Indian Journal of Science and Technology, *Vol 9(26), DOI: 10.17485/ijst/2016/v9i26/93927, July 2016*

ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Performance Evaluation of Smart Antennas Employing Adaptive Elliptical and Hexagonal Arrays using Particle Swarm Optimization and Genetic Algorithm

G. Viswanadh Raviteja[1]*, K. Sridevi[1] and A. Jhansi Rani[2]

[1]Department of ECE, GITAM University, Visakhapatnam - 530045, Andhra Pradesh, India; tejar512@gmail.com, kadiyamsridevi1980@gmail.com

[2]Department of ECE, VR Siddhartha Engineering College, Vijayawada - 520007, Andhra Pradesh, India; jhansi9rani@gmail.com

Abstract

Background: With the advent of smart antennas, there has been a phenomenal technological development in wireless communications industry. They paved path to number of new inventions that gave a boost to mobile industry. In this paper a comparison on elliptical array and hexagonal array of uniformly excited isotropic antennas are studied. **Methods:** The configurations generate maximum directive beam with reduced side lobe level. Two optimization techniques were used, particle swarm optimization and genetic algorithm. Both the arrays are evaluated in terms of efficient null placing and side lobe levels reduction using the algorithms taken into consideration. **Findings:** Hexagonal array using particle swarm optimization has better beam forming capabilities with reduced side lobe levels when compared elliptical array configuration. **Applications:** Smart antennas combat signal fading and suppress interfering signals from unwanted directions and thereby increase the capacity of wireless systems.

Keywords: Array Synthesis, Elliptical Array, GA, Hexagonal Array, PSO, Smart Antennas

1. Introduction

With the advent of wireless technologies it became necessary for efficient and reliable signal transmission. Providing high data rate services to the end users became extremely limited[1]. It is to be noticed that in future there will be rise in traffic levels for mobile communication systems which would be a result of increased users and the need for high data rates. Also other problems such as co-channel interference and mutual coupling degrade the wireless signal transmission[2]. As a solution to all the above stated problems, smart antennas came into existence using which we can effectively increase the data rates[3].

Another important aspect of these smart antennas is that harmful effects of multipath can be minimized to a reduced level which benefits mobile communications[4]. In phased array the term adaptive antenna is used weighting of each element in done in a dynamic fashion. The amount of weighting is not fixed at the time of array design but decided by the system later at the processing time of signals. In other words, the process is under control of the system in use and the antenna array just adjusts to the situation[5]. Antenna array constitute the integral part of smart antenna technology. Array can be defined as a systematic arrangement of radiating elements grouped together[6].

Linear array has the highest capability of forming a narrow main beam in a given direction, but it does not perform well in all the specified azimuthal directions. Circular arrays have certain advantages when

*Author for correspondence

compared to linear array since it does not have edge elements. But the thing is that circular array does not have nulls in azimuthal plane which is most important when it comes to smart antennas as nulls should be placed in azimuthal plane to reject Signals-Not-of-Interest (SNOI)[7]. Use of elliptical arrays is preferred in this case over circular arrays. The hexagonal array concept is introduced in[8].

Genetic algorithm (GA) is developed based on the principle of survival of the fittest given by[9]. Particle Swarm Optimization is developed based on the social behaviour of birds[10]. The synthesis of arrays using different schemes available are explained in[11,12]. The PSO based implementation in given in[13]. In GA the selection procedure is important as it gives the top fit individuals. These top fit individuals have the least cost function[14]. Genetic algorithms are shown to be a very powerful adaptive search scheme technique for large and complex spaces[15]. The other applications and related theory of GA and PSO are studied and the nulling techniques followed are given in[16-18].

Spatial filtering can be achieved by adaptive array; the received signal at first is weighted and then summed to achieve the spatial filtering[19]. Smart antennas gained much importance in the last few years as they can increase the system capacity by tuning out the interference, giving much focus to the desired user. The improved digital signal processors makes the smart antennas really smart[20]. The synthesis of adaptive arrays using SMI algorithm is given in[21]. And using nature inspired Meta heuristic algorithms the work is given in[22].

This paper is divided into four sections. Section I deals the introduction Section II explains the array geometries Section III deals with optimization algorithms used Section IV explains the computed results and Section V finally concludes the paper.

2. Array Geometry

2.1 Elliptical Array

The array geometry with origin as center of the elliptical array is given by[11] (Figure 1)

The array factor is given by[11]

$$AF(\theta,\varphi) = \sum I_n \exp(j[k\sin(\theta)(a\cos(\theta_n)\cos(\varphi) + b\sin(\theta_n)\sin(\varphi)) + \alpha_n]) \quad (1)$$

And $a_n = -k\sin(\theta_0)(a\cos(\phi_n)\cos(\phi_0) + b\sin(\phi_n)\sin(\phi_n)) \quad (2)$

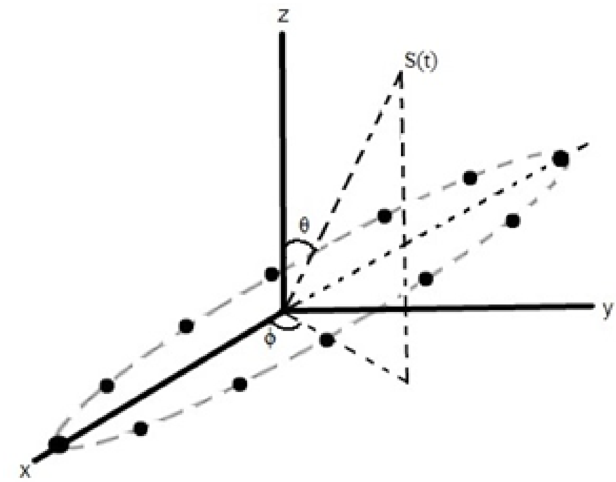

Figure 1. Geometry of elliptical array in XY plane.

Where I_n is amplitude excitation, α_n is the phase of n[th] element, θ is elevation angle from z axis, *e* is the eccentricity of elliptical array i.e., 0.5,

$\theta_0 = 90°$, $\phi_0 = 0°$, N = number of elements

Area (A) = πab, Circumference(c) = $\pi(3(a+b) - \sqrt{(3a+b)(a+3b)}$

2.2 Hexagonal Array

The hexagonal array can be designed using two concentric N-element circular arrays composing of two different radii r_1 and r_2.The figure below shows the arrangement of regular hexagonal array of 2N elements (N=6), out of which N elements are located at vertices of hexagon and the other N number of elements located at midpoints of sides of hexagon[7]. The array geometry for the hexagonal array is given in the following way. (Figure 2)

The array factor for the hexagonal array is given by[7]

$$AF(\theta,\phi) = \sum_{n=1}^{N} [A_n e^{jkr_1 \sin\vartheta(\cos\varphi_{1n}\cos\varphi + \sin\varphi_{1n}\sin\varphi)} + B_n e^{jkr_2 \sin\theta(\cos\varphi_{2n}\cos\varphi + \sin\varphi_{2n}\sin\varphi)}] \quad (3)$$

$$r_2 = r_1 \cos(\pi/N),\ r_1 = d_e/\sin(\pi/N)$$

Where d_e is the inter element spacing along sides of the hexagonal antenna array. $\phi_{1n} = 2\pi(n-1)/N$ denotes angle in xy plane between x axis and n[th] element at vertices of hexagon. $\phi_{2n} = \phi_{1n} + \pi/N$ denotes angle in xy plane between x axis and n[th] element at middle of the each line of hexagon. Finally, A_n and B_n represent amplitudes of n[th] element placed at vertices and middle of hexagon.

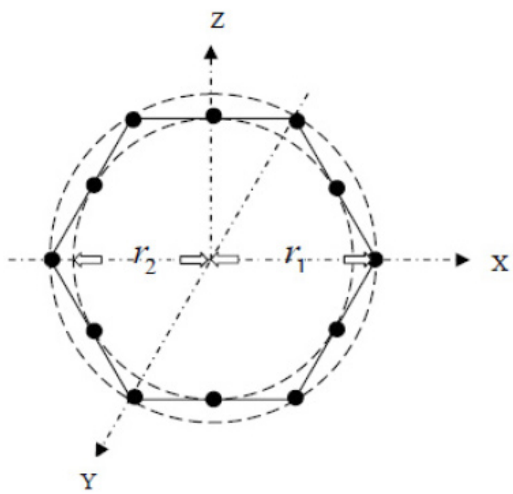

Figure 2. Hexagonal array structure

3. Optimization Techniques

3.1 Genetic Algorithm

This evolutionary algorithm is most useful for problems that constitute number of variables more and local minima. GA is efficient in exploring entire solution space, which may be large and complex[15,16]. The genetic algorithm is computed with the use of computer simulation, which employs population of individuals, called as the search space or solution space. The selection process for the individuals is done by the evaluation of the fitness function using mutation and crossover.

The reproductive cycle for the genetic algorithm is given as follows[14] (Figure 3)
Parameters for genetic algorithm are

1. Crossover type & crossover rate.
2. Mutation type & mutation rate.
3. Population size.
4. Selection Procedure.
5. Number of generations.

The process is repeated till a termination condition is reached[14], i.e.,

1. A solution satisfying minimum criteria.
2. Number of generation specified being reached.
3. Computation time specified is reached.
4. Arrival of fitness value.
5. Manual inspection.

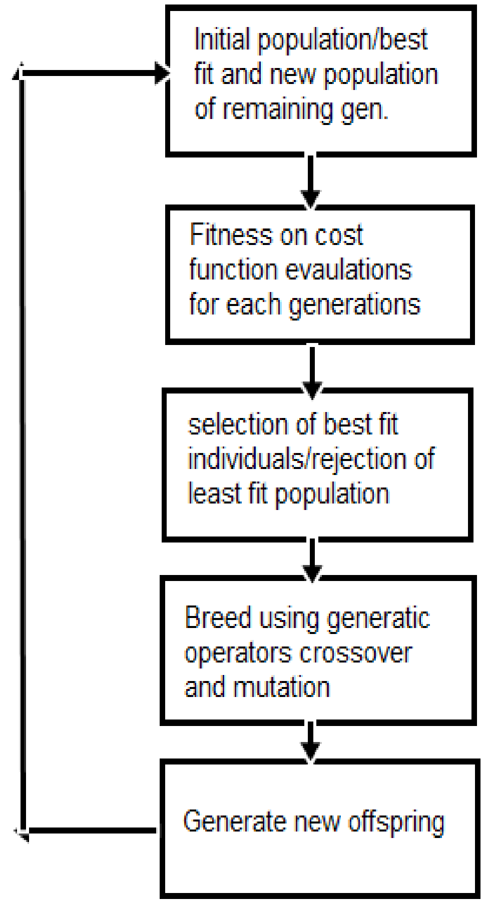

Figure3. Genetic algorithm reproduction cycle.

3.2 Particle Swarm Optimization

In PSO, from a population of available solutions also termed as particles, an optimal solution is searched by the algorithm. The best solution achieved by any particle being (*pbest*) and (*gbest*) is the global best solution. These two are compared and stored for future iterations. The velocity towards p*best* and *gbest* are updated in an iterative manner[17,18].

With PSO, an optimal solution from a population of solutions searched by the algorithm is given by[18] (4) (5)

$$v_{n+1} = w * v_n + c_1 r_1 (p_{best,n} - x_n) + c_2 r_2 (g_{best,n} - x_n) \quad (4)$$

$$x_{n+1} = x_n + v_{n+1} \quad (5)$$

Where v_n is the particle velocity and x_n is the particle position, c_1 and c_2 are taken to be scaling constants.

The fitness function and the corresponding correlation matrix for the received signal is given by[17] (6),(7)

$$f(w) = \frac{\left|w^H . x_s\right|^2}{w^H . R_{xx} . w} \tag{6}$$

$$R_{xx} = R_{ss} + R_{ii} + R_{nn} \tag{7}$$

R_{ss} is the correlation matrix of desired signal, R_{ii} is the correlation matrix of interference signal and R_{nn} is the correlation matrix of the noise signal

4. Simulation Results and Discussion

The simulations are carried out using MATLAB software. The number of elements in case of elliptical array is taken to be N=8 and for the case of hexagonal array number of elements are taken N=12. In this paper up to 4 interferences were tested for both the arrays using GA and PSO algorithms. The simulated plots are given in the following way.

Figure 4,5 and 6 deals with the radiation plot of elliptical array with comparison made between GA and PSO for 2,3 and 4 interferences. (Figure 4) (Figure 5) (Figure 6)

Figure 7,8 and 9 deals with the radiation plot of hexagonal array with comparison made between GA and PSO for 2,3 and 4 interferences. (Figure 7) (Figure 8) (Figure 9)

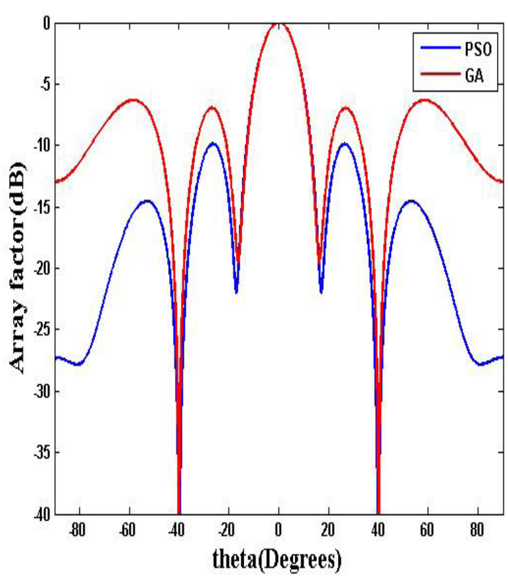

Figure 4. Elliptical array with 2 interferences at 40° and −40°.

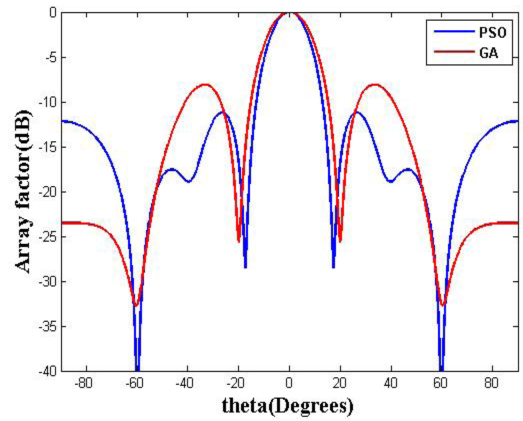

Figure 5. Elliptical array with 3 interferences at −60°, −20° and 60°.

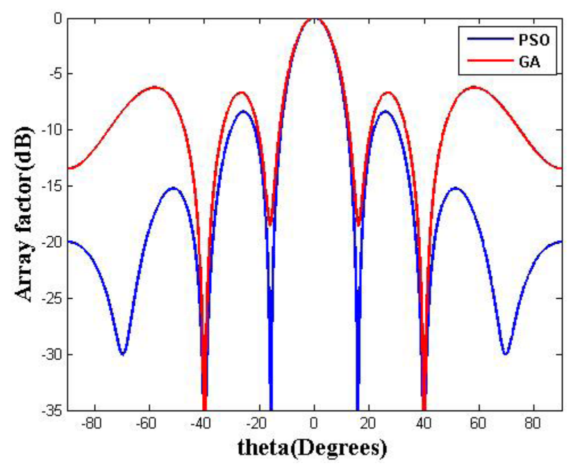

Figure 6. Elliptical array with 4 interferences at −40°, −15°, 15° and 40°

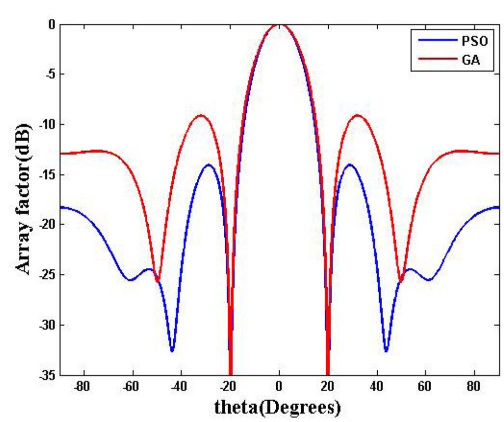

Figure 7. Hexagonal array with 2 interferences at 20° and −20°.

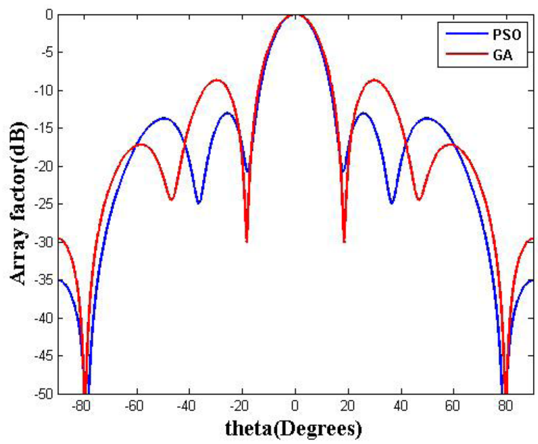

Figure 8. Hexagonal array with 3 interference at –80°,–20° and 80°.

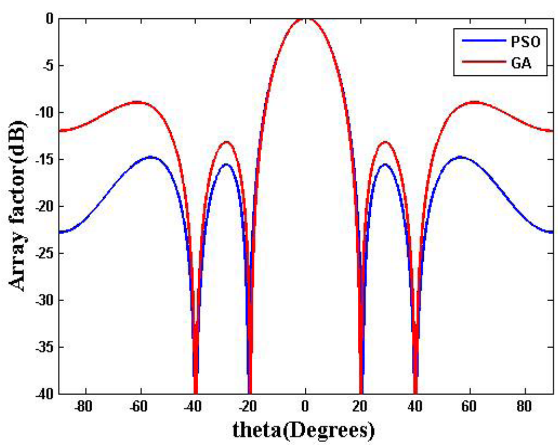

Figure 9. Hexagonal array with 4 interferences at –40°, –20°, 20° and 40°.

Figure 10 shows the comparison of UCA, PUCA, Elliptical and Hexagonal arrays using Particle Swarm optimization and Figure 11 shows the comparison of cost function versus iterations for Genetic algorithm and Particle swarm optimization (Figure 10) (Figure 11)

Figure 10. Comparison of UCA, PUCA, Elliptical and Hexagonal arrays using only PSO with 1st Interference at 40^0 and 2nd interference -40°.

The radiation pattern results observed for different direction of interferences and their corresponding SLL and HPBW values using GA and PSO for both arrays are tabulated. (Table 1) (Table 2) (Table 3)

From the conclusions drawn from the simulated results, it is clearly evident that PSO is better than GA

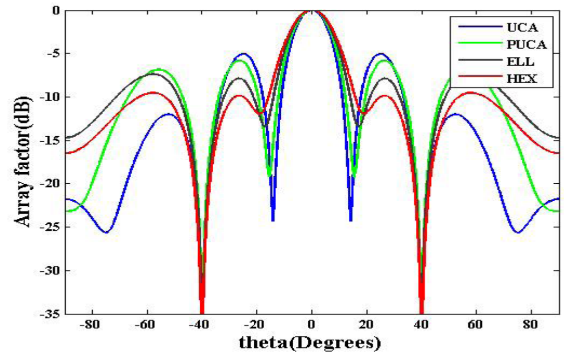

Figure 10. Comparison of UCA, PUCA, Elliptical and Hexagonal arrays using only PSO with 1st Interference at 40° and 2nd interference –40°

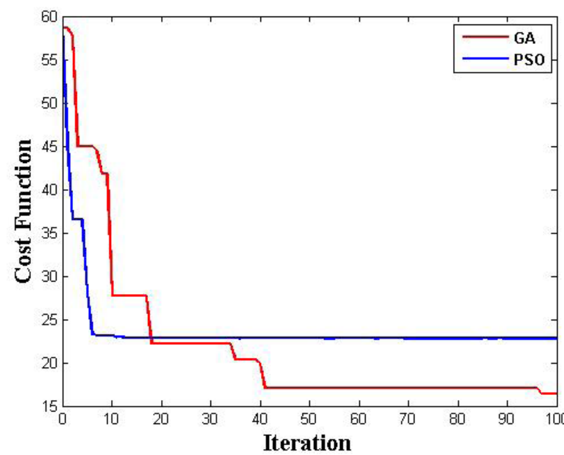

Figure 11. shows the convergence curve for GA and PSO algorithms.

Table 1. Results from synthesis of Elliptical array using GA and PSO

Array configuration	Number of interferences	Algorithm	HPBW[Deg.]	SLL(dB)
Elliptical	2	GA	15.7°	–6.99
		PSO	15.28°	–9.95
	3	GA	18.9°	–8.09
		PSO	16.1°	–11.3
	4	GA	19.94°	–7.3
		PSO	17.34°	–9.34

in factors such as SLL reduction, faster convergence and more precise main beam direction. Also it is proven that hexagonal array is better than elliptical array configuration and the same when used with PSO algorithm yields

Table 2. Results from synthesis of Hexagonal array using GA and PSO

Array configuration	Number of interferences	Algorithm	HPBW[Deg.]	SLL(dB)
Hexagonal	2	GA	18.8°	–9.29
		PSO	18.48°	–14.1
	3	GA	17.7°	–8.96
		PSO	17.44°	–13.13
	4	GA	18.5°	–13.29
		PSO	18.36°	–15.69

Table 3. Amplitude Excitations generated using PSO algorithm

Array configuration	Number of elements	Amplitudes = [I1,I2,……..In]
Elliptical	12	0.02115, 0.13878, 0.60327, 0.13009, 0.30838, 0.21597, 0.6893, 0.64139, 0.56815, 0.89215, 0.95124, 0.75125
Hexagonal	12	0.83256, 0.06140, 0.11081, 0.90372, 0.72708, 0.70605, 0.93218, 0.64216, 0.12487, 0.12727, 0.06463, 0.64274

optimum results. SLL for elliptical array with 2 interferences using GA and PSO is -6.99 dB and -9.95 dB whereas for hexagonal array it is -9.29 dB and -14.1 dB. Similarly, for elliptical array with 3 and 4 interferences using GA and PSO the SLL values are -8.09 dB, -11.3 dB and -7.3 dB, -9.34 dB whereas in the case of hexagonal array the SLL values are-8.96 dB,-13.13 dB and -13.29 dB,-15.69 dB. Therefore, hexagonal array is more preferable when compared to elliptical array and PSO algorithm is better suited for the synthesis of hexagonal array when compared to genetic algorithm.

5. Conclusion

This paper illustrates genetic algorithm and particle swarm optimization for optimization of elliptical array and hexagonal array. The simulated results show that PSO converges faster than GA for both the array geometries. It is also shown that hexagonal array with PSO as optimization algorithm has better beam forming capabilities. Also by the comparison of SLL performances of the two array configurations, hexagonal array showed better performance with reduced Side lobe levels and more precise main beam when compared to the elliptical array.

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