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Failure Recovery in a Smart Antenna System for Remote Applications

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Abstract: This paper focusses on recovering the degraded pattern in the event of failure of elements in a Smart Antenna System. A well-known optimisation algorithm namely: Levy Harmony Search (LHS) Algorithm is employed to optimise the excitations of the remaining 'healthy' elements to recover from the degradation caused due to the element failures. A 1×10 Microstrip Patch Antenna Array, working in the 5G frequency band 3.3-3.7 GHz, is designed to closely observe the effects of element failures, followed by the recovery of the pattern by modifying certain parameters. Algorithm considered is simulated using MATLAB and the results of the simulation are validated using HFSS.
Keywords: Antenna Arrays, Smart Antenna Systems, Failure Recovery, Optimisation, Metaheuristics, Levy Flights

I. INTRODUCTION

Array Signal Processing is a vital aspect of Smart Antenna Systems owing to its immense potential for research and deployment in applications such as: Radio Astronomy, Satellite Communication, RADAR etc. Remote applications are of prime importance in this era of modernisation due to the need for global connectivity. Antenna Arrays play a vital role in supporting the ever-growing subscriber base and extending the range of communication. In the event of failure of elements in the Array, the overall radiation pattern gets influenced in a way that distorts the entire pattern. The degradations are observed in terms of increased Side Lobe Levels (SLL), change in Beamwidth, displacement of nulls etc. It may not always be possible to immediately replace the faulty elements or it may not be cost effective to do so. Suppressing interference is of utmost importance in the array signal processing to enhance the Signal to Interference ratio (SINR). This requires reducing the power radiated in the interfering directions and reinforcing it in the desired directions to boost the desired signal strength. SLL reduction plays a vital role in enhancing SINR. Amplitude tapering is the most commonly employed technique for lowering the SLL, but it comes at the cost of lowered Gain and broadened beamwidth. Antenna Optimisation is a highly non-Convex problem since it has many Local optimum values. To demonstrate the applications of the failure recovery in a Smart Antenna system, Antenna Optimisation has been addressed using the Metaheuristic Algorithm namely Levy Harmony Search (LHS) Algorithm. LHS Algorithm [2] is the modified version of the existing HS [3] Algorithm, hybridized with the Levy Flight concept [6-7]. To enable the Metaheuristic algorithms to escape local maximum, step lengths employed in updating the solutions will be hybridized with Levy walk concept [6-7]. Thus, facilitating the algorithms to approach global optima. Amplitude tapering employed to lower SLL provides most excitation to the centre elements and the least excitation to the edge elements. This paper considers the event of failure of the most excited element followed by the recovery mechanism. The LHS Algorithm will be employed using 1×10 Microstrip Patch Antenna Array to achieve both objectives to recover from the failure of elements namely: lowering the SLL and recovering a displaced null position by optimizing the excitations.

II. MICROSTRIP PATCH ANTENNA DESIGN

Microstrip Patch Antenna Array [1] operating in the 5G frequency band 3.3-3.7 GHz, with the centre frequency 3.5 GHz is designed. The specifications of a single Patch are chosen as follows:

1) Resonant frequency f_0=3.5 GHz
2) Dielectric substrate material: FR
3) Dielectric constant ε_r=4.
4) Dielectric Thickness t=1.6 mm
5) Width of the patch is calculated as

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} = 26.1\ mm \tag{1}$$

Where, c is the speed of light 3×10^8 m/s

6) Effective dielectric constant ε_{reff} is calculated

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2} = 3.9904 \qquad W/h > 1 \tag{2}$$

7) Due to the fringing effect, increased length of the patch ΔL

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} = 0.734\ mm \tag{3}$$

8) Length of the patch:

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L = 20.1\ mm \tag{4}$$

The specifications of a single patch antenna are shown in Fig. 1. The 1×10 Array is designed as shown in Fig. 2.

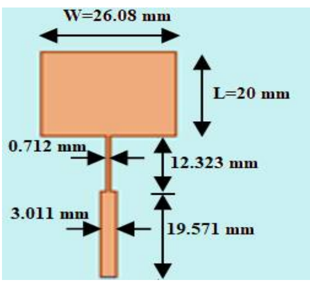

Fig. 1 Microstrip Patch

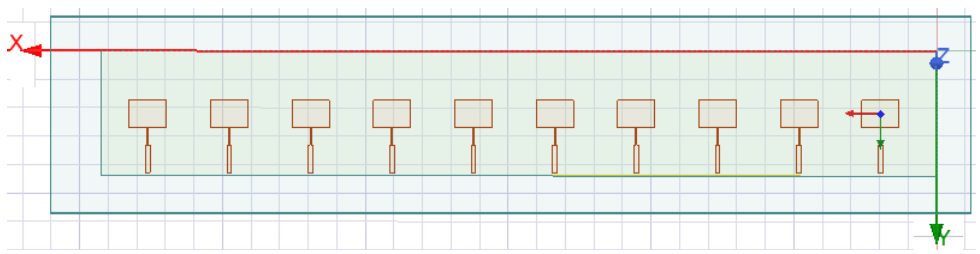

Fig. 2 1×10 Microstrip Patch Antenna Array

The Gain plot of the Array when all the elements are working is shown in Fig. 3. The array has a Maximum Gain of 14.4 dBi, beamwidth is 18^0 and Peak SLL is -13.44 dB with reference to the Maximum Gain. The aperture length of the Array is 5.986λ. This paper focusses on the position of 3rd null in the pattern, positioned at 27^0.

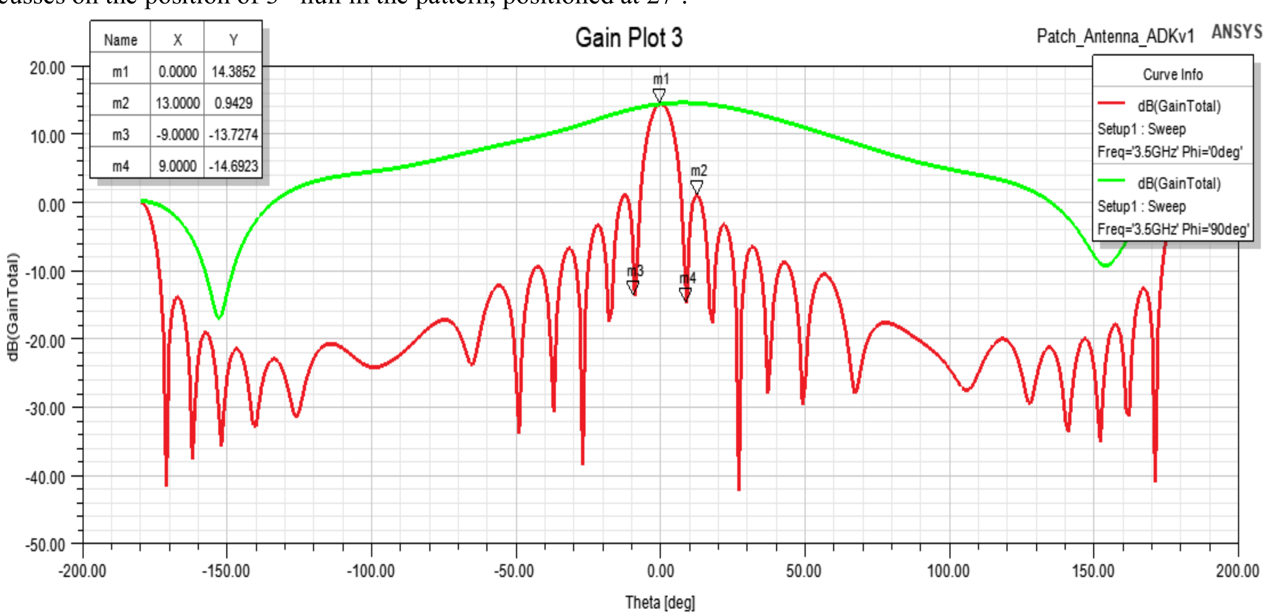

Fig. 3 Rectangular Gain Plot of the Microstrip Patch Antenna Array

The designed Array will be used to demonstrate the effectiveness of the considered optimisation technique, a scenario of the centre element failure is considered in this paper. Two objectives are addressed independently: Firstly, lowering the SLL and secondly, repositioning the null at 27^0. The following section explains the optimisation technique considered.

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III.OPTIMISATION ALGORITHM

A. Prerequisites of Optimisation algorithms [2]

1) A population of preliminary solutions is generated: $x_n = (x_n^1, x_n^2, x_n^3, \ldots\ldots, x_n^M)$ (5)

Where, each x_n is a solution which consists of a set of M complex weights generated randomly using the search space.

2) Search space of each decision variable is lower and upper bound as:

$$x_{low} \le x_n^i \le x_{high} \quad i = 1, 2, \ldots M \tag{6}$$

Where, x_{low} and x_{high} are the bounds for the generation of the initial solution.

3) Decision variables for each solution are chosen as:

$$x_n^i = x_{low} + (x_{high} - x_{low}) \times rand \tag{7}$$

Where, $rand$ is a random number [0,1], x_n^i are the complex weights in each solution.

4) Fitness examination is carried out using:

$$f_{fit} = n_a \times (PSL - DPSL) + n_b \tag{8}$$

Where, f_{fit} is the fitness value, n_a and n_b are numerical constants, PSL is the Peak Side Lobe Level of the solution and $DPSL$ is the Desired Peak Side Lobe Level.

5) Objective function is employed in each iteration:

$$f_{obj} = max(f_{fit}) \tag{9}$$

Where, f_{obj} is the objective function value.

B. Harmony Search Algorithm (HSA) [3]

1) *Step 1:* Harmony Memory HM is initialised using the N 'harmonies', each containing d variables [x_1, x_2,… , x_d] representing the complex weights.

$$HM = \begin{bmatrix} Harmony\ 1 \\ Harmony\ 2 \\ . \\ . \\ . \\ Harmony\ N \end{bmatrix} = \begin{bmatrix} x_{1,1} & x_{1,2} & \cdots & x_{1,d} & | f_1 \\ x_{2,1} & x_{2,2} & \cdots & x_{2,d} & | f_2 \\ . & . & \cdots & & |.. \\ . & . & \cdots & & |.. \\ . & . & \cdots & & |.. \\ x_{N,1} & x_{N,2} & \cdots & x_{N,d} & | f_N \end{bmatrix} \tag{10}$$

2) *Step 2:* Fitness value of each harmony is evaluated considering the objective at hand, a random Harmony Memory Consideration Rate (HMCR) value, rand, Pitch Adjustment Rate (PAR) using (11) and (12) are generated:

$$HMCR = 0.9 + 0.1 \times rand \tag{11}$$

$$PAR = \frac{1-rand}{2} \tag{12}$$

If $rand \le HMCR$, a harmony is randomly chosen from HM using: $x_{new,j} = x_{k,j}$ (13)

3) *Step 3:* If $rand > HMCR$, new harmony is created:

$$x_{new} = [x_{new,1} \ \ x_{new,2} \ \ \cdots \ \ x_{new,d}] \tag{14}$$

4) *Step 4:* New Harmony is adjusted as :

$$x_{new,i} = x_{new,i} + bw \times (rand - 0.5) \times |u_i - l_i| \tag{15}$$

5) *Step 5:* If the fitness value of the new harmony is good compared to the worst fitness in the *HM*, the new harmony will replace the worst harmony in *HM*. Steps 2-5 are repeated for the pre-set number of iterations.

C. Levy Walk Concept [6-7]

Levy walk [6-7] is a very effective walk concept which is known to be more efficient than the Brownian motion in exploring any search space. It has a good balance of shorter and longer steps hence, covers a larger search space. The Fig. 4 shows the Levy flight mechanism in moving from an initial to final point. The step lengths follow the Levy Probability Distribution Function shown in Fig. 5.

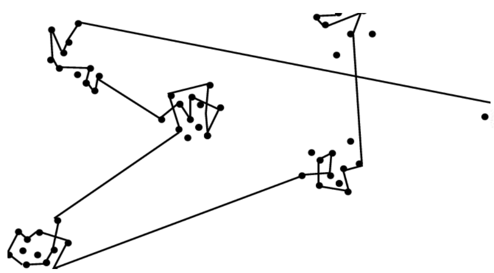

Fig. 4 Levy Walk

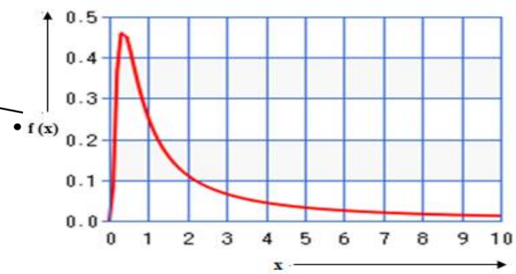

Fig. 5 Levy Distribution

The Levy step lengths are generated as:

$$Step = \alpha \xi_t \times s \tag{16}$$

Where, $\alpha>0$ is used to provide scaling, *s* are values taken from levy distribution, ξ_t=(rand-0.5) is the 1×M vector containing positive and negative step sizes. Solution update of HS Algorithm in (15) is modified to result in Levy HS (LHS) Algorithm as:

$$x_{new,i} = x_{new,i} + bw \times (rand - 0.5) \times |u_i - l_i| + Step \tag{17}$$

IV. FAILURE OF CENTRE ELEMENT

A. Centre Element Failure

The 5th or 6th element failure is considered in this paper. Both failure scenarios tend to give similar results since the Array considered is symmetric. The aperture length of the Array is 5.986λ, equal to the ten-element Linear Array of Microstrip Patches. Gain plot of the array with 5th element failure is as shown in Fig. 6.

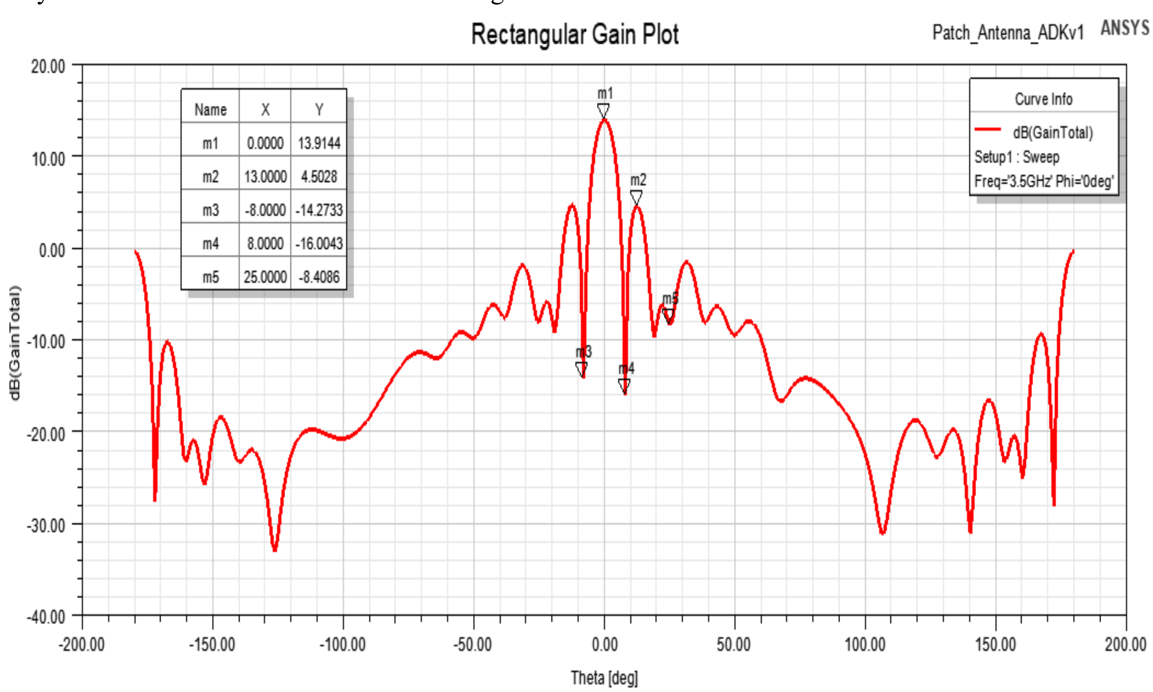

Fig. 6 Rectangular Gain plot of the degraded pattern with 5th element failure

Fig. 6 shows the degradation in the pattern compared to Fig. 3. The Maximum Gain is reduced to 13.9 dBi, with beamwidth 16^0 and Peak SLL -9.4116 dB with reference to Maximum Gain. The Nulls are displaced and now positioned at: [8^0, 19^0, 25^0].

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B. SLL Reduction

SLL reduction is majorly influenced by the amplitude taper provided across the array. The optimised Excitation Amplitudes by LHS Algorithm are: [0.2214 0.5667 0.2939 0.3936 0 1.0 0.3842 0.2288 0.3351 0.6128]. The rectangular Gain plot of LHS optimised pattern compared with the Degraded Pattern is shown in Fig. 7.

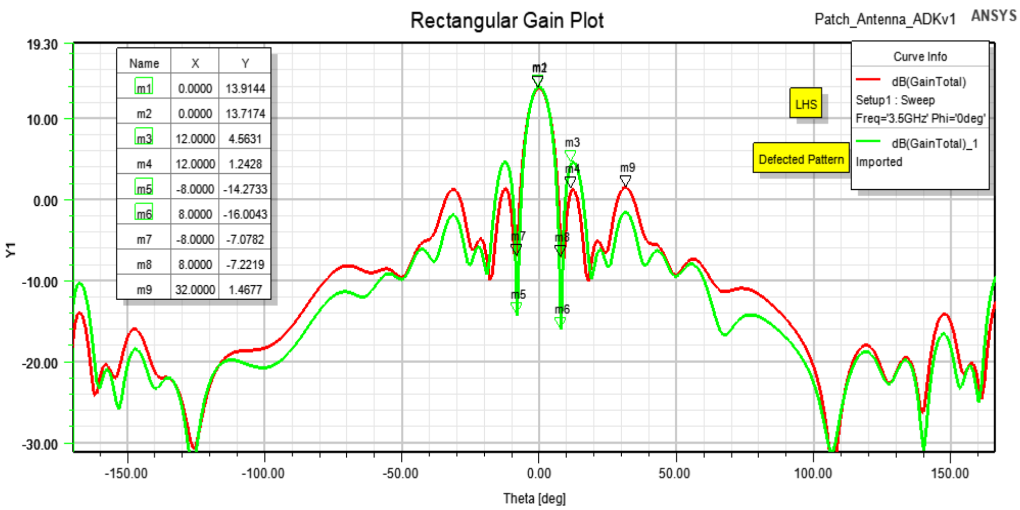

Fig. 7 Rectangular Gain plot comparison of LHS optimised and degraded pattern

Fig. 7 gives a comparison of the pattern optimised by LHS algorithm with the degraded pattern. Optimised pattern is symmetric with peak SLL -11.7261 dB with reference to Maximum Gain, beamwidth is 16^0 and Maximum Gain is 13.6564 dBi. Thus, demonstrating that optimizing of the Excitation Amplitudes of the 'healthy' elements using LHS enables the reduction of the Peak SLL by 2.31 dB, but it comes at the cost of 0.24 dB reduction in Gain, with equivalent beamwidth as the degraded pattern.

C. Recovering Null Positions

The complex weights optimised by LHS Algorithm are a combination of Excitation Amplitudes and the Excitation phases as: [1 1 1 1 0 1 1 1 1 0.808] & [90^0 84.4025^0 61.7019^0 78.0114^0 0^0 79.3249^0 90^0 90^0 57.6871^0 87.2331^0] respectively. The rectangular Gain plot of LHS optimised pattern compared with the Degraded Pattern is shown in Fig. 8.

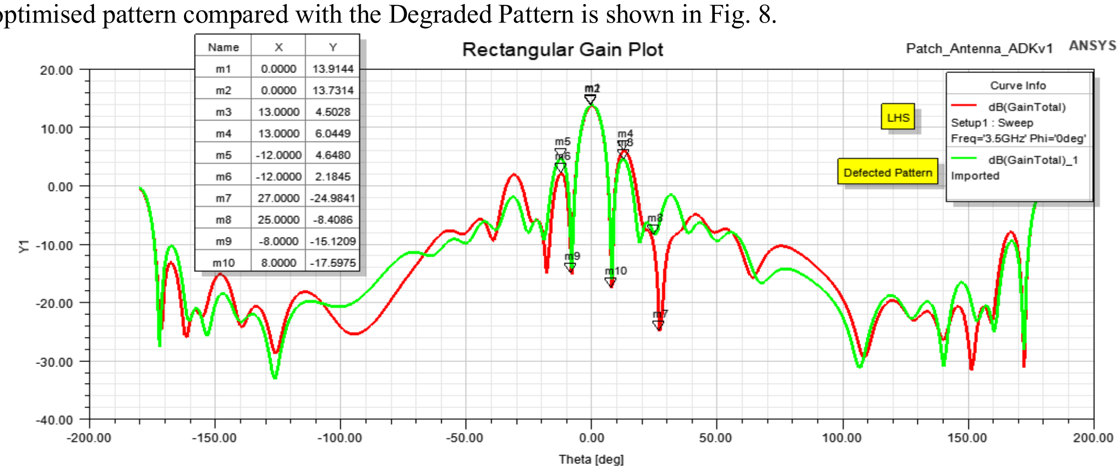

Fig. 8 Rectangular Gain plot comparison of LHS optimised and degraded pattern

Fig. 8 gives a comparison of the pattern optimised by LHS algorithm with the degraded pattern. Optimised pattern is symmetric with beamwidth 16^0 and Maximum Gain 13.7314 dBi. Thus, demonstrating that optimization of the complex weights of the 'healthy' elements using LHS helps in recovering the position of 3rd null at 27^0 with a depth -38.7155 dB, equivalent beamwidth at the cost of peak SLL increased by 1.7251 dB and Maximum Gain reduced by 0.183 dB with reference to the degraded pattern. The results achieved by LHS Algorithm in meeting both objectives are summarized in Table I

TABLE I
Summary of Results

Parameters	Degraded Pattern Null displaced to 25^0	SLL Reduction	Optimised Patterns with Null position recovered
Max. SLL (dB)	-9.4116	-11.7261	-7.6865
Null Depth (dB)	25^0, -22.323 dB	Not Applicable	-38.7155
FNBW (in deg)	16^0	16^0	16^0
Max. Gain (dBi)	13.9	13.6564	13.7314

V. CONCLUSIONS

The 1×10 Array of Microstrip Patch Antennas, working in the 5G frequency band 3.3-3.7 GHz, has been designed to observe the effects of element failures. Levy Harmony Search (LHS) Algorithm has been employed to optimise the excitation parameters to meet the objectives of lowering SLL and repositioning a null. The failure of centre element has been considered. The results of lowering SLL by the optimization of Excitation Amplitudes, showed that LHS Algorithm lowered the SLL by 2.3 dB at the cost of 0.24 dB reduction of Gain, while keeping the beamwidth same as the degraded pattern. The results of Null Positioning by the optimization of the complex weights showed that LHS Algorithm repositioned the 3rd null at 27^0 with a depth -38.7155 dB with reference to maximum gain but at the cost of Maximum Gain lowered by 0.17 dB with reference to the degraded pattern.

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REFERENCES

[1] Iffath Fawad and H. V. Kumaraswamy, "Effects of Microstrip Array Failures in a Smart Antenna System for 5G Mobile Communication," 2021 IEEE International Conference on Computation System and Information Technology for Sustainable Solutions (CSITSS), 2021, pp. 1-6, doi: 10.1109/CSITSS54238.2021.9682895.

[2] Iffath Fawad and H. V. Kumaraswamy, "Enhanced Performance Smart Antenna System using Levy Based Optimisation Algorithms for Mobile Communication," 2021 IEEE International Conference on Mobile Networks and Wireless Communications (ICMNWC), 2021, pp. 1-7, doi: 10.1109/ICMNWC52512.2021.9688419K

[3] Bressler, Steven L. Gao, X. Z., Xu, H., Wang, X., Zenger, K., "Harmony Search Method: Theory and Applications", 2015 Computational Intelligence and Neuroscience, Hindawi Publishing Corporation.

[4] Maryam Hesari and Ataallah Ebrahimzadeh, "Introducing Deeper Nulls and Reduction of Side-Lobe Level in Linear and Non-Uniform Planar Antenna Arrays Using Gravitational Search Algorithm", Progress in Electromagnetics Research B, Vol. 73, 131–145, 2017

[5] Dzakyta Afuzagani, Suyanto Suyanto, "Optimizing BTS Placement Using Hybrid Evolutionary Firefly Algorithm", 2020 8th International Conference on Information and Communication Technology (ICoICT)

[6] A. Eid and S. Kamel, "Optimal Allocation of Multiple Distributed Generations in Radial Distribution Systems Using Levy Flight Distribution Algorithm," *2021 IEEE International Conference on Automation/XXIV Congress of the Chilean Association of Automatic Control (ICA-ACCA)*, 2021, pp. 1-5, DOI: 10.1109/ICAACCA51523.2021.9465307.

[7] Y. Chen, Y. R. Gel and K. Avrachenkov, "LFGCN: Levitating over Graphs with Levy Flights," 2020 IEEE International Conference on Data Mining (ICDM), 2020, pp. 960-965, DOI: 10.1109/ICDM50108.2020.00109.

[8] H. L. Van Trees, Optimum Array Processing: Part IV of Detection, Estimation, and Modulation Theory. New York, NY: John Wiley and Sons, 2002.

[9] Om Prakash Acharya, Amalendu Patnaik, Balamati Choudhury, "Fault Finding in Antenna Arrays using Bacteria Foraging Optimisation Technique", 2011 National Conference on Communications (NCC), IEEE, Bangalore, India

[10] L. Godara, "Application of antenna arrays to mobile communications, Part II: Beam-Forming and Direction-of-Arrival Considerations," Proceedings of the IEEE, Vol. 85, No. 8, pp. 1195–1245, Aug. 1997.