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Comparison of GA, SGOA, and PSO for Linear Antenna Array Optimization

Jyothi Budida[1*], Dr Kamala Srinivasan[2]

[*1]Faculty of Physics, H&BS Department, Aditya University, Surampalem, A.P.

[2]Academic Consultant, Department of Physics, Sri Venkateswara University, Tirupati, A.P.

Email ID: kamalasrinivasan@rediffmail.com

***Corresponding Author:**

Jyothi Budida,

Email ID: jyothi_bse@acoe.edu.in

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ABSTRACT

The performance of a linear antenna array is crucial in applications such as wireless communication, radar, and satellite systems. Achieving optimal radiation characteristics, including minimized sidelobe levels, enhanced directivity, and efficient beam steering, requires advanced optimization techniques. This research paper presents a comparative analysis of three prominent optimization algorithms—Genetic Algorithm (GA), Social Group Optimization Algorithm (SGOA), and Particle Swarm Optimization (PSO)—for optimizing linear antenna arrays. GA, inspired by the principles of natural selection and evolution, uses genetic operators such as selection, crossover, and mutation to explore the search space and find an optimal solution. SGOA is a social learning-based algorithm that models individual learning, social learning, and group influence to enhance convergence efficiency and solution accuracy. PSO, based on swarm intelligence, optimizes the antenna array by adjusting element excitations and positions through the collective movement of particles in a multidimensional search space. The study evaluates these algorithms based on key performance metrics such as sidelobe suppression, directivity enhancement, convergence speed, computational complexity, and radiation efficiency. Through extensive simulations, it is observed that GA effectively reduces sidelobe levels but suffers from slow convergence due to the stochastic nature of genetic operations. SGOA offers superior adaptability and faster convergence, making it suitable for real-time applications. PSO, known for its computational efficiency, demonstrates quick convergence but can struggle with local optima in highly complex optimization scenarios. The findings of this study provide valuable insights into selecting the most appropriate optimization technique based on specific antenna array design requirements. Future research can focus on hybrid approaches and machine learning-based optimizations to further improve antenna performance.

Keywords: *Optimization, S LL ,radiation efficiency, directivity, beam steering*

1. INTRODUCTION

Antenna arrays play a critical role in modern wireless communication, radar, and satellite systems due to their ability to focus electromagnetic waves in desired directions. Linear antenna arrays, in particular, are widely used because of their simplicity and effectiveness in beamforming applications. However, achieving optimal radiation characteristics requires careful design considerations, including element spacing, excitation amplitude, and phase adjustments. One of the main challenges in designing linear antenna arrays is the trade-off between main lobe directivity and sidelobe suppression. High sidelobe levels can cause unwanted interference and degrade the overall performance of the system. Therefore, optimization techniques are required to enhance the radiation pattern and improve overall antenna array performance.

a. Traditional analytical and numerical methods for antenna array design, such as Fourier synthesis and Woodward-Lawson methods, often fail to provide optimal solutions for complex and large-scale antenna arrays. These conventional methods rely on deterministic approaches, which may not be sufficient in handling the nonlinear and multidimensional nature of the problem. To overcome these limitations, meta-heuristic optimization algorithms have been widely adopted in recent years. These algorithms employ nature-inspired computational techniques to efficiently search for optimal solutions in large design spaces without requiring gradient information.

b. This study focuses on three well-known optimization techniques—Genetic Algorithm (GA), Social Group Optimization Algorithm (SGOA), and Particle Swarm Optimization (PSO)—for optimizing linear antenna arrays. GA, inspired by Darwinian evolution, operates through genetic operators such as selection, crossover, and mutation to evolve a population of candidate solutions toward an optimal design. SGOA, a relatively new meta-heuristic algorithm, mimics the learning and decision-making processes of individuals within a social group to find optimal solutions. PSO, inspired by swarm intelligence, models the collective movement of particles in search of the best solution. These algorithms have been widely applied in antenna design and other engineering fields due to their ability to efficiently explore and exploit the search space.

The objective of this research is to compare the performance of GA, SGOA, and PSO in optimizing linear antenna arrays based on key metrics such as sidelobe level reduction, directivity enhancement, convergence speed, computational complexity, and radiation efficiency. The study aims to provide insights into the strengths and limitations of each algorithm, helping researchers and engineers select the most suitable optimization technique for their specific application requirements.

2. FORMULATION OF THE LINEAR ARRAY

The LA is one of the most widely employed geometry of array. It has several practical applications. Considering its simplicity and beam shaping property, it is said to versatile. The typical geometry of broad side LA is as shown in Fig 2.1. the depicted figure has the arrangement of elements in Z-axis..

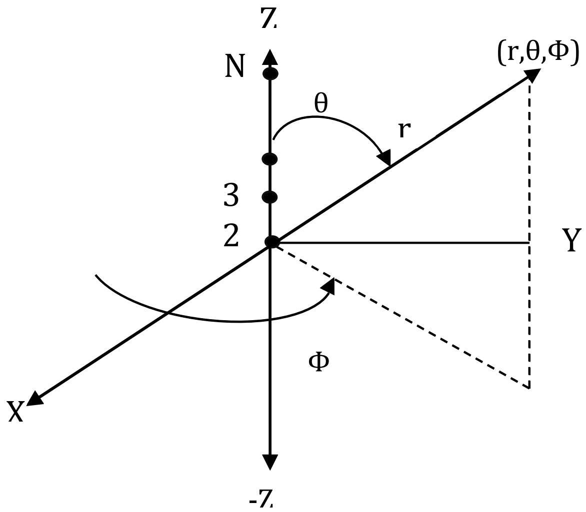

Fig. 1: Geometry of broadside linear array

The AF of LA is given as

$$E(\theta) = \sum_{n=1}^{N} A_n \exp\left[j(n-1)(kd\cos\theta + \beta)\right] \quad (1)$$

Here,

A_n = n^{th} elements current excitation

d = Inter-element distance, θ = Plane wave look angle

λ = wavelength, β = - $kd\cos\theta_d$

Optimization Algorithms Overview

a. Genetic Algorithm (GA) GA is an evolutionary optimization technique inspired by natural selection. It operates through selection, crossover, and mutation to iteratively improve candidate solutions. GA is effective in optimizing linear arrays by adjusting element parameters to minimize sidelobe levels and improve directivity. However, it may suffer from slow convergence and getting trapped in local optima.

b. Social Group Optimization Algorithm (SGOA) SGOA is a bio-inspired algorithm based on the learning and interaction behavior of individuals in a social group. It incorporates self-learning, social learning, and group influence to guide solutions towards optimal configurations. SGOA offers fast convergence and adaptability, making it a promising approach for antenna array optimization.

c. Particle Swarm Optimization (PSO) PSO is a swarm intelligence-based technique that simulates the movement of birds in search of food. Each particle in the swarm represents a potential solution and updates its position based on personal best (pBest) and global best (gBest). PSO is computationally efficient and provides quick convergence, but it may sometimes struggle with local optima in highly complex optimization problems.

3. RESULTS

Linear antenna arrays composed of 12, 16, and 20 isotropic radiating elements, with an inter-element spacing of λ/2, are considered for reference. RGA is applied to obtain deeper nulls and to reduce the SLLs. RGA was executed with 500 iterations, and the population size was fixed at 120. For the RGA, the mutation probability was set to 0.05, and uniform crossover was used. The RGA algorithm is initialized using random values of the excitation (0<In<1) and the spacing between the elements (λ/2⩽d<λ). The nulling performances are improved for predefined nulls of the radiation pattern. Similarly, nulls are imposed at predefined peak positions. The program was written in Matlab and run in MATLAB version 7.8.0(R2009a) on a 3.00 GHz core (TM) 2 duo processor with 2 GB RAM.

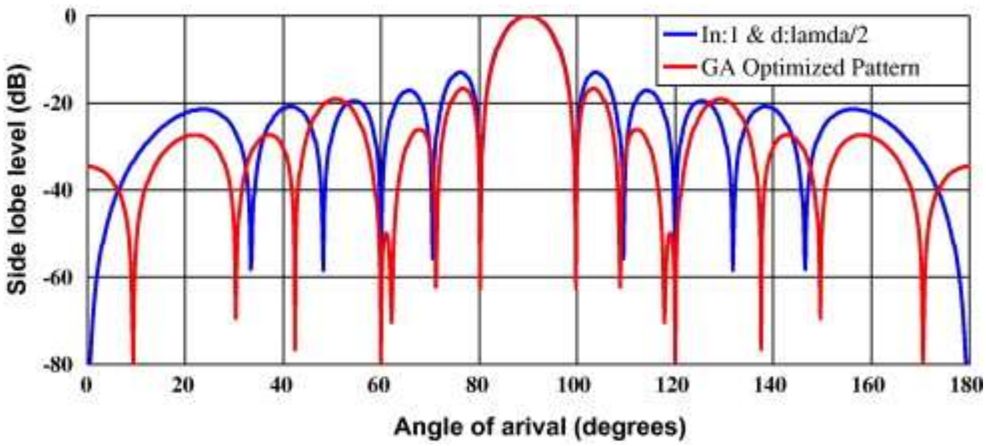

Fig 2. Best array pattern found by RGA for the 12-element array case with an improved null at the 3rd null; i.e., $\theta = 60°$ and $\theta = 120°$.

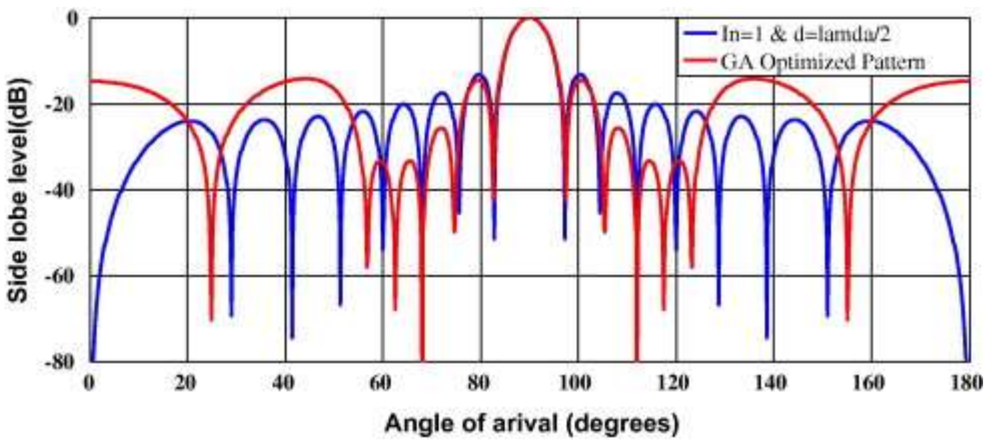

Fig 3. Best array pattern found by RGA for the 16-element array case with an improved null at the 3rd null; i.e., $\theta = 68°$ and $\theta = 112°$.

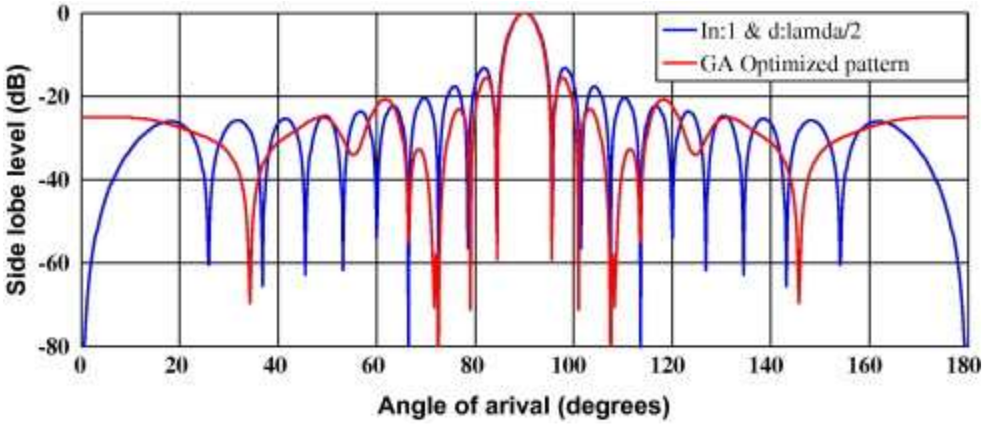

Fig 4. Best array pattern found by RGA for the 20-element array case with an improved null at the 3rd null; i.e., θ = 72.5° and θ = 107.5°.

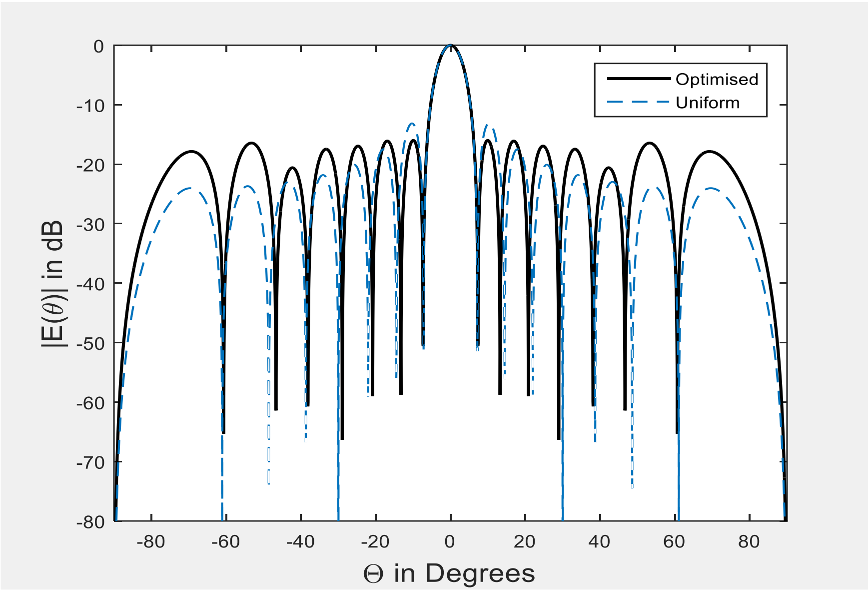

Fig 5 : Optimized RP of 16 element LA by SGOA

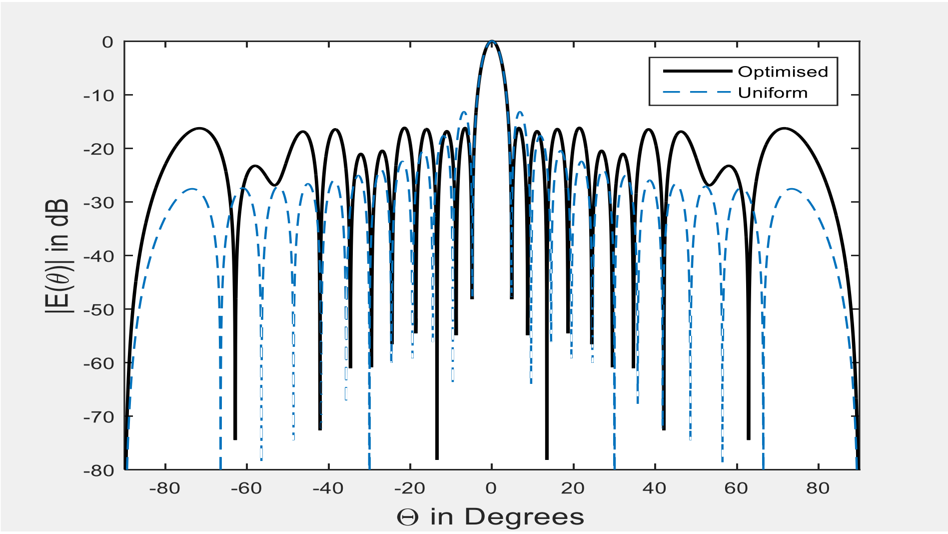

Fig 6 Optimized RP of 24 element LA by SGOA

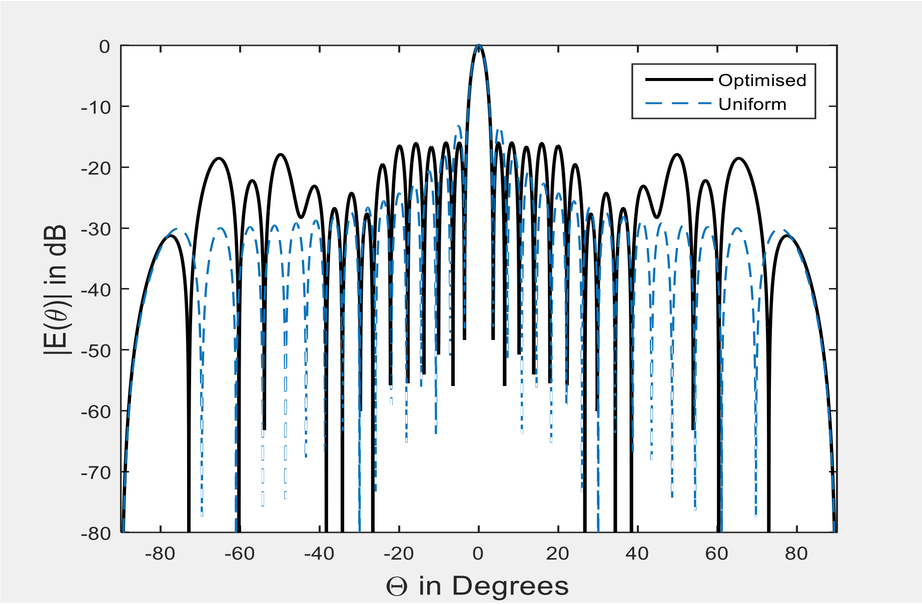

Fig7. Optimized RP of 32 element LA by SGOA

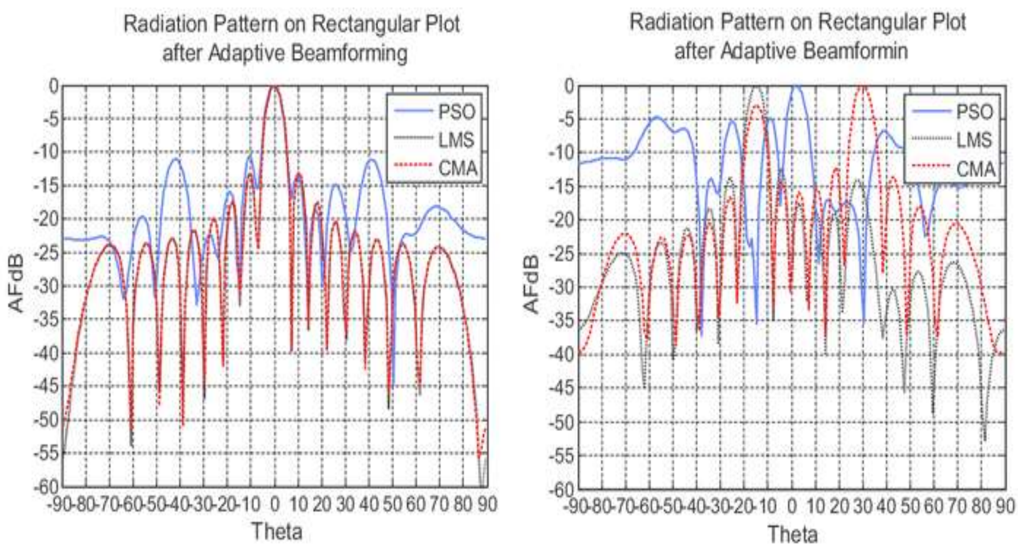

Fig 8 Best radiation pattern found by PSO, LMS and CMA for 16 element antenna array with user at 0° and interferers at À15° & 30° with SNR = 30 dB (a) Rectangular Plot for SIR = 30 dB (SLL PSO = À15.41 dB, SLL LMS = À19.12 dB, SLL CMA = À19.14 dB) (b) Rectangular Plot for SIR = À30 dB (SLL PSO = À10.35 dB).

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Comparison of Performance of Algorithms

a. Advantages of GA in Antenna Array Optimization:

i. Capable of handling complex, multi-objective optimization problems.

ii. Does not require gradient information, making it suitable for non-differentiable functions.

iii. Can optimize various parameters, including element spacing, amplitude, and phase.

b. Advantages of PSO in Antenna Array Optimization:

i. Fast Convergence: Finds near-optimal solutions quickly.

ii. Simple Implementation: Requires fewer parameters compared to evolutionary algorithms like Genetic Algorithm (GA).

iii. No Gradient Requirement: Can handle non-differentiable and discontinuous functions.

iv. Efficient in Large-Scale Problems: Suitable for optimizing large antenna arrays.

Applications in Antenna Array Optimization:

PSO can be used to optimize various parameters in antenna arrays, including:

i. Minimizing Sidelobe Levels (SLL): Improves signal quality by reducing interference.

ii. Beamforming and Beam Steering: Enhances directivity for better signal reception.

iii. Optimizing Element Spacing and Amplitudes: Achieves efficient radiation patterns.

c. Application of SGOA in Antenna Array Optimization

SGOA has gained attention in antenna design due to its ability to optimize parameters such as:

- Element spacing
- Amplitude excitation
- Phase distribution
- Side lobe level (SLL) minimization
- Beam width optimization

SGOA's social learning mechanism allows for fast convergence, making it suitable for real-time antenna optimization applications, such as adaptive beamforming in wireless communication, radar systems, and satellite networks.

Performance Evaluation Metrics The performance of these algorithms is evaluated based on the following metrics:

a. Sidelobe Level Reduction (SLL): Lower sidelobes improve signal quality and minimize interference.
b. Main Lobe Beamwidth (MLB): Determines the resolution and directivity of the array.
c. Convergence Speed: Faster convergence is preferable for real-time applications.
d. Computational Complexity: Affects the feasibility of implementation in large-scale arrays.
e. Radiation Efficiency: Measures the effectiveness of the array in radiating energy.

Simulation and Results The optimization algorithms are implemented in a simulation environment to analyze their effectiveness in designing linear antenna arrays. The results include:

i. GA achieves significant sidelobe reduction but at the cost of higher computational complexity and slower convergence.
ii. SGOA provides faster convergence and better adaptability but may require fine-tuning for optimal performance.
iii. PSO demonstrates efficient convergence and good directivity control but may struggle with local minima in some cases.

4. CONCLUSION

This comparative study demonstrates that each algorithm has its strengths and weaknesses. GA offers robust optimization but is computationally intensive. SGOA provides rapid learning and adaptability, making it suitable for dynamic optimization scenarios. PSO delivers fast convergence and is well-suited for real-time applications. The choice of optimization algorithm depends on specific performance requirements and computational constraints. Future work may explore hybrid optimization techniques and machine learning-based approaches to further enhance linear antenna array performance.

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