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A beamforming comparative study of least mean square, genetic algorithm and grey wolf optimization algorithms for multipath smart antenna system

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ABSTRACT

Multipath environment is a limitation fact in optimized usage of wireless networks. Using smart antenna and beamforming algorithms contributed to that subscribers get a higher-gain signal and better directivity as well as reduce the consumed power for users and the mobile base stations by adjusting the appropriate weights for each element in the antenna array that leads to reducing interference and directing the main beam to wanted user. In this paper, the performance of three of beamforming algorithms in multipath environment in terms of Directivity and side lobe level reduction has been studied and compared, which are least mean square (LMS), genetic algorithm (GA) and grey wolf optimization (GWO) technique. The simulation result appears that LMS algorithm aids us to get the best directivity followed by the GWO, and we may get most sidelobe level reduction by using the GA algorithm, followed by LMS algorithm in second rank.

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1. INTRODUCTION

The fact of limited spectrum capacity makes impossible to dispel it for unwanted signals. From here, researchers started searching for solutions that lead to the optimized utilization for bandwidth [1-3]. One of the important characteristics of wireless channels is multipath fading effect, which causes the signal to be weak and distracted, makes the band width busy with interfaces, multipath is considered one of the determinants factors of network quality [4-6]. The definition of multipath fading in a simple way is the reflection of the transmitted signal because it collides with existing obstacles such as buildings and vehicles, and this leads to the arrival of several copies of the signal to the receiver at various time intervals, Figure 1 illustrates a simplified scenario for multipath signal formation [7-9]. The beamforming is used to steer multiple beams towards the desired user while the interferers are canceled at the same time. This can be achieved via adjustment of the beamformers weight vectors, where the quality of the communication channel can maximize through the process of varying the complex weight [10-12]. A narrow beam with high gain can be achieved through a large number of antenna elements that combine to construct the array [13]. The antenna array can steer the beam pattern electronically in particular directions, minimal side lobe level (SLL), and suppress interference

[14, 15]. However, different techniques have been studied to enhance the system performance in terms of several objectives, for example, to increase the directivity or reduce the interference. In this article, we used three different techniques, least mean square (LMS), genetic algorithm (GA) and grey wolf optimization (GWO) to study the directivity and SSL in a smart antenna system.

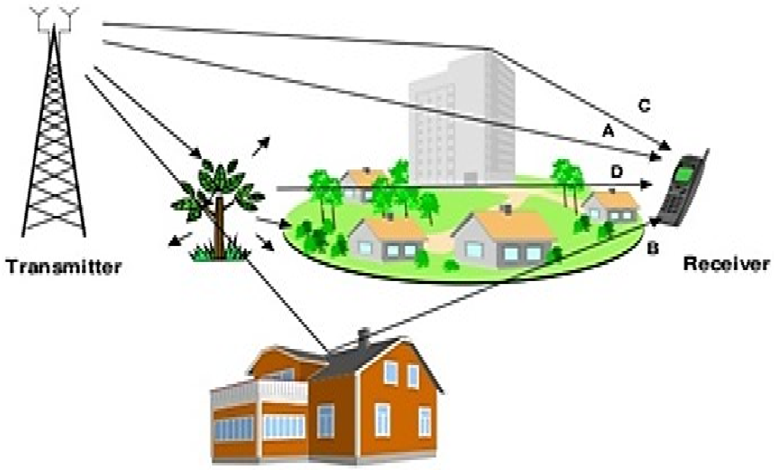

Figure 1. Multipath propagation scenario

The main contributions of this paper are:
- The average of directivity has been increased significantly in multipath environment when a LMS is used for beamforming compared to GA and GWO, which gives a sharper and more precise beam patterns.
- The most average SLL reduction in multipath environment is achieved when using GA for beamforming followed by LMS in the second level.
- The results show that convergence of a GWO is achieved faster than GA based method. LMS method is most slow down convergence between these three methods.

The remaining of this paper is organized as follows: in section 2, a geometry configuration of a linear antenna array and the array factor equations are discussed. A description of the LMS, Genetic and GWO algorithms and its implementation steps are discussed in same section. A simple explanation about simulation enforcement is included in section 3, as well as the results of simulation for all three algorithms are presented and discussed in section 4. While the conclusion presents in section 5.

2. ANTENNA ARRAY CONFIGURATION

The N-element array is considered a common general linear array. For simplicity, all elements in this study are assumed that have equal amplitudes and equally spaced. Figure 2 depicts a linear array of an N-element, which collected isotropic radiation of antenna elements. In this paper, a uniform linear array along the x-axis consisting of 2N isotropic elements is studied. The array factor (AF) is calculated using the following equations;

$$AF = 1 + e^{j(kdsin\emptyset+\partial)} + e^{j2(kdsin\emptyset+\partial)} + e^{j3(kdsin\emptyset+\partial)} + \cdots + e^{j(N-1)(kdsin\emptyset+\partial)} \quad (1)$$

where $r >> d$ represents the far-field condition, a far-field distance is given as

$$d = 2D^2/\lambda \quad (2)$$

where D is the maximum antenna dimension, r is the distance from element n to far-field point, and ∂ is the phase shift between successive elements as shown in (1) can more precisely express as

$$AF = \sum_{n=1}^{N} e^{j(N-1)(\psi)} \quad (3)$$

where $\psi = kd\sin\emptyset + \partial$. It is noted that if the array is lined up along the $z-axis$ then $\psi = kd\cos\emptyset + \partial$.

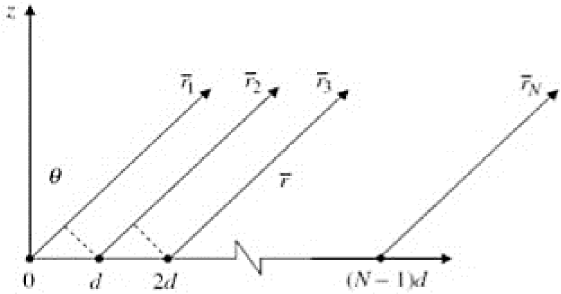

Figure 2. Uniform linear array geometry

3. LEAST MEAN SQUARE ALGORITHM

In 1959 Widrow and Hoff introduced the LMS algorithm to the world. It is one of the earliest adaptive algorithms that depends on gradient based method of abrupt. LMS is a search algorithm that use the modifying of objective function to simplify the gradient vector computation. Figure 3 articulate the flow chart of LMS algorithm [16-18]. The LMS algorithms can defined mathematically by following equations:

$$y(n) \ = \ w(n).X(n) \tag{4}$$

$$e(n) \ = \ d(n) - y(n) \tag{5}$$

$$w(n+1) \ = \ w(n) + \eta \, X(n).e(n) \tag{6}$$

η = gain constant and monitor the adaptation rate.
$x(n)$ = input signal.
$e(n)$ = error between desired and output signal
$d(n)$ = desired signal.
where R is the correlation matrix
$\eta = 1/trace\ (R)$

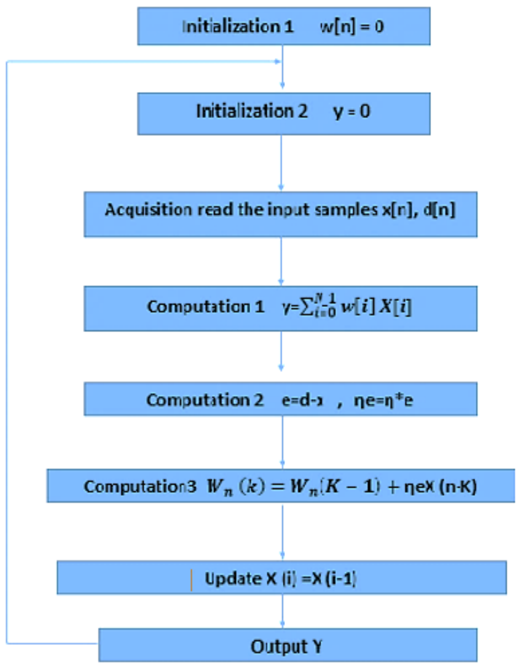

Figure 3. Flowchart of LMS algorithm

4. GENETIC ALGORITHM

Genetic algorithm is considered one of the first's meta-heuristic algorithms. It is classified as global numerical optimization methods, which got popular by John Holland in 1970s. The GA uses five basic steps to solve problems and it can be summarized as follow [19-22]:

- Creating initial population of chromosomes randomly. Each chromosome is a possible solution.
- Determine the fitness value and fitness function to solve the problem, and is it need to minimized or maximized.
- Initially, all the created chromosomes are passed on the Fitness function for evaluation, and then the best chromosomes that gave us the best solutions are identified. The chromosomes that gave us the worst results are discarded and in case, we have a new generation of chromosomes.
- Cross over process takes place between the best chromosomes to create new chromosomes. May mutation process applies on some chromosomes with a certain percentage to give us new chromosomes and new solutions
- This process of step 3 and 4 is repeated within certain iterations to obtain the results required to solve the problem.

5. GREY WOLF OPTIMIZATION ALGORITHM

The GWO algorithm is considered one of the meta-heuristic algorithms that emulate the social hunting manner and hierarchical of the grey wolves group. The hunting manner of the grey wolves can be summarized as follows [23-25]: The first grade, which represents the chi (χ) that they are the leaders and can be males or females. The second grade in the hierarchical is consists of the rho (ρ) wolves, which followed by the wolves called gamma (γ), while the down sorting of the grey wolves is named mu (μ). The hierarchical of the grey wolves are constituted mathematically throughout counting χ as the best solution that followed by the 2nd and the 3rd finest solutions ρ and γ, respectively. The remaining of the nominated solutions are supposed to be μ.

The major steps sequence of the grey wolf hunting can be summarized as follows:

- Pursuit, chasing after and draw near the prey.
- Keep tracking, surrounding, and beset the prey until it stops moving.
- Raid towards the prey.

During a hunting process, grey wolves hedge the prey that is mathematically modelled as [9]:

$$\vec{D} = \left|\vec{C}.\overrightarrow{Yp(t)} - \overrightarrow{Y(t)}\right| \tag{7}$$

$$\overrightarrow{y(t+1)} = \overrightarrow{Yp(t)} - \vec{A}.\overrightarrow{(D)} \tag{8}$$

where $\vec{C}$ and $\vec{A}$ are the coefficient vectors, t is referred to the current iteration, $\overrightarrow{Yp}$ represents the location vector of the prey, and $\vec{Y}$ refers to the location vector of the grey wolf. The vectors $\vec{C}$ and $\vec{A}$ are evaluated as;

$$\vec{C} = 2.\vec{r_2} \tag{9}$$

$$\vec{A} = 2\vec{\chi}.\vec{r_1} - \vec{\chi} \tag{10}$$

where components of $\vec{\chi}$ are decreased linearly from 2 to 0 during the iterations and $\vec{r_1}$, $\vec{r_2}$ are random vectors that lie in the range [0,1]. In the GWO algorithm process, the hunting approach has led by χ, ρ, and γ, where the other wolves follow those three types of wolves. Further, in the pack of the wolves, it is supposed that the wolves' χ, ρ, and γ have the best familiarity about the potential position of the prey. Consequently, the first three best solutions will be save, and the other searching operators will update their locations according to the position of the best search operator. For this purpose, we use the following equations:

$$\left.\begin{aligned}
\overrightarrow{D\chi} &= \left|\overrightarrow{C1}.\overrightarrow{Y\chi} - \vec{Y}\right| \\
\overrightarrow{D\rho} &= \left|\overrightarrow{C2}.\overrightarrow{Y\rho} - \vec{Y}\right| \\
\overrightarrow{D\gamma} &= \left|\overrightarrow{C3}.\overrightarrow{Y\gamma} - \vec{Y}\right| \\
\overrightarrow{Y1} &= \overrightarrow{Y\chi} - \overrightarrow{A1}.\overrightarrow{(D\chi)} \\
\overrightarrow{Y2} &= \overrightarrow{Y\rho} - \overrightarrow{A2}.\overrightarrow{(D\rho)} \\
\overrightarrow{Y3} &= \overrightarrow{Y\gamma} - \overrightarrow{A3}.\overrightarrow{(D\gamma)} \\
\vec{Y}(t+1) &= \frac{\overrightarrow{Y1}+\overrightarrow{Y2}+\overrightarrow{Y3}}{3}
\end{aligned}\right\} \tag{11}$$

By using (11), and according to the parameters χ, ρ, and γ in the nth-dimensional searching domain, where a search operator will be updating its location. Also, the final location of the search domain would be in a random place within a circle that is clarified by the locations of χ, ρ, and γ. So that, χ, ρ, and γ evaluate the location of the prey, while the rest of the wolves update their locations randomly throughout the prey [26].

6. MATERIALS AND METHODE

In this paper, the performance of the three explained algorithms in section 3 to 4 in beamforming was compared in multipath environment. To embody multipath environment, two users with three transmitted signals with different direction of arrival angel for each user were taken. The case of study considered the distance between the array elements is 0.25λ and the number of elements is 32 in antenna design. A simulation tool of MATLAB software has been used to analyze the performance of the systems in beamforming, where a curve between the SLL and main beam pattern has taken into consideration. The main simulation parameters of this paper are shown in Table 1.

Table 1. Simulation parameters

Parameter	Description
Direction of arrival (DOA) angle (1st user)	DOA11 = 50, DOA12 = -30, DOA13 = 70
Direction of arrival (DOA) angle (2nd user)	DOA21 =-50, DOA22 = 0, DOA23 = 30
Frequency	900MHZ
Element spacing	900MHZ
Fitness function for GA and GWO	$min(max(20log\|AF(\Theta)\|))$
No of iteration for each technique	GWO = 10, GA = 200, LMS = 600

7. RESULTS AND DESCUSSIONS

In Table 2 it is noticed that the average value of directivity equal to 14.95 which is higher than the directivity in the other two algorithms. The higher directivity related to DOA12, DOA21 and DOA23 with value equal to 15. In Table 3, it is clear that the directivity in the genetic algorithm ranges from 13.76 for DOA22 to 14.26 for DOA13. In Table 4, it is recorded that the average of directivity is about 14.28 and the highest one is for DOA23 with value equal to 14.5. Directivity average in GA method is the lowest among the three algorithms with a value equal to 14.03. Average of SLL value for LMS algorithm method is recorded about 0.207 in Table 2, as it is seen in Figure 4 the highest level of side lobe is for DOA23 with value count to 0.23 and the lowest level of side lobe is o.15 for DOA13 as it is clear in Figure 5. It is chained in Tables 3 and 4 that average of SLL is 0.18 in GA algorithm and 0.21 in GWO algorithm, and it is represented in Figures 6 and 7 that the highest sidelobe level is for DOA22 with value equal to 0.23 and most sidelobe level reduction is for DOA13. The GWO algorithm has the less SLL reduction in multipath environment. Figure 8 shows that highest side lobe level is 0.28 for DOA12. In Figure 9, it is obvious that lowest level of side lobe is obtained for DOA21. Despite the simple differences, the outcomes of all three algorithms are generally close; the GWO algorithm needs the least number of samples and repetition, means that needs less computation time than the rest of the algorithms, while the LMS algorithm needs the largest number of samples compared to two other algorithms. The results elaborated in the following Figures 4-9.

Table 2. Antenna parameters results for array with 32 elements and 0.25 λ inter spacing, by LMS algorithm

DOA	Directivity	SLL	SLL in dB	main pattern in dB
DOA11	14.88	0.190476	-4.39	8.18
DOA12	15	0.210526	-9.66	4.15
DOA13	14.98	0.152672	-11.95	1.13
DOA21	15	0.241135	-11.76	1.068
DOA22	15	0.219231	-10.25	3
DOA23	14.86	0.230769	-4.78	8.21
average	14.953	0.207468	-8.79833	4.2896

Table 3. Antenna parameters results for array with 32 elements and 0.25 λ inter spacing, by GA algorithm

DOA	Directivity	SLL	SLL in dB	main pattern in dB
DOA11	14.21	0.1643192	9.4	24.63
DOA12	13.94	0.2140673	9.54	24.24
DOA13	14.26	0.14	8.84	25.84
DOA21	13.86	0.207	9.97	25.08
DOA22	13.76	0.233882	10	23.8
DOA23	14.15	0.1582609	8.96	24.7
average	14.03	0.1821059	9.451667	24.715

Table 4. Antenna parameters result for array with 32 elements and 0.25 λ inter spacing, by GWO algorithm

DOA	Directivity	SLL	SLL in dB	main pattern in dB
DOA11	14.35	0.21	47.33	59.37
DOA12	14.02	0.28	48.56	58.37
DOA13	14.31	0.2	47.24	59.14
DOA21	14.13	0.15	42.32	58.26
DOA22	14.38	0.27	49.6	60.16
DOA23	14.5	0.2	46.53	60
average	14.28167	0.218333	46.93	59.21666667

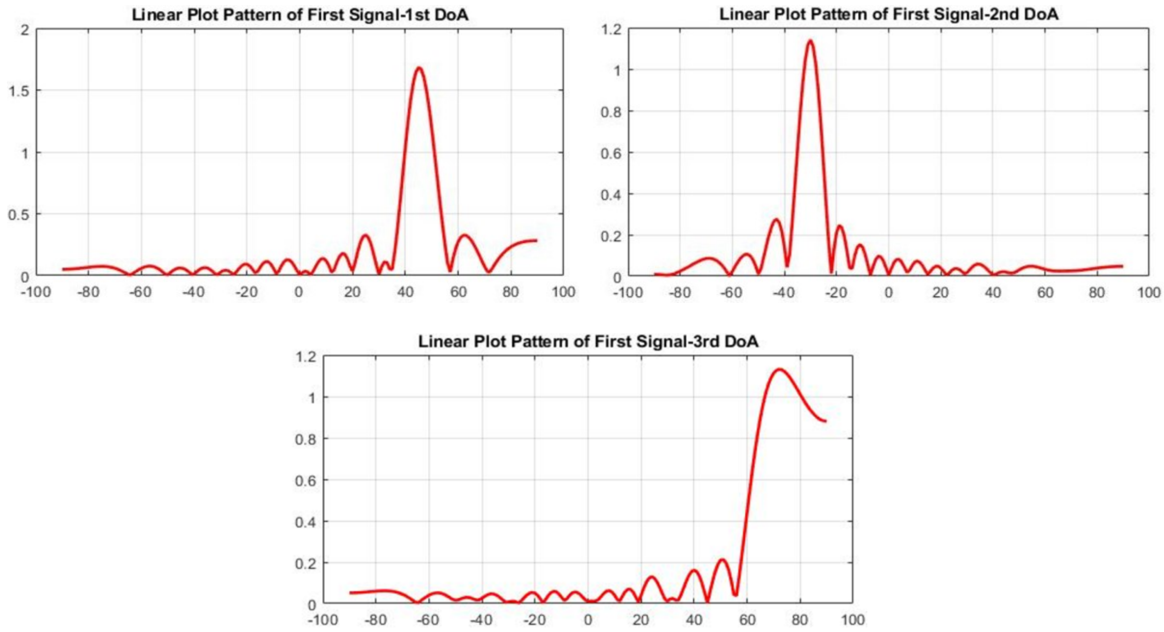

Figure 4. SLL, main lobe of first user and its 3DOAs for N = 32, λ = 0.25 optimized with LMS

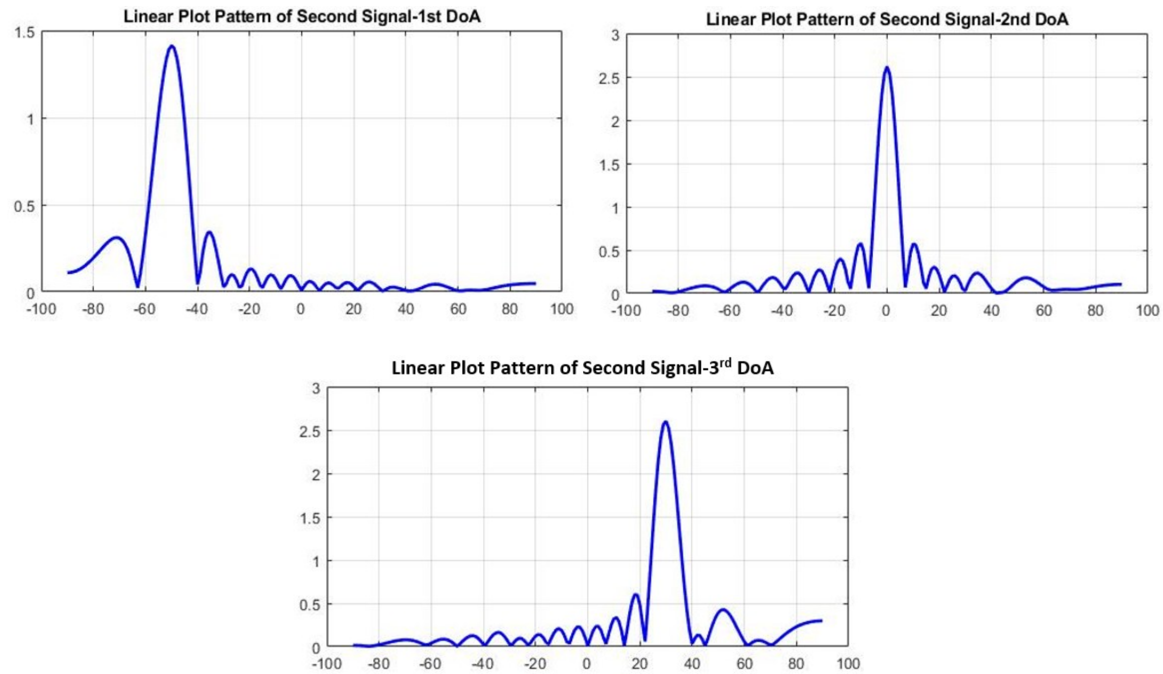

Figure 5. SLL, main lobe of second user and its 3DOAs for N = 32, λ = 0.25 optimized with LMS

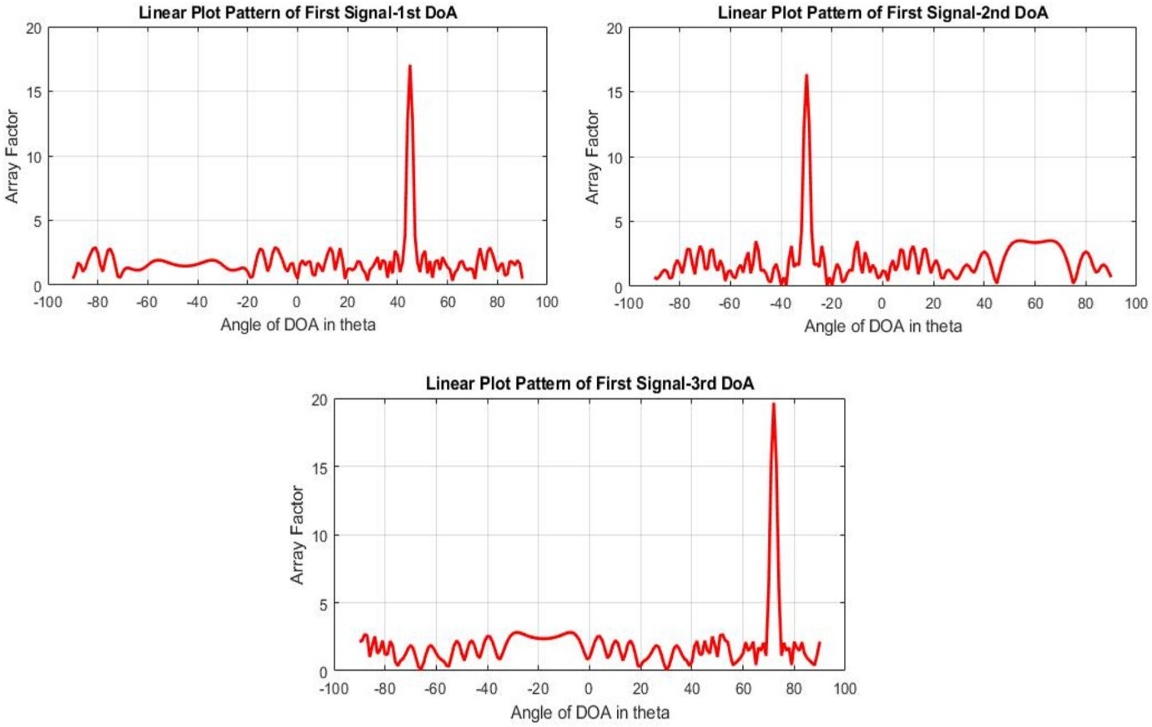

Figure 6. SLL, main lobe of first user and its 3DOAs for N = 32, λ = 0.25 optimized with GA

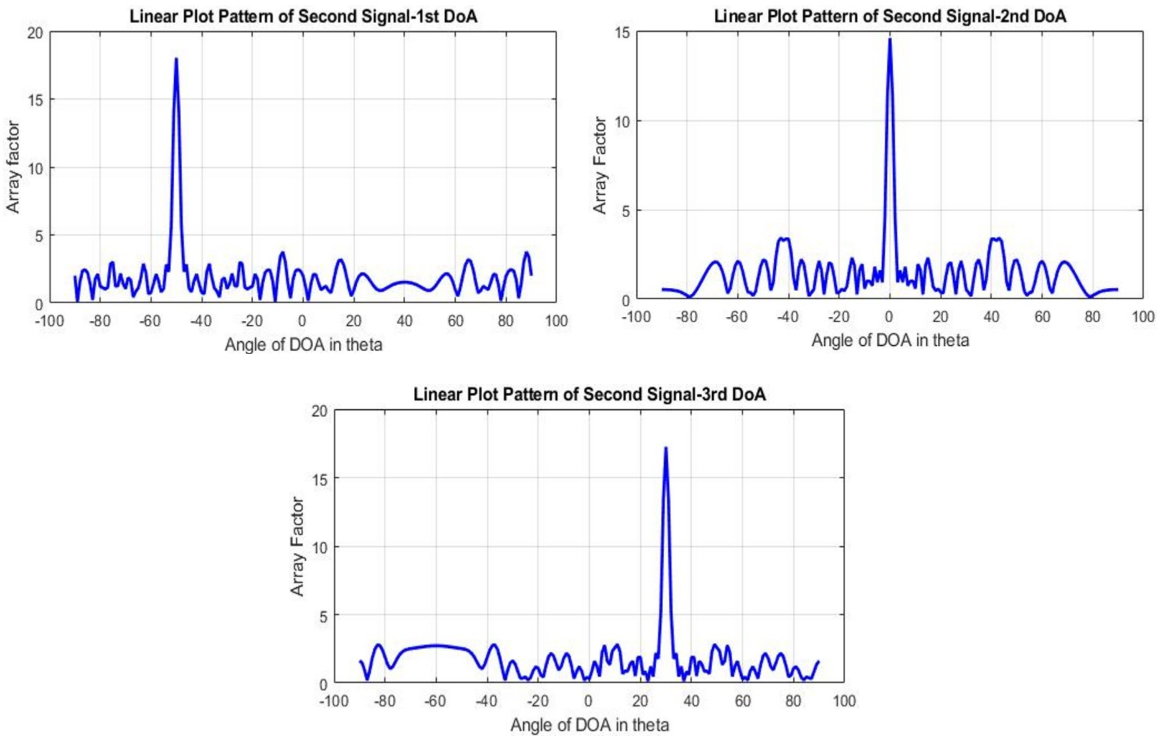

Figure 7. SLL, main lobe of second user and its 3DOAs for N = 32, λ = 0.25 optimized with GA

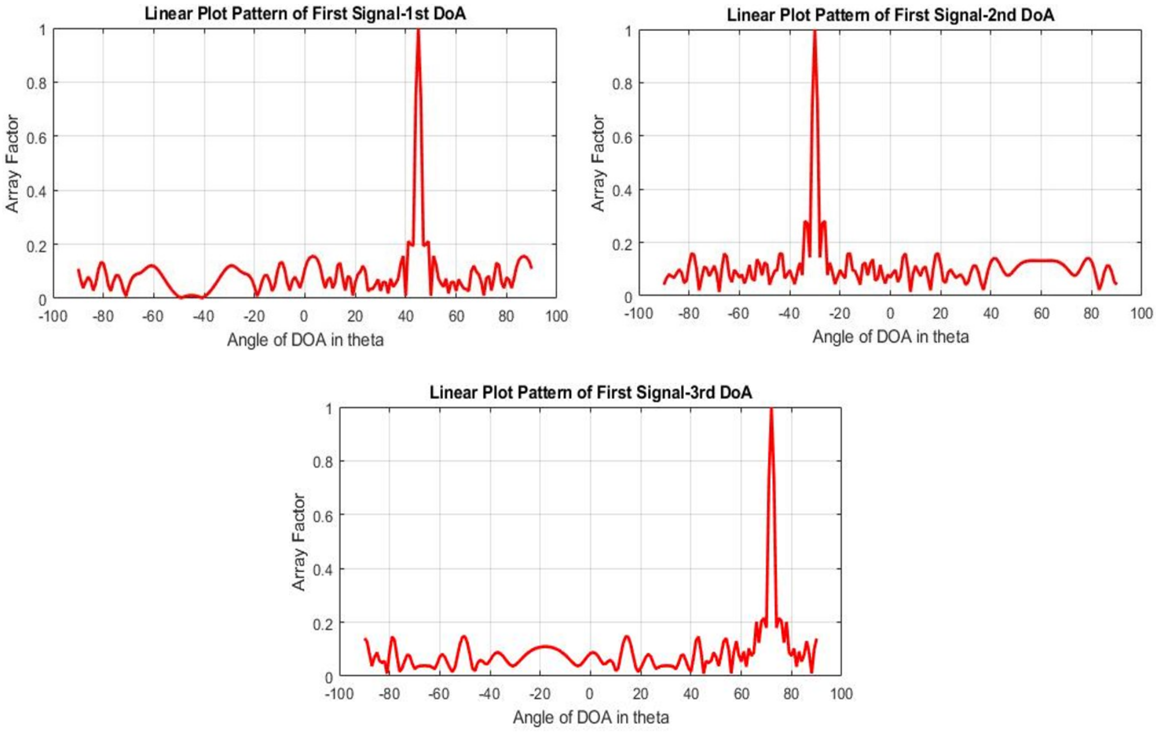

Figure 8. SLL, main lobe of first user and its 3DOAs for N = 32, λ = 0.25 optimized with GWO

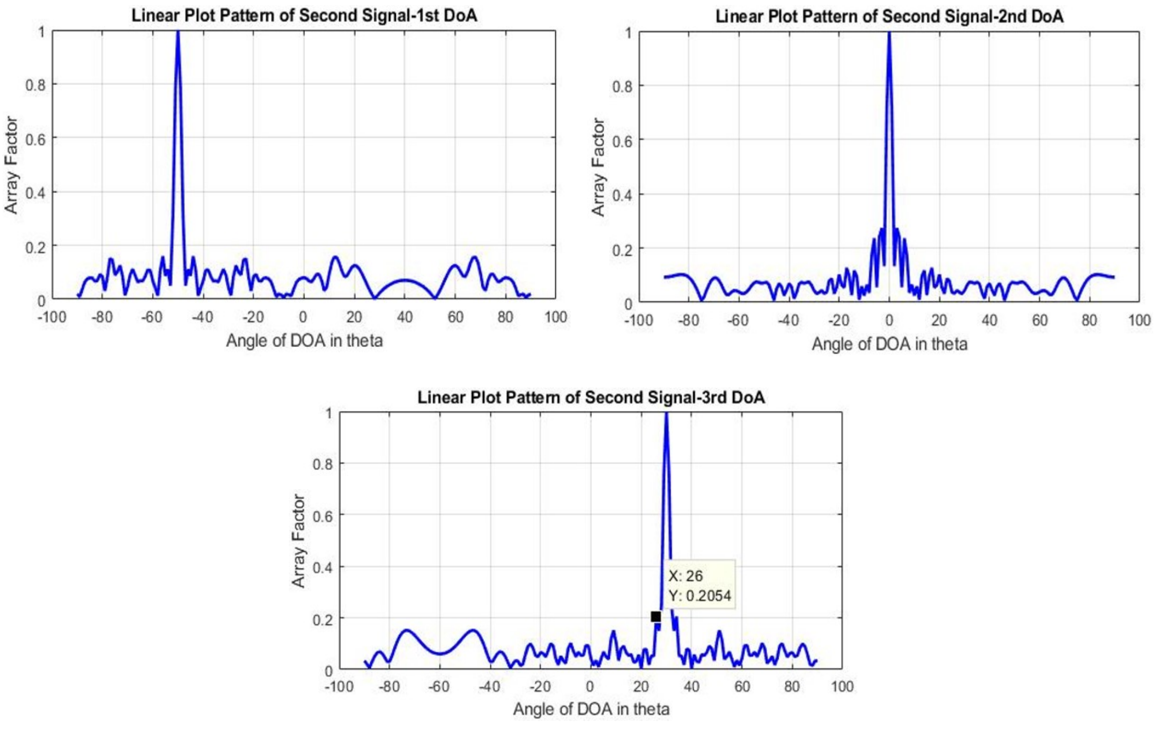

Figure 9. SLL, main lobe of second user and its 3DOAs for N = 32, λ = 0.25 optimized with GWO

8. CONCLUSION

In this paper, the performance of three types of adaptive algorithms for the beam forming in smart antenna systems, in terms of preference in directivity and the extent of sidelobe level reduction for multipath environment has been studied. Despite the simple differences, the outcomes of all three algorithms are generally close; the GWO algorithm needs the least number of samples and repetition, means that needs less computation time than the rest of the algorithms, while the LMS algorithm needs the largest number of samples compared to two other algorithms. The study shows us that the most sidelobe level reduction occurs when using the genetic algorithm, followed by the LMS algorithm. The findings demonstrates that LMS algorithm achieves better results in terms of directivity in multipath environment, followed by GWO algorithm in the second rank.

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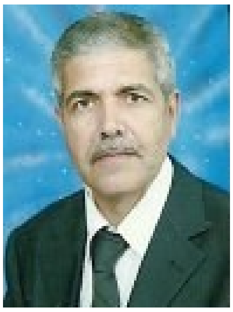

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