Optimization of Three Dimensional Beamforming in Planar Array using Firefly Algorithm

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ABSTRACT
The efficient way of improving the system capacity by filtering the interferers spatially is achieved through beam forming in smart antennas. Unlike Omni directional antennas, smart antennas radiate power only in the desired direction where the users are present at the moment. The spatial filtering of the signals from entire angular region is monitored and the desired radiation pattern is achieved towards the user and nulls in the interferers. The optimization of radiation pattern provides the above purpose. To optimize radiation pattern the direction of arrival is to be known. The beam scanning is performed to get the desired angle of reception for beam steering. In this paper, the firefly algorithm is analyzed for radiation pattern synthesis in planar array.

Keywords
Direction of arrival, beam forming, planar array, firefly algorithm.

1. INTRODUCTION
The recent advancements in the beam forming plays an important role in better optimization of radiation pattern in fulfilling the increased demands of mobile communication. The desired radiation pattern is either achieved by directional antenna array beam forming only in the intended angular region or adaptive radiation in particular angular region with respect to continuously changing demand of the user. The array pattern synthesis is easier with modern mathematical tools available. The optimization of radiation pattern can be position, amplitude and phase coefficients. Individual array elements are progressively phase shifted to get the desired direction of interest. Estimation of direction of arrival done spatially by beam scanning in the entire azimuth and elevation plane. The direction of arrival of desired direction can be found by focusing the highest power signal received direction in presence of multi-path signals. Phased array antennas used for narrow beam patterns for better spatial coverage. Beam forming weight vectors are calculated to optimize radiation pattern of desired direction by using variable phase shifters. The weights vectors of the beam former changed adaptively to provide optimized radiation pattern. Smart antenna radiation patterns are dynamically changed via algorithms based on demand of the spatial coverage area.

To control beam in certain direction some techniques are followed by adaptive algorithms. Algorithms considers maximizing the signal-to-interference-plus-noise ratio (SINR), minimizing the variance, minimizing the mean-square error (MSE),etc. These techniques are implemented through digital signal processors and this beam forming is called digital beam forming. The antenna array consists of individual antenna elements are connected to a receiver by amplitude and phase shifters. Adaptive algorithms are used to adjust weights used by amplitude and phase shifter to each elements or portion of the array antenna. The best solution of an optimization algorithm for a given problem depends entirely on its initial parameters. To enhance the performance of the algorithm control parameters should be chosen effectively for the algorithm to converge to the desired solution. During the evaluation of choosing desired solution some parameters are used to control the solution which values change in every iteration and some are used to skip undesired solutions. Control strategies can be deterministic or adaptive. A large number of generations for a given optimization provide more converged solutions.

Firefly algorithm performance to the multi-objective maximization problem of cost function provides better optimization is analysed [2]. They considered simple queuing systems with single class of service with finite capacity and impatient customers. In Minimum variance distortion less beam former uses weights by minimizing the output noise power. However, MVDR can be used with high signal to noise ratio, low noise level and considers signal passing through the beam former is undistorted [3]. Minimization of side-lobe level in linear array using firefly algorithm in single plane is possible with control of phase coefficients. [4]. Interference rejection in certain undesirable ranges is nullified using fitness function while increasing the signal to interference (SIR). Heuristic particle swarm optimization uses fitness function for maximizing signal interference ratio performed and produced optimal solutions.

In this paper, the firefly algorithm is to optimize the weights of beamfomer to achieve the maximum gain in the maximum signal interference noise power (SINR) [5] direction while nulls placed in radiation pattern in the direction of the interferers.

1.1 Firefly Algorithm
The movement of a firefly reaching the maximum brightness in firefly group inspires to give better solutions for optimization problems.

The basic rules for a movement of firefly

• All fireflies are unisex, and they will move towards more Attractive and brighter ones.
• The attractiveness of a firefly is proportional to its brightness, This decreases as the distance from the other firefly increases. If there is not a more attractive firefly than a

Particular one, it will move randomly.
• The brightness of a firefly is determined by the value of the Objective function. For maximization problems, the brightness

is proportional to the value of the objective function.

$$\beta(r) = \beta_0 e^{-\gamma r^m}, \qquad m \geq 1.$$

Attractiveness value initially taken as β_0 maximum and it is based on the distance between two fireflies assumed to be zero.

Distance between fireflies is given by

$$r_{ij} = \|x_i - x_j\| = \sqrt{\sum_{k=1}^{d} (x_{i,k} - x_{j,k})^2}$$

The movement of firefly is given by

$$x_i = x_i + \beta_0 e^{-\gamma r_{i,j}^2}(x_j - x_i) + \alpha\left(rand - \frac{1}{2}\right).$$

Initial position x_i gets changed when it is attracted towards other firefly located in the spatial region by second term in the above equation. The randomness $\alpha = 1$ of the firefly is fixed when it is able to find best attracted one nearby. If it is not then the random movement changed by having different values α between 1 and 0.

1.2 Uniform Rectangular Array

Let us assume uniform rectangular array under consideration is an array of M x N array elements positioned along the XY-plane spacing each other as shown in Figure 1.The array factor is a multiplication of two plane array of sum of individual elements.

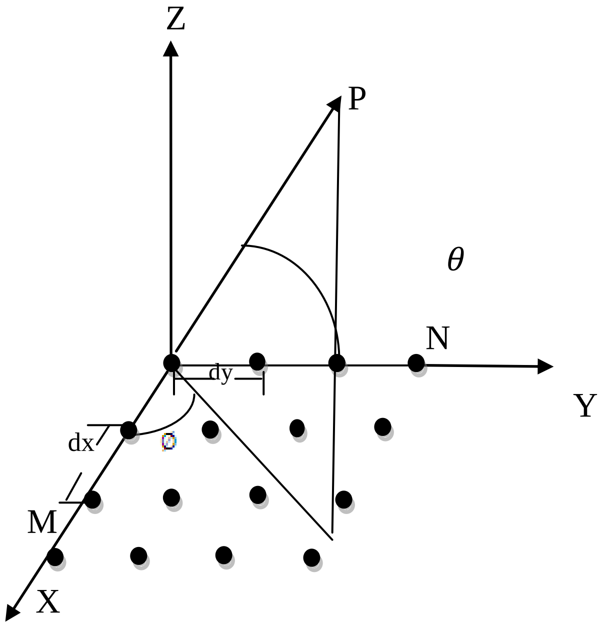

Fig.1

The array factor for the rectangular array is given by

$$AF(\Theta, \emptyset) = \sum_{m=1}^{M} a_m\, e^{j(m-1)(k\,d_x \sin\theta \cos\emptyset + \beta_x)} \sum_{n=1}^{N} b_n\, e^{j(n-1)(k\,d_y \sin\theta \sin\emptyset + \beta_y)}$$

Where,

a_m- constant amplitude coefficient weight along x- direction

b_n - constant amplitude coefficient weight along y-direction

$d_x = d_y = \lambda/2$

β_x - phase shift coefficient weight along x- direction

β_y - phase shift coefficient weight along y-direction

the amplitude coefficient weights a_m and b_n are used to control the side lobes in the radiation pattern.

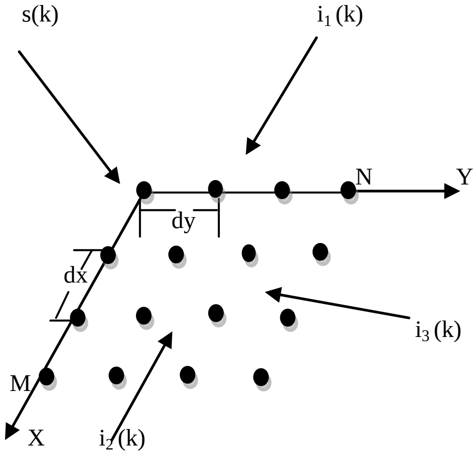

Fig.2

s(k) – Main Signal Direction of Arrival at ($\theta, \emptyset$)

i_1 (k), i_2(k) and i_3(k) – Interference Signal at Different Direction of Arrival at ($\theta, \emptyset$)

Phase shift between adjacent array elements will be

$$\beta = \frac{2\pi}{\lambda}[m\, d_x \sin\Theta + n\, d_y \sin\emptyset]$$

The number phase shifts required to steer the entire planar array elements to the desired user coverage region going to be mxn weights for mxn array elements.

The total array antennas output response is given by an optimization criterion proposed by Applebaum[5] to maximize the SINR.

$Y(t) = W^H X(k)$

Where X(k) is the collective response of all the individual array elements with interference and noise consideration and the same relation given by

$X(k) = a_0 S(k) + [a_1\ a_2 \ldots a_{16}][i_1(k)\ i_2(k)\ i_2(k) \ldots i_N(k)]^H + n(k)$

$= X_S(k) + X_I(k) + X_N(k)$

$P_S = E[\,|W^H X_S|^2\,] = W^H R_S W$

Where $R_S = E[X_s X_s^H]$

$P_{IN} = E[\,|W^H U|^2\,] = W^H R_I W$

Where $R_{IN} = R_I + R_N$

$SINR = \frac{P_S}{P_{IN}} = \frac{a^2 |W^H X_S|^2}{W^H R_{IN} W}$ Where P_S - Desired Signal Power

P_{IN} – Interference and noise power

This SINR is the fitness function taken into consideration for optimization process. Weight vectors are optimized for maximum number of firefly generation to reach the best vector for the optimized radiation pattern.

2. PROPOSED FIREFLY ALGORITHM OPTIMIZATION

In the proposed firefly algorithm, the optimization is done based on the radiation pattern objective function for a given problem which follows a similar process of a fire-fly getting attracted towards brighter light intensity. Fireflies are attracted to other firefly/fireflies based only on the signal power of the other firefly. The attractiveness is proportional to the signal power, and they both decrease as their distance increases. If there is no brighter one than a particular firefly, it will move randomly. The brightness of a firefly is determined by the value of the objective function. The objective function is the formula for maximizing the SINR.

Optimization performed after the beam scanning over the angular sector of desired interest for both azimuth angles and elevation angles. The threshold power is set to restrict the undesired power angle of arrival. The initial attractiveness of the i^{th} firefly is the threshold power attractiveness hence the scanning starts from i^{th} firefly to complete initial population of fireflies. The initial population of fireflies is generated by beam scanning with multiple sets angle of arrival directions. The optimization weight vector starts with the initial set of direction of arrival then the procedure for maximum number of generations for entire fireflies gives required solutions for the all the individual antenna array elements. The scanning range for elevation and azimuth angle take as upper bound and lower bound for fireflies comparison to the region of interest.

Table 1. Firefly Initial Population

Parameters	Parameter Values
ϴ -Scan Range	-30:5:30
∅ - Scan Range	-60:5:60
No. of fireflies	360
α	0 ,1
β_0	0,360
γ	5
R	Distance between i^{th} and j^{th} Firefly position.

The objective function for maximizing the gain towards highest powered signal direction will be

Objective Function = AF_S - AF_{IN}

Initial population of fireflies for optimizing weights will depends upon the objective function. The controlling weights depend on the previously attracted best firefly. If best firefly with maximum attractiveness is identified in further evaluations then the current best is changed with the very optimal values of the recent best. The convergence depends on the γ value chosen. The high value may get faster evaluations however missing the convergence of previous weights. The low γ may get convergence but with maximum evaluations of firefly generation.

Flow Chart

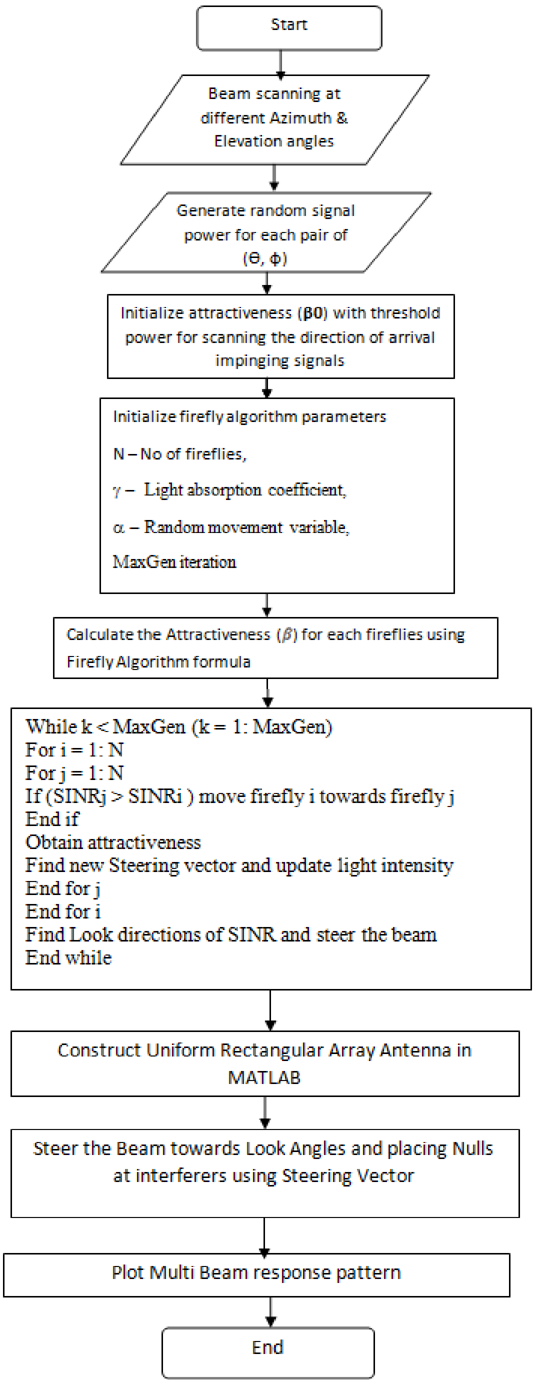

Fig.3

3. SIMULATION RESULTS

The direction of arrival of best signal power directions are estimated using firefly algorithm and the same has been plotted in line plot using MATLAB. Objective is to find the best firefly with maximum brightness at end of the each iteration. Each position x represent a set of phase delay and represent a solution for radiation pattern. Each solution is decided by 360 number of fireflies.

3.1 Beam forming for multiple Look Directions

The simulation results shows firefly optimized radiation pattern for uniform rectangular array of 4x4. The prediction of direction of arrival of multipath signals estimated for various azimuth and elevation angles for beam steering in multi-beam directions are [Ɵ =40, $\emptyset = -30$], [Ɵ =-60, $\emptyset = -20$] and [Ɵ =-20, $\emptyset = 70$]. Figure 4. Shows the radiation pattern in line plot shows multi-beam forming in desired direction of arrival using MATLAB.

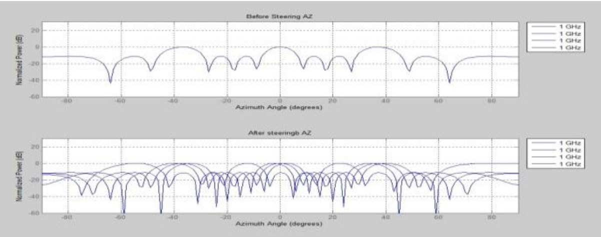

Figure 4.

3.2 Optimized Weights

Initialize the space with 'n' number of solutions which are based on the direction of arrival of desired and interferers. This gives 'n' number of sets of steering vectors. 'α' will be the value of random movement of firefly when no neighbor power attractiveness is not desirable.'α'=0 is set when firefly is attracted to another ($I_j > I_i$)'α'=1 is set when firefly chose random movement ($I_j < I_i$).

Table 2. Optimized Weights

Phase shifter	Weights
$\beta 1$	0.9055
$\beta 2$	-0.8967
$\beta 3$	0.2137
$\beta 4$	0.6299
$\beta 5$	-1.0000
$\beta 6$	0.6207
$\beta 7$	0.2252
$\beta 8$	-0.9018
$\beta 9$	0.9018
$\beta 10$	-0.2252
$\beta 11$	-0.6207
$\beta 12$	1.0000
$\beta 13$	-0.6299
$\beta 14$	-0.2137
$\beta 15$	0.8967
$\beta 16$	-0.9055

The speed of evaluations to reach the optimal solution can be varied by having different values for light absorption coefficient. Firefly algorithm suggest the 'γ' value range is 0.1< 'γ'<10. Choosing higher 'γ' value will speed up the iteration process, but may skip convergence. Choosing lower 'γ' value will slow the iteration process, but will reach convergence. Thus optimal value needs to be decided after trials.

I_j = max (AF) = Array Factor for i^{th} solution which returns the gain of the antenna array as a function of Azimuth and elevation angle.

The objective function will be the maximum gain of array factor of desired signal direction subtracted from the gain of array factor of interferers and noise.

4. CONCLUSION

In this paper, the direction of arrival of the best signal direction is found by scanning the particular region of azimuth and elevation angles in maximum SINR criterion in the presence of multipath signal interference and noise conditions. The weights for beam forming towards the desired angle are optimized with firefly algorithm and best optimized weights are obtained. Further, the firefly algorithm is to be compared with other meta-heuristic algorithms for its performance.

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