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Reduction of Side Lobe Level in a Time-Modulated Linear Array Using Invasive Weed Optimization and Particle Swarm Optimization

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Abstract: Time Modulated Array (TMA) is an electromagnetic system that radiates a controlled power pattern. The process of the array has a non-linear nature which causes the appearance of unwanted side lobes. This study presents two algorithms with two schemes to reduce the side lobes level. The first algorithm is the Invasive Weed Optimization (IWO). While the second one is the Particle Swarm Optimization (PSO). Different numbers of array elements (4, 8, 16, 32, 64) are used and tested in this research. In the first scheme (one stage), each algorithm is used alone in one stage to achieve maximum power in the antenna pattern direction by reducing the side lobe level to the lowest value. The results appeared that the IWO algorithm reduced side lobe level to -40.53 dB at N = 64 and it is better than PSO algorithm which reduced the side lobe level to -25.49 dB. The second scheme (two stages) the algorithms used in double stages with four cases IWO-IWO, IWO-PSO, PSO-IWO and finally PSO-PSO. In the two stages scheme, the results showed that the IWO-IWO scheme is better than other schemes which reduced the SLL to -43.19 dB.

Key words: (IWO) Invasive Weed Optimization, (PSO) Particle Swarm Optimization, Time Modulated Array, (TMA), pattern, power, scheme

INTRODUCTION

Phased arrays have the ability of electrical steering which is very attractive for antenna engineers. To achieve it, side lobe level and the inherent sideband patterns are decrease by used time modulated array (Godara, 2004).

An array of antennas is used in phased array antenna. An element of the array is the antenna which forms the array. The signal which is produced by the array, output is the collection of signals for all the elements of the array. The collection of signals from elements is a process called beamforming. The direction in which the array has the maximum response and the largest gain is called the beam pointing direction. It becomes wide to the linear array when the signals are merged without any change and change in phase and becomes vertical on the line that connects all elements of the vertical array and can be controlled on it by adapting the phase difference during various antennas (Borzabadi and Heidari, 2010). Due to the source and after adjusting the phase in the beam pointing direction the induced signals are added to different elements in the phase. As a result, the total gains of an individual antenna represent an array gain (or equivalent, a common antenna gains).

Kummer *et al*. (1963) introduced the term TMA in 1963 with the concept of "time modulated antenna". From Hughes Aircraft Company which has been empirically expanded to antenna arrays. Several experiments were performed including the introduction of a group of radio frequency "RF" switches programmed into the feeding system of a linear wave array of 8 waves operating on the X band according to a specific periodic sequence and the results showed a significant reduction in ultra-low sidelobe patterns. Kummer *et al*. (1963) notice that the system cost increases by applying the time modulation to improve the SLL.

The time modulated antenna array has a distinct reality which includes an additional degree of freedom. Bick more introduced the common principles for studying of the time modulated antenna system. The design flexibility and significantly reduced SLL dynamic range contrast to those desired in standard SLLs are characteristic of this type of antenna arrays. Because of a large number of sideband signals, the fabricate of time modulated arrays is remain complex. Sideband signals vary by frequency modulation multipliers which convert to the side bands a large portion of the radiated or received power (Nath and Mitra, 2012).

There are five important characteristics in the composition of an antenna array: the geometric shape of the total array (circular, linear, spherical and rectangular), the amplitude of excitation of individual elements, the relative pattern of individual elements, the distance

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between the elements and the excitation phase of the individual elements. The high directional antenna is used in many communication applications. The gain and direction of the individual radiation element is much less than the gain and direction of the antennas in the array. The process of placing the elements in a direct line with the equality of the distance between the elements is called the linear array (Hreshee and Al-Gayem, 2015; Hreshee, 2013). To produce a radiation pattern closer to the required pattern, the physical layout of the array must be determined by installing an antenna array geometry (Hreshee, 2013). The reason for the increase in techniques that eliminates the pattern of the array is due to the increasing amount of electromagnetic pollution. Signal-to-noise ratio can be reduced using these techniques that play an active role in sonar, radar and communications systems due to unwanted interference. Many recent researches on antenna arrays focuses on the use of powerful and effective techniques to improve the performance of cancellations (Hreshee and Al-Gayem, 2015; Hreshee, 2013).

Proposed Time Modulated Array (TMA) Models: The radiated power patterns of antenna arrays can be controlled periodically by enabling and disabling individual array elements. This is called TMA. The suggested TMA is a linear array of N isotropic elements which have equally distances between elements. In addition can be excited by a complex amplitude and controlled by a high-speed (RF) Radio Frequency switch in each element. Sending a rectangular pulse is the objective of using an array in this field which has a width of T and prf = $1/T_P$ where prf is a pulse repetition frequency and T_P represents the pulse repetition period. The array operator is taken as in Goswami and Mandal (2013):

$$F(\theta, t) = e^{j2\pi f_0 t}.\sum_{k=1}^{N} A_k e^{j\alpha_k} U_k(t) e^{j\beta(k-1)d\sin\theta} \quad (1)$$

Where:

- θ = The angle calculated from the broadside direction
- f_0 = The centre operating frequency
- β = The wave number in free space
- A_k = The static excitation amplitude
- α_k = The phase of the kth element
- d = The spacing between element
- U_k = The periodic 'switch-on' time sequence functions in each period
- T_p = Each element is switched on for τ_k $(0 \le \tau_k \le T)$

By applying Fourier series on Eq. 1, radiation patterns can be easily obtained at each harmonic frequency m. Prf (m = 0, ±1, ±, ..., α) is given by Mehrabian and Lucas (2006):

$$F_m(\theta, t) = e^{j2\pi(f_0 m.prf)}.\sum_{k=1}^{N} a_{mk}.e^{j[(k-1)\beta d\sin\theta + \alpha_k]} \quad (2)$$

where, a_{mk} is the complex amplitude and is given by:

$$a_{mk} = A_k \tau_k f_p.\frac{\sin(\pi m \tau_k.prf)}{\pi m \tau_k.prf}.e^{-j\pi m \tau_k.prf} \quad (3)$$

when (m = 0) at the center frequency, Eq. 3 becomes:

$$a_{0k} = A_k \tau_k f_p \quad (4)$$

To minimize the side lobe levels an Invasive Weed Optimization (IWO) and Particle Swarm Optimization (PSO) algorithm have been used.

Invasive Weed Optimization (IWO) algorithm: By Mehrabian and Lucas (2006) had presented invasive weeds optimization as a population-based algorithm. This algorithm is one of the algorithms that have an important role of biology in the simulation of the normal conduct of weeds in colonialism and find a convenient location for growth and propagation. IWO has a lot of characteristics such as reproduction, spatial dispersion and competitive exclusion made it distinct from other developmental supplements. The research of the IWO algorithm is to generate a population set then randomly create a group of initial solutions to the problem space. You can see the flowchart of the IWO algorithm in Fig. 1 (Mehrabian and Lucas, 2006).

Depending on the relative fitness of individuals, the seed population is produced. In other words, the worst member has a small number of seeds represented by S_{min} and the best member has a large number of seeds which increases linearly to S_{max}. For the third step, randomly distribution for random numbers is used with a standard deviation and mean equal zero to randomly disperse these seeds on the search area. For each generation the Standard Deviation equation (SD) is presented as follows (Borzabadi and Heidari, 2010; Mehrabian and Lucas, 2006):

$$\sigma_{iter} = \frac{(iter_{max} - iter)^n}{(iter_{max})^n}(\sigma_{initial} - \sigma_{final}) + \sigma_{final} \quad (5)$$

Where:

- n = The nonlinear modulation index
- $iter_{max}$ = The maximum number of iterations
- σ_{iter} = SD at the present iteration

Moreover, those probable solutions for the following generation are taken from productive seeds and their

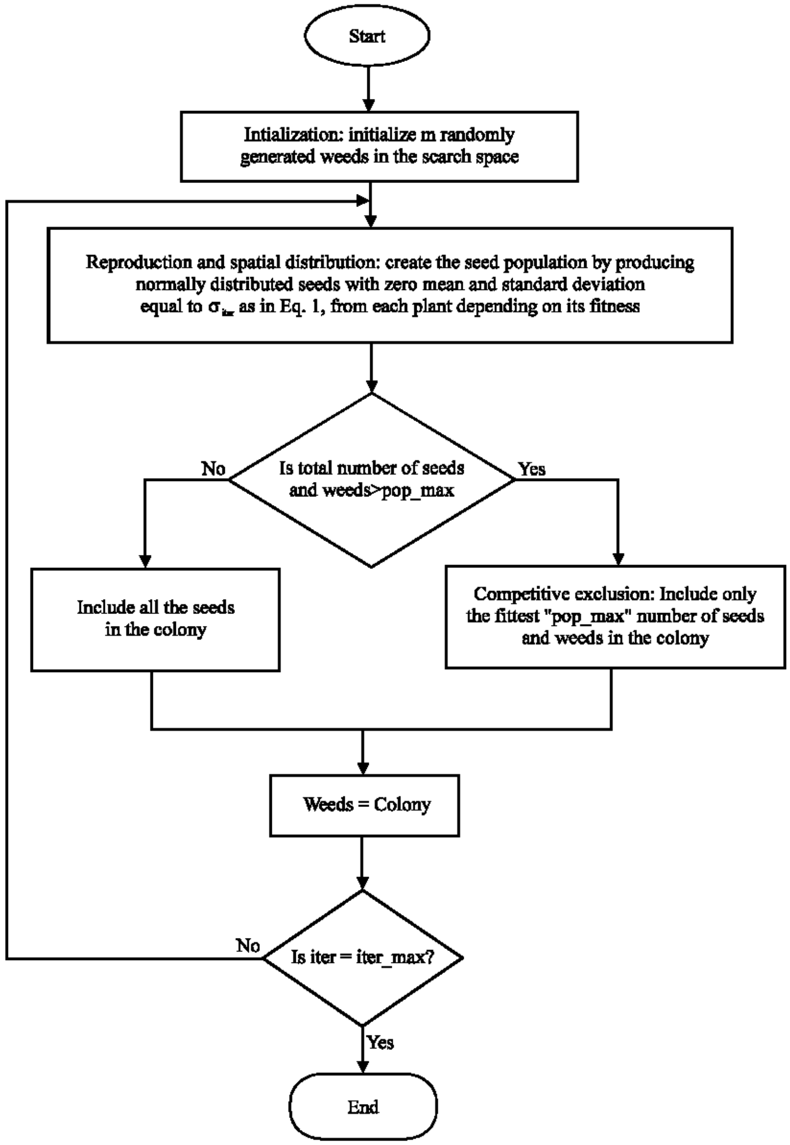

Fig. 1: Flowchart of IWO algorithm

parents. Finally, the population reaches the maximum after many repetitions where a competitive exception is made in the algorithm and to this end the removal mechanism should be used and who enjoy better physical fitness (after sorting seed and their parents) are still alive and are born with reproduction.

Particle Swarm Optimization (PSO): It is a modern technology in evolutionary computing. It is depend on population to find an appropriate solution to global optimization problems. The PSO include many characteristics such as the parameters which its adjustment is few and the speed of rapid convergence (Mehrabian and Lucas, 2006).

PSO interferes with social life such as bird flow or fish flow and enters the evolutionary account in a distinctive and common way such as fitness assessment. PSO does not work with coding parameters but with real number, it can handle the simulated scramble motion simulation in an optional n dimensional area. Transfer vector V found for each particle, own position x, xp_{best} (the best position) and xg_{best} (the best position for all the particles), all the particles share in it (Chen *et al*., 2017). There are many steps as flows performed on each body individually (Najjar and Khodier, 2008): create a group in the problem area that includes particles with random placements and speeds in M dimensions. Applies optimal fitness function to each particle in the variables M. Particle velocity is updated by changing particle velocity through proportional positions of p_{best} and q_{best}. The greatest fitness is achieve through Eq. 6 when the directions of these sites are accelerated:

$$\nu_n = w * \nu_n + c_1 rand()*\left(g_{best,\, n} - x_n\right) + c_2 rand\ ()*\left(p_{best,\, n} - x_n\right)$$

where, x_n and ν_n are the particle coordinate and the velocity of the particle, respectively, in the n-th dimension while c_1 is scaling factors that determine the relative "pull" of p_{best} and c_2 is scaling factors that determine the relative "pull" of q_{best} also, 2.0 is a value for previous action has shown that it is a good choice for both parameters and rand () is a random number uniformly divided in interval (0, 1).

The speed of the current particles depends on their previous velocity at a certain weight that can be determined by the parameter w which is within the range [0, 1] and so, called inertia and also to what extent the particle reaches the best state and the world of the best positions. If w is linearly discouraged with iterations beginning at 0.9 and linearly ends to 0.4 at the last iteration shown that the PSO algorithm become converges faster. It is simple to carry the particle to its following position. Once, the speed is determined, the new coordinates of each dimension are calculated according to the next equation:

$$x_n \leftarrow x_n + \nu_n$$

In order to get the higher fitness by wrapping to step (2) until the standard is met, usually the maximum number of iterations. Fig. 2 states the algorithm of PSO.

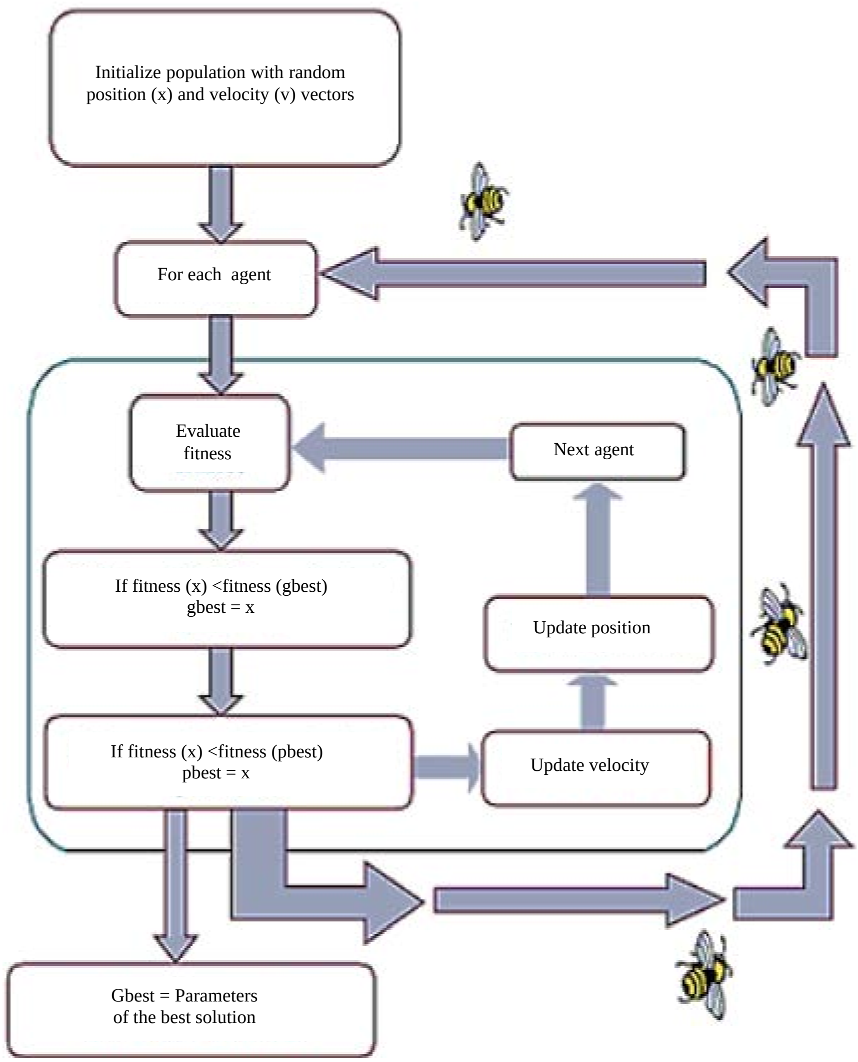

Fig. 2: Flowchart of PSO algorithm (Sarkar *et al*., 2014)

RESULTS AND DISCUSSION

Two schemes with five atypical antenna array are considered schemes as five problem instantiations. These are 4, 8, 16, 32 and 64 elements time-modulated antenna array. In the first scheme (one stage), each algorithm used alone in one stage to reduce the side lobe level to achieve maximum power in the antenna pattern direction. The results appeared that the IWO algorithm is better than PSO algorithm. Figure 3 shows the results of using single stage TMA beamformer with the algorithms of IWO and PSO (Table 1 and 2).

The second scheme (two stages) the algorithms used in double stages with four cases IWO-IWO, IWO-PSO, PSO-IWO and finally PSO-PSO as seen in Fig. 4 which states the results of using two stages TMA beamformer with the algorithms IWO and PSO together. In the two stages scheme, the results showed that the IWO-IWO

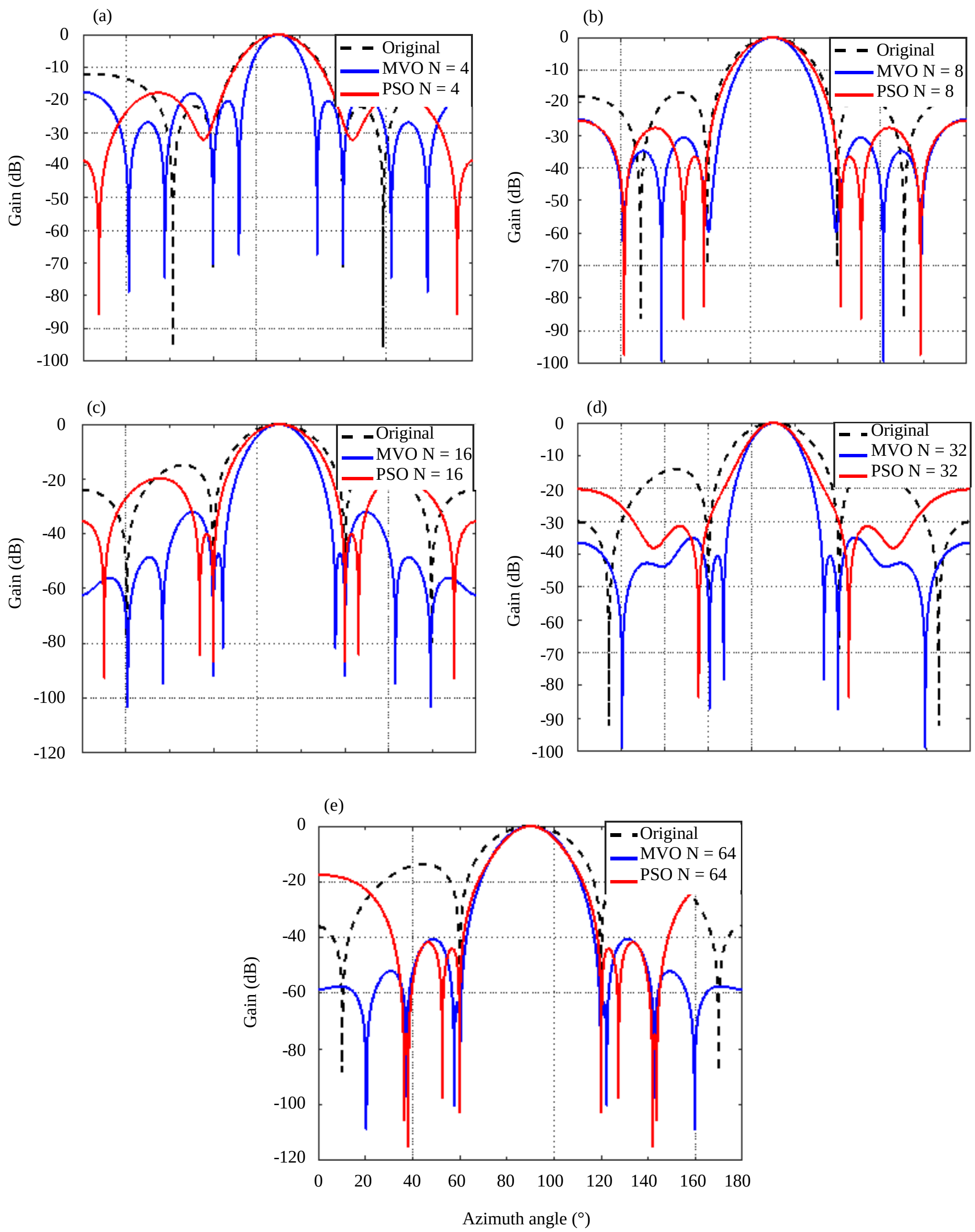

Fig. 3: a-e) Results of using single stage TMA beamformer with the algorithms IWO and PSO

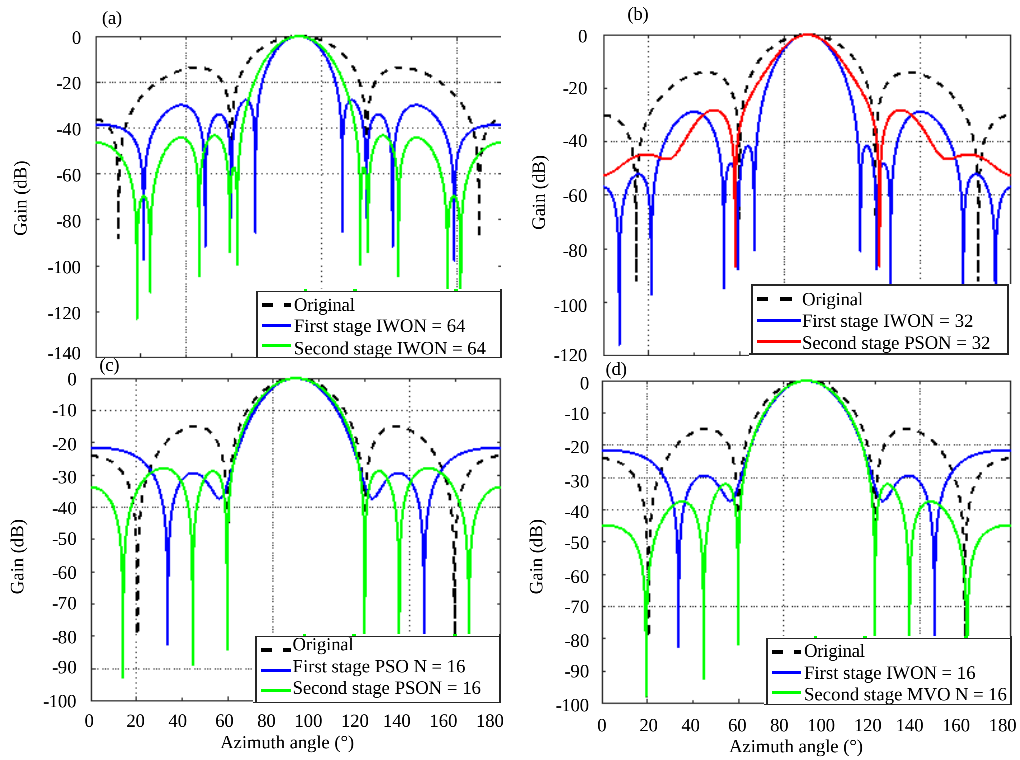

Fig. 4: a-d) The results of using two stages TMA beamformer with the algorithms IWO and PSO together

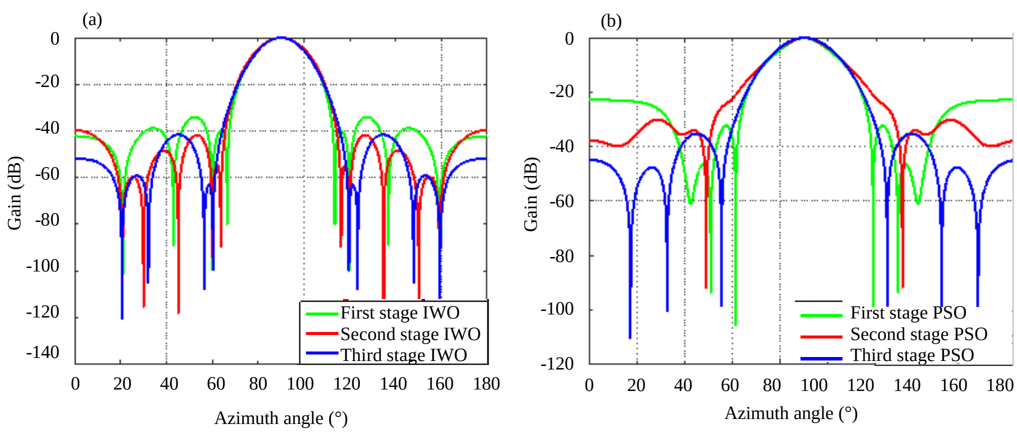

Fig. 5: a, b) The results of using more than two stages TMA beamformer with and without IWO algorithms

Table 1: The average side lobe level readings for the proposed algorithms (alone) with TMA antenna.

Type of algorithm	No. of element				
	4	8	16	32	64
IWO	-17.99	-25.1	-32.06	-34.97	-40.53
PSO	-17.8	-25.49	-19.7	-20.23	-17.45
Origin	-12.04	-16.82	-14.9	-14.05	-13.65

Table 2: The average side lobe level readings for the proposed algorithms with TMA antenna.

Type of algorithm	No. of element				
	4	8	16	32	64
IWO-IWO	-25.25	-28.85	-29.13	-32.43	-43.19
IWO-PSO	-22.82	-21.11	-24.52	-28.11	-25.46
PSO-PSO	-21.82	-23.74	-27.88	-19.67	-19.91
PSO-IWO	-23.72	-28.2	-32.06	-30.14	-31.55
Origin	-12.04	-16.82	-14.9	-14.05	-13.65

scheme is better than other schemes. While Fig. 5 depicts the ability of using tow type of algorithms like IWO and PSO algorithm and multi stage of IWO and PSO.

CONCLUSION

It can be concluded form the results the minimum side lobe level to achieve maximum direction in antenna pattern can easily found. The application of evolutionary algorithms Particle Swarm Optimization (PSO) and Invasive Weed Optimization (IWO) are used in linear array antenna. These algorithms used with different type of array elements numbers (4, 8, 16, 32 and 64). The best result for IWO algorithm is when N = 64 it's clear that the side lobe level reduced to -40.53 dB while it was -13.65 dB in the origin (dashed line). But the best result for PSO algorithm is when N = 8 it's clear that the side lobe level reduced to -25.49 dB while it was -16.82 dB in the origin (dashed line) from all results proved that, the IWO algorithm is better than PSO algorithm.

By using multi stage of antenna, there are four type of multi stage: first stage is IWO and second stage is IWO the best value is -43.19 dB when N = 64 , first stage is IWO and second stage is PSO the best value is -28.11 dB when N = 32, first stage is PSO and second stage is PSO the best value is -27.88 dB N = 16, first stage is PSO and second stage is IWO the best value is -32.06 dB N = 16.

The study proved that the two method are good methods for the redaction of the side lobes. In addition when they are used in multi stage scheme, the best way to reduce the side lobe level was the IWO-IWO algorithm. However, the results also show that this operation was efficient only for two stages in other word when we increase the number of stages, the side lobe level is ranges between increase and decrease.

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