. If a directional radiation lobe on the receiver antenna is formed, multi-path instances would be effectively attenuated according to the far field radiation pattern of the receiver antenna. Further more a direction lobe of the transmitter system aligned to the receiver antenna, will direct a majority of the electromagnetic to the receiver thus reducing reflections and diffractions of the electromagnetic energy that causes the multi-path fading effect. The gain of the directional lobe has a major impact on the influence of multi-path fading as it implies strength of the radiation intensity in a given direction compared to intensity in the remaining directions. This value is directly related to the size of the antenna.

Recently switched parasitic antennas embedded into a dielectric material have been proposed for wireless computing utilizing the 802.15b standard [1] due to their reduced size and ergonomics. This article investigates the tradeoff between the size of the switched parasitic array antennas and the absolute gain of the directional lobe using a multi-objective optimization algorithm.

2. Dielectric Embedded Switched Parasitic Array Antenna

The antenna array proposed in this article consists of 7-elements combining six parasitic elements arranged in a circular array spaced at 60° intervals and one active element located at the centre of the array, embedded in a dielectric material and situated on a ground plane. This configuration is illustrated in figure 1 where element 1 is active and the remaining elements are parasitic. Due to the symmetrical nature of the antenna, any radiation pattern formed by the antenna may be reproduced at 60° intervals throughout the azimuth plane. A hollow cylindrical ground skirt is also used to reduce the lateral ground plane size. Ultimately, formulation of a full or partial analytical electromagnetic solution for the proposed antenna is arduous and impractical therefore the design methodology must shift towards an optimization and finite element simulation routine providing a more practical and effective design tool. In this instance the design of the antenna was reformulated in the form of a multi-objective optimization problem with the objective of finding the trade-off between antenna gain and radial size by varying the dimensions of the antenna and the size of the parasitic elements. The dimensions included the height of the elements, distance from element 1 and the size of the dielectric material. The ground skirt however was kept constant at 0.25λ.

3. Multi-Objective Optimization

A multi-objective optimization problem with m objectives is generally defined by:

minimize \( F(x) \), \( F_2(x), \ldots, F_m(x) \)
Where the decision vector \( \mathbf{x} = \{x_1, x_2, \ldots, x_n\} \) belongs to a feasible region defined by \( \mathbf{x} \in \mathbb{R}^n \). \( \mathbb{R}^n \) may be bounded, depending on the constraints of the problem.

In multi-objective optimization, to determine whether one decision vector is more attractive than another, a domination relation is used. For decision vectors \( \mathbf{x}_1 \) and \( \mathbf{x}_2 \), the following conditions are met:

- \( \mathbf{x}_1 \) is at least as good as \( \mathbf{x}_2 \) for all the objectives, and
- \( \mathbf{x}_1 \) is strictly better than \( \mathbf{x}_2 \) for at least one objective

then \( \mathbf{x}_1 \) is said to "dominate" \( \mathbf{x}_2 \) (denoted \( \mathbf{x}_1 \prec \mathbf{x}_2 \)).

In the case where \( \mathbf{x}_1 \) and \( \mathbf{x}_2 \) dominate others but not each other they are deemed mutually optimal solutions and referred to as Pareto-optimal. The output of a multi-objective optimization is a set of Pareto-optimal solutions which reflect the trade-off surfaces between the different objectives. This set of Pareto-optimal solutions is referred to as the global Pareto-front.

4. Multi-Objective Particle Swarm Optimization

In this instance a Multi-Objective Particle Swarm Algorithm was used to approximate the global Pareto Front of the antenna gain and radiation. The formulation of a particle swarm algorithm begins with the definition of an \( N \)-sized population, or swarm, of decision vectors, denoted \( \mathbf{P}^i \), where \( i \) represents the generation. Each \( i \)-th particle in the swarm has a position and velocity defined in parameters space at time \( t \) as \( \mathbf{x}_i^t = \{x_{i1}, x_{i2}, \ldots, x_{in}\} \) and \( v_i^t = \{v_{i1}, v_{i2}, \ldots, v_{in}\} \) respectively. After each generation these vectors are routinely updated using:

\[
\begin{align*}
\mathbf{v}_i^{t+1} &= w\mathbf{v}_i^t + c_1\mathbf{R}_1(\mathbf{p}_i^t - \mathbf{x}_i^t) + c_2\mathbf{R}_2(\mathbf{p}_g^t - \mathbf{x}_i^t) \\
\mathbf{x}_i^{t+1} &= \mathbf{x}_i^t + \mathbf{v}_i^{t+1}
\end{align*}
\]

(2)

Position \( \mathbf{p}_i^t \) is defined as the best position found by the \( i \)-th particle so far. This vector is updated after each generation. \( \mathbf{p}_g^t \) is the global best vector of all the particles in the swarm. Both these positions may contribute in determining the direction and velocity of the particular particle. The \( c_1 \) and \( c_2 \) terms are positive. The \( w \) term is referred to as the inertial weight which limits the effect of updates on the velocity vector. \( \mathbf{R}_1 \) and \( \mathbf{R}_2 \) are randomly generated values in the range of \([0,1]\) used to add a stochastic element when updating the velocity.

5. Results

Figure 2 shows the preliminary results of the approximated Pareto Front for the size of the antenna and the radiation gain as well as the dominated simulated points. The future paper will present a comparison of the radiation performance of the various Pareto-optimal solutions and illustrate the performance gain in using multi-objective optimization techniques.

6. References