Adaptive Beam-forming Optimization Based Hybrid PSOGSA Algorithm for Smart Antennas Systems

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Abstract— In this paper, a novel technique is presented to enhance the performance analysis of smart antennas systems with different geometries based on Hybrid Particle Swarm Optimization with Gravitational Search Algorithm (Hybrid PSOGSA) algorithm. Complex excitations (phases) of the array radiation pattern are optimized based on Hybrid PSOGSA algorithm using N elements for a Uniform Circular Array (UCA) geometry. The results are compared with those obtained using Uniform Linear Array (ULA) in the previous work. Simulation and discussion results prove enhancement in performance when using the proposed adaptive strategy based UCA smart antenna for different scenarios even for a big set of simultaneously incident signals in terms of normalized array factor.

1. INTRODUCTION

Adaptive beam-forming capabilities for smart antenna arrays are nowadays used in different applications such as suppression and reduction of interference in wireless mobile communication, besides its effects on the overall quality of service [1, 2]. There are different optimization techniques deal with Adaptive beam-forming for smart antennas. Particle Swarm Optimization (PSO), Central Force Optimization (CFO), and Bacterial Swarm Optimization (BSO) are well known Global optimization techniques that are based on a nature-inspired heuristic [3–5]. It was proven that CFO requires higher computational complexity but on the other hand it has better performance than PSO in [6].

Recently, Gravitational Search Algorithm (GSA) is considered as a new optimization technique [7]. Where a set of various standard benchmark functions, synthesis of thinned scanned concentric ring array antenna, and a fully digital controlled reconfigurable concentric ring array antenna problems were examined in [8, 9]. In most cases the GSA provided superior or at least comparable results with PSO and CFO. The GSA was proposed in [10, 11] for calculating the dimensions of a rectangular patch antenna, and for Direction of Arrival (DOA) estimation using a Uniform Circular Array (UCA) of 12 elements based on maximum likelihood (ML) criteria and showed better performance results over PSO and multiple signal classification (MUSIC) in terms of computational time for fitness function and RMSE. In [12], planar ultra-wide band (UWB) antennas with irregular radiator shapes are designed using GSA and compared with those obtained using CFO algorithm, it was found that, the GSA gives better performance than CFO. In [13], GSA was implemented using Open-MP and its results outperform the PSO by 65.09% in terms of normalized array factor. In [14], an algorithm is used for finding the best optimal excitation weights, and optimal uniform inter-element spacing for hyper beam-forming of linear antenna arrays. In [15], a new algorithm based on Hybrid Particle Swarm Optimization with Gravitational Search Algorithm (Hybrid PSOGSA) technique was proposed and showed better performance than standard PSO and GSA in terms of computational speed.

In this paper, a novel algorithm that is based on the hybrid PSOGSA technique is developed for optimal beam-forming using ULA and UCA. The goal is to maximize the beam of the radiation pattern towards the intended user or Signal of Interest (SOI) and minimize the beam of the radiation pattern towards Signal Not of Interest (SNOI) based on controlling the complex weights (phase) of ULA or UCA. The paper is organized as follows. In Section 2, the system model and problem formulation for adaptive beam-forming is explained. However hybrid PSOGSA algorithm is proposed in Section 3. Simulation results and discussions for beam-forming are discussed in Section 4. Finally, Section 5 presents the conclusion.

2. PROBLEM FORMULATION

Smart antenna based on UCA topology by using N elements is showed in Figure 1. In this section, 12 elements in array structure are distributed uniformly along the circle of radius r, where θ is the azimuth angle, λ is the wavelength, the angle between adjacent elements is θ_0, and $d = 0.5\lambda$ is the space between two adjacent elements. In the synthesis of beam-forming, the complex excitation for each element must be optimized to minimize radiation power intensity at certain directions and maximize the main-lobes to other directions. The following fitness function must be minimized to maximize the total output power toward the desired signal at θ_i and minimize the total output power in the direction of the interfering signals at θ_j.

$$\text{fitness function} = -\sum_{i=1}^{k} a_i AF(\theta_i) + \sum_{j=1}^{L} b_j AF(\theta_j) \tag{1}$$

where the number of SOI users is represented in constant k, and L represents the number of SNOI hackers. $AF(\theta_i)$ is the array factor that will be maximized or minimized in specific directions for ULA and UCA using evolutionary algorithms.

$$AF\left(\theta_i\right) = \sum_{n=1}^{N} e^{j[\beta * r * \cos(\theta - pos_n) - \alpha_n]} \quad \text{for UCA} \tag{2}$$

$$AF\left(\theta_i\right) = \sum_{n=1}^{N} e^{j[\beta * (n-1) * d * \cos(\theta) - \alpha_n]} \quad \text{for ULA} \tag{3}$$

where α_n represents the complex excitation phase of the n-th element, pos_n is the angular position of the n-th element, and β is the phase shift constant.

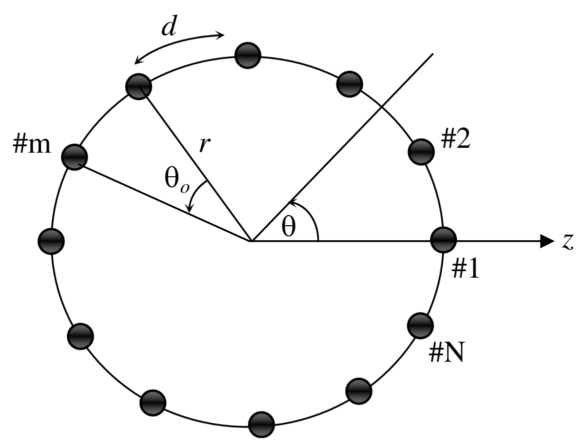


Figure 1: Geometry of the UCA with N elements.

In this paper, our model assumes user #2 as transmitter, desired user #1 as receiver at desired angle SOI $= \theta_d$ from user #2, and hacker at angle SNOI $= \theta_h$ from user #2. In this work, smart antennas array using linear and circular topology are obtained.

3. HYBRID PSOGSA ALGORITHM OPTIMIZATION TECHNIQUE

Several different hybridization methods for heuristic algorithms were presented in [16], when two different algorithms can be hybridized in high-level or low-level with relay or co-evolutionary method as homogeneous or heterogeneous. In this paper, PSO with GSA was hybridized using low-level co-evolutionary heterogeneous hybrid. The basic idea of hybrid PSOGSA is to combine the ability of social thinking (gbest) in PSO with the local search capability of GSA. In order to combine these algorithms, updating velocity is proposed as follow:

$$v_i(t+1) = w * v_i(t) + C1 * \text{rand} * a_i(t) + C2 * \text{rand} * (\text{gbest} - x_i(t)) \tag{4}$$

where $v_i(t)$ is the velocity of agent i at iteration t, w, rand, gbest, $C1$ and $C2$ are taken from PSO algorithm in [4]. On the other hand, from GSA in [7], $a_i(t)$ is the acceleration of agent i at iteration t can be calculated by,

$$a_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)} \tag{5}$$

where, inertia mass, active gravitational mass and passive gravitational $M_{ai} = M_{pi} = M_{ii} = M_i$; $i = 1, 2, \ldots, K$, $F_i^d(t)$ is the total force acting on ith agent calculated as:

$$F_i^d(t) = \sum_{i=1,\, j\neq 1} \text{rand}_j F_{ij}^d(t) \tag{6}$$

where $F_{ij}^d(t)$ is the force acting on agent 'i' from agent 'j' at dth dimension and tth iteration is computed as below:

$$F_{ij}^d(t) = G(t)\frac{M_{pi}(t)M_{aj}(t)}{R_{ij}(t)+\epsilon}\left(x_j^d(t) - x_i^d(t)\right) \tag{7}$$

where, $R_{ij}(t)$ is the Euclidian distance between two agents 'i' and 'j' at iteration t, $G(t)$ is the computed gravitational constant at the same iteration, and ϵ is a small constant.

$$G(t) = G_0 e^{(\alpha t/T)}. \tag{8}$$

In this problem G_0 is set to 100, α is set to 20 and T is the total number of iterations. In each iteration, the positions of particles are updated as follow:

$$x_i(t+1) = x_i(t) + v_i(t+1) \tag{9}$$

In hybrid PSOGSA [15], firstly, each agent is considered as a candidate solution. As can be seen in Figure 2, after initialization, evaluate the fitness function based on Equation (1). Gravitational force, gravitational constant, and resultant forces among agents are calculated using (6), (8) and (7) respectively, After that, the accelerations of particles are defined as (5). In each iteration, the best solution so far (gbest) must be updated. After calculating the accelerations and with updating the best solution so far, the velocities and the positions of all agents can be updated using (4) and (9) respectively. Finally, after agents are updated. The process of updating velocities and positions will be stopped by meeting an end criterion.

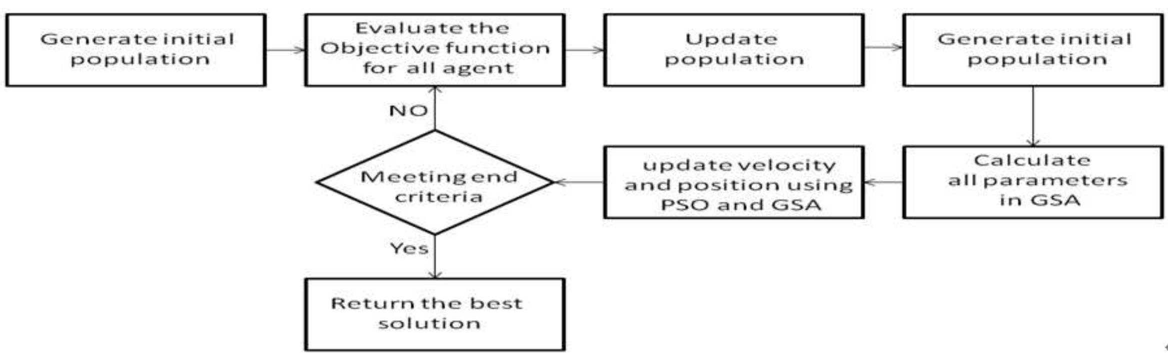
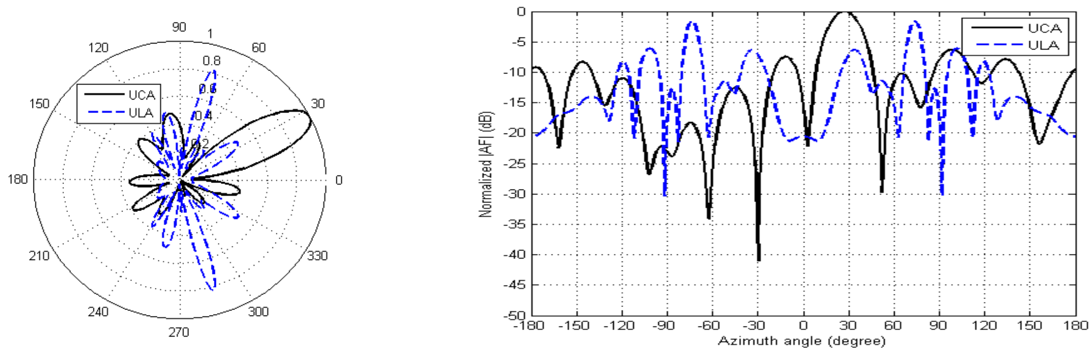


Figure 2: Flow chart for steps in hybrid PSOGSA algorithm.

4. SIMULATION AND DISCUSSION RESULTS

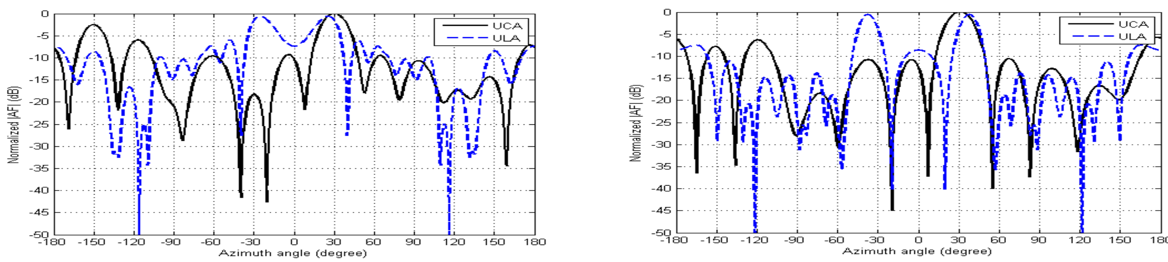
In this section, the capability of hybrid PSOGSA technique for adaptive beam-forming with a UCA and ULA is studied. In this section our model is discussed according to end of Section 2, the first scenario is SOI 30° and SNOI $-30° = -330°(360° - \text{SOI}(\theta_h)$ (broadside direction)). Figure 3 is obtained for normalized array factor comparison using ULA and UCA by Hybrid PSOGSA at SOI 30° and SNOI $-30°$ in polar and rectangular representation. It is found that, only UCA topology has capability to direct the main beam toward user #1 (SOI) and null at hacker #1 (SNOI). It is clear that the directed power toward the intended direction (30°) using UCA is better than that obtained by ULA more than 6 dB (approximately 55%). On the other hand, the directed null (zero power) toward the intended direction ($-30°$) using UCA is better than that obtained by ULA by approximately 35 dB.

In the real applications user #2 in our model may not be located at certain 30°, for this reason the second scenario is proposed where SNOI changed around $-30°$. Figure 4(a) shows SOI at 30° and a changed value $-40°$ for SNOI. Accordingly the results showed an improvement of more than



(a) (b)

Figure 3: Normalized array factor comparison using ULA and UCA by Hybrid PSOGSA at SOI 30° and SNOI −30° = 330°, (a) polar representation and (b) rectangular representation.



(a) (b)

Figure 4: Normalized array factor comparison using ULA and UCA by hybrid PSOGSA at (a) SOI 30° and SNOI −40°, (b) SOI 30° and SNOI −20°.

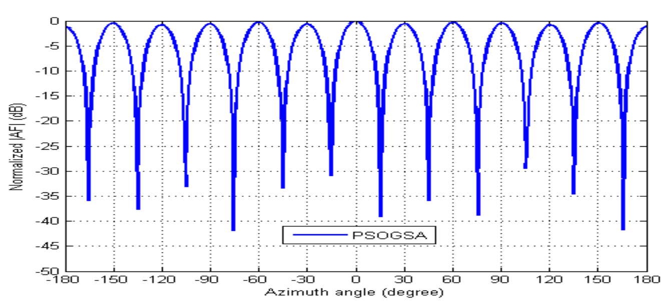


Figure 5: Normalized array factor using hybrid PSOGSA for UCA smart antenna.

1.5 dB and approximately 14 dB for SOI and SNOI respectively. Figure 4(b) shows SOI at 30° and a changed value −20° for SNOI. Accordingly the results showed an improvement of more than 3.5 dB and approximately 5 dB for SOI and SNOI respectively.

Also, it can be noticed that an extra undesired main beam in the broadside direction is obtained in the ULA geometry. Therefore, the first case is the worst case in ULA because SNOI $= \theta_h = (-30°(330°)) = 360 - \mathrm{SOI}(\theta_h)$ (broadside direction). In general, the results obtained by UCA are better than those obtained from ULA which used in [14] for all directions in all scenarios. Finally, Figure 5 proves hybrid PSOGSA has great ability for optimization in beam-forming even for a big set of simultaneously incident signals (k in (1) = 11 desired angles where UCA has 12 elements). Algorithm is employed with a population size of 30 and 150 iterations. The hybrid PSOGSA is used to adjust the weights of phase shift of the excitation of each element of the UCA array for beam synthesis to maximize the output power toward the desired signals at SOI $\theta_i = [-150°, -120°, -90°, -60°, -30°, 0°, 30°, 60°, 90°, 120°, 150°]$ where a_i in (1) at section #2 = [1.4, 1.5, 1.4, 1.4, 1.4, 1, 1.4, 1.4, 1.4, 1.5, 1.4] for previous angle respectively.

5. CONCLUSION

In this paper, a novel technique is proposed for smart antennas systems based on ULA and UCA to enhance the performance of adaptive beam-forming in wireless communications applications. As can be seen from our model that the directed power in terms of normalized array factor toward the intended direction (SOI) using UCA is better than ULA more than 6 dB (approximately 55%), more than 3.5 dB and more than 1.5 dB for different scenarios, on the other hand, directed null to SNOI better than ULA by approximately 35 dB, 5 dB and 14 dB for several scenarios. In addition, simulations of beam-forming showed ability on accurate results even for a big set of simultaneously incident signals. It is found that hybrid PSOGSA is more attractive for beam-forming applications based on our fitness function.

REFERENCES

1. Lehne, P. H. and M. Pettersen, "An overview of smart antenna technology for mobile communications systems," *IEEE Commun. Surveys Tutorials*, Vol. 2, 2–13, 1999.
2. Chryssomallis, M., "Smart antennas," *IEEE Antennas Propag. Mag.*, Vol. 42, 129–136, 2000.
3. Kennedy, J. and R. Eberhart, "Particle swarm optimization," *IEEE International Conference on Neural Networks*, Vol. 4, 1942–1948, Perth, Australia, 1995.
4. Mahmoud, K. R., M. El-Adawy, R. Bansal, S. H. Zainud-Deen, and S. M. M. Ibrahem, "Analysis of uniform circular arrays for adaptive beamforming applications using particle swarm optimization algorithm," *Int. J. of RF and Microwave Computed Aided Eng.*, Vol. 18, 42–52, 2008.
5. Formato, R. A., "Central force optimization: A new metaheuristic with applications in applied electromagnetics," *Progress In Electromagnetics Research*, Vol. 77, 425–491, 2007.
6. Mahmoud, K. R., "Central force optimization: Nelder-Mead hybrid algorithm for rectangular microstrip antenna design," *Electromagnetics*, Vol. 31, 578–592, 2011.
7. Rashedi, E., H. Nezamabadi-Pour, and S. Saryazdi, "GSA: A gravitational search algorithm," *Information Sciences*, Vol. 179, No. 13, 2232–2248, 2009.
8. Chatterjee, A., G. K. Mahanti, and N. N. Pathak, "Comparative performance of gravitational search algorithm and modified particle swarm optimization algorithm for synthesis of thinned scanned concentric ring array antenna," *Progress In Electromagnetics Research B*, Vol. 25, 331–348, 2010.
9. Chatterjee, A., G. K. Mahanti, and P. R. S. Mahapatra, "Design of fully digital controlled reconfigurable dual-beam concentric ring array antenna using gravitational search algorithm," *Progress In Electromagnetics Research C*, Vol. 18, 59–72, 2011.
10. Altinoz, O. T. and A. E. Yilmaz, "Calculation of optimized parameters of rectangular patch antenna using gravitational search algorithm," *2011 International Symposium on Innovations in Intelligent Systems and Applications (INISTA)*, 349–353, Jun. 15–18, 2011.
11. Mohamed, A. M., K. R. Mahmoud, S. G. Abdel Gawad, and I. I. Ibrahim, "Direction of arrival estimation based on maximum likelihood criteria using gravitational search algorithm," *PIERS Proceedings*, 1162–1167, Taipei, Mar. 25–28, 2013.
12. Mahmoud, K. R., "UWB antenna using gravitational search algorithm," *Journal of Engineering Sciences*, Vol. 41, No. 5, Faculty of Engineering, Assiut University, Sep. 2013.
13. Mahmoud, K. R. and S. Hamad, "Parallel implementation of hybrid GSA-NM algorithm for adaptive beam-forming applications," *Progress In Electromagnetics Research B*, Vol. 58, 47–57, 2014.
14. Ram, G., D. Mandal, R. Kar, and S. P. Ghoshal, "Optimized hyper beamforming of linear antenna arrays using collective animal behaviour," *The Scientific World Journal*, Vol. 2013, 13 pages, Article ID 982017, 2013.
15. Mirjalili, S. and S. Z. Mohd Hashim, "A new hybrid PSOGSA algorithm for function optimization," *IEEE International Conference on Computer and Information Application, ICCIA*, 2010.
16. Talbi, E. G., "A taxonomy of hybrid metaheuristic," *Journal of Heuristics*, Vol. 8, No. 5, 541–546, 2002.