Synthesis of directional modulation signal using a hybrid Optimization algorithm

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***Abstract*—Directional Modulation (DM) technique, as an emerging promising approach to secure wireless communications, has been attracting increasing attention for its unique characteristic in the past decade. The baseband signal is synthesized at the antenna level for maintaining the standard constellation format along the prescribed direction(s) while simultaneously distorting the signal constellations in other undesired directions. In this paper, we present a novel DM signal synthesis method based on phased array using a hybrid genetic algorithm (GA) and particle swarm optimization (PSO) algorithm, which takes advantages of both GA and PSO algorithm. Then, the bit error rate of the proposed method is analyzed and simulated. Simulation results are presented to verify that the proposed DM signal have a narrower information beam-width. Therefore, it can offer a better physical layer security (PLS) performance compared with the conventional directional modulation signal.**

Keywords—DM, GA, PSO, PLS, hybrid algorithm.

I. INTRODUCTION

Directional modulation (DM) technique offers security by transmitting digitally modulated information signals along preassigned direction while simultaneously distorting the constellation formats of the same signals in other directions [1-10]. Only receivers located within the information beam-width of the antenna can properly recover the signal, which is extremely advantageous for secure wireless communication in the physical layer [1-2]. DM technique using phased arrays to produce the modulation is presented in [3-4], which introduces phased arrays to synthesize DM signals using a single-objective genetic algorithm. However, this synthesis method only focuses on maintaining the constellation at the desired direction, while the distortion degree of constellation formats in undesired directions are not taken into account. Moreover, the objective function has multiple local optimums. Therefore, the genetic algorithm may converge to local extrema randomly. DM signal based on multi-objective genetic algorithm is proposed in [5], which results in a narrow information beam-width. But, the convergence speed for the signal synthesis is not considered. In [6], Ding Y linked the DM system bit error rate (BER) performance to the settings of phase shifters, and then he utilized the particle swarm optimization algorithm to synthesize DM signal. However, the capability of global search for the optimization algorithm is not considered.

In this paper, a DM signal synthesis method based on multi-objective hybrid GA-PSO algorithm is proposed. The phase shift values are generated according to the relationship between Euclidean distance of constellation points and BER performance. It takes both advantages of GA and PSO algorithm, which integrates global searching ability with high convergence speed. The proposed algorithm is an efficient method for solving the optimization problem. And the DM signal has a narrower information beam-width, which offers a better physical layer secure performance.

II. PHASED DM TECHNIQUE AND A HYBRID GA-PSO ALGORITHM

The structure of a DM transmitter based on phased array is depicted in Fig. 1. The array is an *N*-element linear array of micro-strip patches, and the elements are separated by half wavelength. QPSK modulation is adopted. The electric field from the *n*th element for the *i*th symbol can be written as

$$E_{i,n}(\theta,\varphi) = a_n e^{j\psi_n(i)} \frac{e^{-j\beta R_n}}{R_n} f_e(\theta,\varphi), \quad (1)$$

where a_n denotes the amplitude excitation and ψ_n represents the phase of the excitation. $\beta = 2\pi/\lambda$ is the propagation constant and λ is the wavelength. Without loss of generality, let $R_n = R_0 - nd\sin\theta$, $a_n = 1$, $f_e(\theta,\varphi) = 1$. Then, the superposition of all electric fields from *N* elements at a far-field observation point *P* can be written as

$$E_i(\theta) = \frac{e^{-j\beta R_0}}{R_0} \sum_{n=0}^{N-1} e^{j[\psi_n(i) + n\beta d\sin\theta)]} \quad (2)$$

Therefore, we can synthesize the baseband signal in desired direction θ_s by setting suitable phase shift values $\{\psi_0(i), \psi_1(i), \cdots, \psi_{N-1}(i)\}$. The constellation points for QPSK symbols are $C_i = \exp(j(2i+1)\pi/4)$, $i = 0,1,2,3$. In order to maintain the constellation in the desired direction and to generate the maximally distorted constellation diagram in undesired directions, a multi-objective optimizing model can be designed as follows

$$\begin{cases} \min\ f_1 = \sum_{i=0}^{3} \left| E_i(\theta_s) - C_i \right| \\ \max\ f_2 = \sum_{i=0}^{3} \sum_{k=0}^{2\theta_c/step} \left| E_i(\theta_s - \theta_c + 0.01\times k) - C_i \right| \end{cases} \quad (3)$$

$$s.t. -\pi \le \psi_0, \psi_1, \psi_2, \cdots, \psi_{N-1} \le \pi.$$

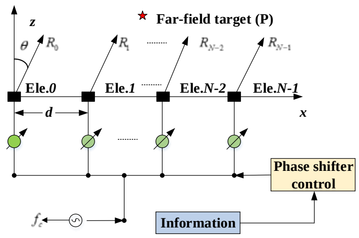


Fig. 1. A DM transmitter based on a N-element phased array.

where θ_c denotes the information beam-width. *step* designates step size of angle, set to 0.01°.

The characteristics of fast convergence of PSO is used for the previous stage of optimization process to obtain an initial population of a certain degree of evolution. Then, GA is utilized for the latter phase of optimization process to avoid falling into local optimum, as shown in Fig. 2. First, according to the coding rules of the problem, a number of individual are randomly generated to form a population. Then, the population evolves according to the hybrid algorithm, and the new individuals generated by the evolutionary process will be decoded to obtain the corresponding objective function value. Next, the evaluation mechanism compares and evaluates the individuals in the new population based on these objective function values to achieve an optimal solution for the current stage. Finally, the iteration will keep going on until a global optimal individual is obtained.

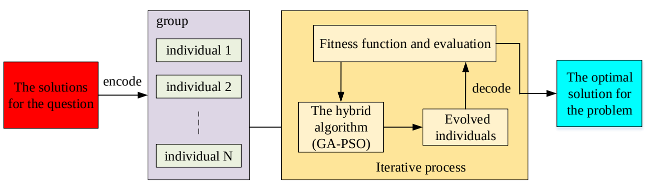
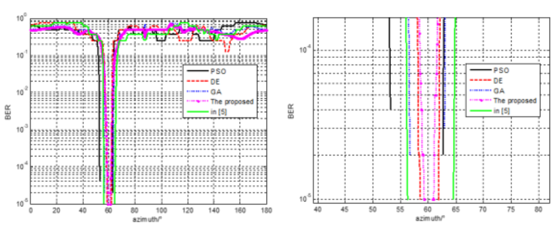


Fig. 2. The framework of the hybrid algorithm.

III. SIMULATION RESULTS



(a) global graph (b) drawing of partial enlargement

Fig. 3. BER performance versus azimuth using different algorithms.

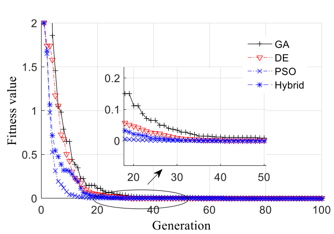


Fig. 4. The convergence curve of the four algorithms.

Fig. 3 illustrates the BER performance versus azimuth angle for four different DM transmitters. We can find that the four BER values are almost the same at the desired direction 60°, and the BER performance of the proposed method is deteriorated obviously compared with the other three transmitters. It shows that the DM signal synthesized with the hybrid algorithm has a narrower information beam-width (BER=10^{-4}) and less notable sidelobes, which leads to enhanced security performance for target users.

Standard GA, PSO, DE and the hybrid algorithm are adopted respectively to synthesize the DM signal. The convergence curves are shown in Fig. 4. It can be observed the convergence speed of the hybrid algorithm is second only to the PSO. Therefore, there is a tradeoff between the convergence speed and securiy performance. It is quite clear that the convergence speed of the hybrid algorithm is getting close to the PSO's with number of the array elements increasing and the security performance is further enhanced.

IV. CONCLUSIONS

By generating the maximally distorted constellation diagram in the undesired directions and setting the scenario for the DM transmitter, a multi-objective optimizing model was designed. A hybrid algorithm is proposed for the DM transmitter signal synthesis. The proposed method brings out good convergence performance and solution quality. Simulation results reveal that the proposed DM signal has a narrower information beam-width and smaller side-lobe level to offer a better physical layer security performance compared with the GA, PSO or DE optimized DM signal.

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REFERENCES

[1] A. Babakhani, D. B. Rutledge, A. Hajimiri, "Transmitter architectures based on near-field direct antenna modulation," *IEEE J. Solid-State Circuits.*, vol. 43, no. 12, pp. 2674-2692, Dec. 2008.

[2] Y. Ding, V. Fusco, "A review of directional modulation technology," *Int. J. Microw. Wirel. T.*, vol. 8, no. 7, pp. 981-993, Jul. 2015.

[3] M. P. Daly, J. T. Bernhard, "Directional modulation technique for phased arrays," *IEEE Trans. Antennas Propag.*, vol. 57, no. 9, pp. 2633-2640, Sep. 2009.

[4] M. P. Daly, E. L. Daly, and J. T. Bernhard, ''Demonstration of directional modulation using a phased array,'' *IEEE Trans. Antennas Propag.*, vol. 58, no. 5, pp. 1545-1550, May. 2010.

[5] T. Hong, M. Z. Song, Y. Liu, "Design of directional modulation signal based on multi-objective genetic algorithm for physical layer secure communication," *Journal of Applied Sciences.*, vol. 32, no. 1, pp. 51-56, Jan. 2014.

[6] Y. Ding, V. Fusco, ''Directional modulation transmitter synthesis using particle swarm optimization,'' in *Proc. IEEE Loughborough Antennas Propag. Conf. (LAPC)*, Loughborough, U.K., 2014, pp. 500-503.