Journal of Information Hiding and Multimedia Signal Processing ©2018 ISSN 2073-4212
Ubiquitous International Volume **9**, Number **6**, November **2018**

SINR Improvement in Space-time Adaptive Processing Systems Based on Meta-heuristic Algorithms

Yanping Liao and Xinke Lv

School of Information and Communication Engineering
Harbin Engineering University
No.145, Nantong Street, Nangang District, Harbin, 150001, China
liaoyanping@hrbeu.edu.cn; lvxinke_bay@foxmail.com

Received May, 2017; revised May, 2018

Abstract. *Signal-to-Interference plus Noise Ratio (SINR) is a significant indicator of anti-jamming capability in Space-time Adaptive Processing (STAP). However, in satellite navigation system, the SINR value of STAP is too low in multi-interference. In allusion to the problem, this paper presents new SINR improvement methods using STAP for meta-heuristic algorithms, including Firefly Algorithm (FA), Cuckoo Search (CS) and Bat Algorithm (BA). The paper simulates SINR value and beamforming in some interference of different numbers and types and analyzes the effect of the number of iterations and populations on running time. Consequently, the proposed approach can increase SINR improvement over 32dB in single interference. Furthermore, the SINR improves 48dB before change in five interferences.*

Keywords: Space-time Adaptive Processing, Firefly Algorithm, Cuckoo Search, Bat Algorithm, Signal-to-Interference plus Noise Ratio

1. **Introduction.** With the development of society, satellite navigation system plays a significant role in military application and our daily life, and becomes an indispensable part of society. However there are many active interference and passive interference in external condition, which affects satellite navigation system normal operation and performance analysis. Hence it is still the important point of military and civil research that satellite navigation anti-interference system.

At present, Space-time Adaptive Processing (STAP) that the antenna array includes linear array, circular array and area array is the most common and advanced anti-interference technology of satellite navigation system [1], and uses both spatial adaptive processing which includes Linearly Constraint Minimum Variance (LCMV), Maximum Signal-to-Interference-plus-Noise Ratio (MSINR) and Minimum Mean-Squared Error (MMSE) and temporal adaptive processing which contains Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) to process interference in two-dimensional space. Due to the computing speed, majority of people choose MMSE, LCMV and FIR instead of MSINR and IIR. STAP adds the degree of freedom (DOF) of array to solve more anti-interference, holding the same array elements. Therefore, it can be reduced that the number and size of arrays of satellite navigation system to reduce power consumption and keep anti-interference performance [2].

As the constant study of STAP, people pay more attention to various indicators after anti-interference, such as computing speed, stability and signal to interference plus noise ratio (SINR) and so on [3, 4]. SINR that is the ratio of the received useful signal to the interference signal (including noise and interference) can explicitly reactive the anti-interference situation. Besides, there is a question that some beamforming or anti-interference technologies will waste power in non-users directions. Thus, improving SINR to solve this problem becomes a research hotspot in recent years. In [3], the SINR of STAP that can achieve 68.72dB in single interference by using LCMV is better than the SINR of STAP based on MMSE, but the SINR is too less (12.74dB) in four interferences. To improve the output of SINR, Doroody applies FA in LCMV beamforming technique increasing from 31.28dB to 47.53dB in single interference and from −4.51dB to 2.5dB in five interferences [5], which makes we lead meta-heuristic algorithms to improve SINR.

Firefly Algorithm (FA), Cuckoo Search (CS) and Bat Algorithm (BA) all developed by Xin-She Yang are new meta-heuristic algorithms that are easier to perform than other optimizing techniques and don't require any gradient information [6]. Meta-heuristic algorithms can optimize many categories problems. In [7], Maya use FA to compensate blind inter carrier interference in MIMO SC-IFDMA system. It is used to correct and efficient beamforming that FA with Harmony Search [8] or BA [9]. There are methods for FIR digital filters using CS algorithm [10, 11]. Rani researches symmetric linear array geometry with minimum sidelobes using CS [12].

In this paper, FA, CS and BA are applied into the STAP anti-interference technology to improve the different SINR between input SINR and output SINR, which aims to achieve more than 32dB in single interference and 22dB in five interferences. We use LCMV as space adaptive processing and FIR as time adaptive processing. The paper is organized as follows: array antenna model and mathematical formulation of STAP are presented in Section 2. A proposed optimizing method and pseudo code of FA-STAP, CS-STAP and BA-STAP are given in Section 3. Experiment results in tables and graphs are provided in Section 4 and Section 5 concludes the paper with future work.

2. **Space-time Adaptive Processing (STAP).**

STAP as space-time processing technology aims to make time filter, frequency filter and space filter extended from one-dimensional to space-time two-dimensional. In Figure 1, every array element links tapped-delay to be a FIR filter that can anti-interference in time. At the same pulse, space adaptive filtering can distinguish interference and generate nulling in space. Hence, STAP has the anti-interference ability in space-time two-dimensional [13].

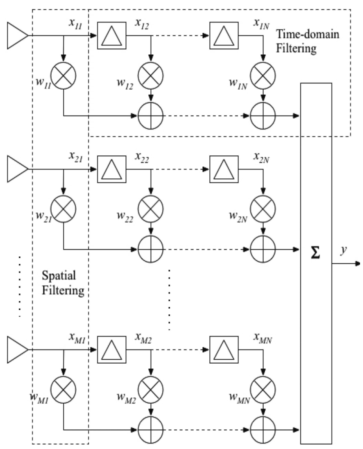


FIGURE 1. Space-time adaptive processing structure

We develop STAP in context of an M elements and N pulses receiving array. $\Delta \leq 1/B$ is the latency of each tapped-delay unit, and B is bandwidth. $\mathrm{R} = E(XX^H)$ is the covariance matrix of receiving, where $X = [x_{11}x_{21} \cdots x_{M1} \cdots x_{1N}x_{2N} \cdots x_{MN}]^T$ is an MN*1 dimensional receiving vector. The space-time steering vector is formed as defined by the following equation

$$v = a_s \otimes b_t \tag{1}$$

Where a_s is the space steering vector and b_t is the time steering vector. $W = [w_{11}w_{21} \cdots w_{M1} \cdots w_{1N}w_{2N} \cdots w_{MN}]^T$ is the space-time two-dimensional weight, which stands for the echo of a target as

$$W = (v^H \mathrm{R}^{-1} v)^{-1} \mathrm{R}^{-1} v \tag{2}$$

The goal of STAP is to suppress the interferences as

$$y = W^H X \tag{3}$$

3. **Proposed optimizing method.** In this paper, based on the STAP anti-interference technology, meta-heuristic algorithms including FA, CS and BA can be realized by joint optimization of the SINR improvement.

3.1. **SINR improvement signal model.** SINR can explicitly reactive the anti-interference situation of STAP. Thus it is noted that one measurement, how to improve difference SINR value. In this paper, we discuss that find the best input to get the best output, SINR improvement value, using FA-STAP, CS-STAP and BA-STAP. According to the section 2, suppose that there is a STAP to combine a meta-heuristic algorithm. $\vec{x}$ is the variable of meta-heuristics. Firstly, we use the initial value $\vec{x}_0$ to calculate $SINR_c(\vec{x}_0)$ that is the difference SINR value of STAP. The target signal and interference signal (interference and noise) are modeled as:

$$X_S(\vec{x}) = S_S(\vec{x}) v_S \tag{4}$$

$$X_{I+N} = S_{I+N} v_{I+N} \tag{5}$$

$$X(\vec{x}) = X_S(\vec{x}) + X_{I+N} \tag{6}$$

where $S_S(\vec{x})$ is a useful signal calculated by $\vec{x}$ and S_{I+N} is an interference signal. v_S and v_{I+N} are the useful signal steering vector and the interference signal steering vector. $X(\vec{x})$ is the signal received by satellite navigation receiver, which can calculate the covariance matrix

$$\mathrm{R_S}(\vec{x}) = E[X_S(\vec{x}) X_S(\vec{x})^H] \tag{7}$$

$$\mathrm{R_{I+N}} = E[X_{I+N} X_{I+N}^H] \tag{8}$$

$$\mathrm{R}(\vec{x}) = E[X(\vec{x}) X(\vec{x})^H] \tag{9}$$

To obtain the SINR improvement, the weight of STAP is given by

$$W(\vec{x}) = [v_S^H \mathrm{R}(\vec{x})^{-1} v_S]^{-1} \mathrm{R}(\vec{x})^{-1} v_S \tag{10}$$

Then, we need get the largest difference SINR value that can be written as

$$\max_{\vec{x}} SINR_c(\vec{x}) = SINR_{out}(\vec{x}) - SINR_{in}(\vec{x}) \tag{11}$$

$$SINR_{out}(\vec{x}) = \frac{W(\vec{x})^H \mathrm{R_S}(\vec{x}) W(\vec{x})}{W(\vec{x})^H \mathrm{R_{I+N}} W(\vec{x})} \tag{12}$$

$$SINR_{in}(\vec{x}) = \frac{P_S(\vec{x})}{P_{I+N}} \tag{13}$$

Here $SINR_{out}(\vec{x})$ is the output SINR and $SINR_{in}(\vec{x})$ is the input SINR. $P_S(\vec{x})$ is the power of the useful signal and P_{I+N} is the power of interference and noise. Thus is can be seen that the weight and SINR value are determined by the input $\vec{x}$. After we use a set of initial inputs and above formulas to get a series of SINR improvement, we can use meta-heuristic optimization algorithm, including FA, CS and BA, to find the best input and the largest difference SINR value.

3.2. **STAP with Firefly Algorithm (FA).** FA, an advanced heuristic algorithm [14], is based a simplification of the biological facts that firefly groups are attracted to each other by bioluminescent and there are some assumptions:

- Each firefly is unisex, which means without regarding their sex when a firefly that has strong light intensity attracts others that have week light intensity.
- Attractiveness parameter and light intensity are proportional to each other.
- The absolute light intensity is the objective function value.

In this section, we introduce signal mode of FA-STAP to get the best SINR improvement. We set firefly populations $\vec{x_i}$ $(i = 1, 2, \ldots, n)$ where n is the number of population, and $SINR_c(\vec{x})$ is the objective function of FA, which is the absolute light intensity I_i. In this paper, three parameters are refered to [5].

3.3. **STAP with Cuckoo Search (CS).** CS stems from the parasitism that cuckoo put their eggs to other birds' nest and a random foraging track to draw modeling [15]. CS algorithm is based on three idealized rules:

- Each cuckoo lays a single egg at a time in a randomly chosen other birds' nest.
- The best better solution (nests) will carry over to the next generation.
- An egg laid by a cuckoo is discovered by the host bird with a probability $p_a \in [0, 1]$. If the host bird throws the egg away, cuckoo will build or find a completely new nest.

In CS-STAP algorithm, $\vec{x_i}(i = 1, 2, \ldots, n)$ is the host nests of which number is n, and the objective function is $SINR_c(\vec{x})$.

3.4. **STAP with Bat Algorithm (BA).** BA is a biologically-inspired meta-heuristic by supersonic characteristic of tiny bat [16], which is based on three hypothetic rules:

- Bats use the different of echolocation to know whether prey or barriers.
- Bats search prey with loudness A and pulse rates r, flying casually velocity v_i at position x_i with frequency f_{min}, which can automatically adjust by distance.
- Loudness A can be a constant or vary from a maximum to a minimum value.

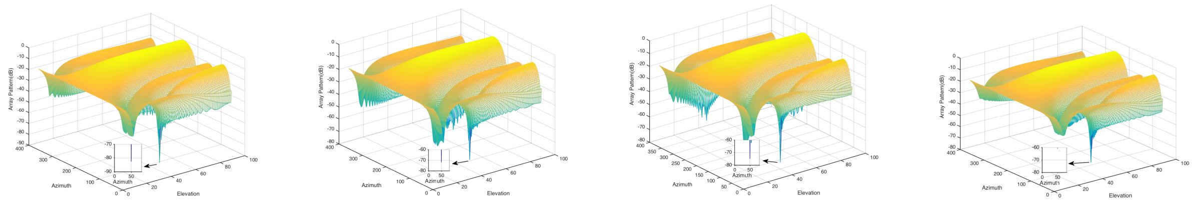
$\vec{x_i}(i = 1, 2, \ldots, n)$ is the bats of which number is n, and $SINR_c(\vec{x})$ is the objective function in BA-STAP.

4. **Optimization algorithm based on signal to noise ratio.** In our simulation, we assume a circular STAP array of $M = 7$ elements and $N = 6$ pulses with a center of a circle, and carrier frequency is 1268.52MHz. The variable of meta-heuristics is the signal-to-interference ratio. We set 10 populations and 10 times iterations of all three algorithms from section 4.1 to section 4.3. The parameters used for all scenarios include: (1) FA: step size factor $\alpha = 0.5$, light intensity coefficient $\gamma = 2$ and the minimum attractiveness parameter $\beta_0 = 0.2$, (2) CS: the probability of being discovered $p_a = 0.25$ and Lévy coefficient $\beta = 1.5$, (3) BA: loudness $A = 1$, pulse rates $r = 0.85$, velocity $v \in [-1, 1]$ and frequency $f \in [0.1, 0.5]$.

4.1. **Single-tone interference.** In the first example, a single-tone interference in $(40°, 50°)$ degree disturbs satellite navigation system to receive desired signal in $(50°, 200°)$ degree. Due to the subtle difference at two decimal places between three new algorithms, we make a table to show the contrast between them. Table 1 illustrates the SINR improvement versus INR (from 20dB to 90dB) performance of the compared algorithms. Figure 2 shows the anti-interference array pattern by four algorithms in three-dimensional.

TABLE 1. SINR improvement versus INR under 1 single-tone interference

INR(dB)	20	30	40	50	60	70	80	90
STAP(dB)	16.34	25.44	36.26	48.29	62.33	72.32	80.14	92.03
FA-STAP(dB)	36.39	46.33	56.29	66.29	76.41	86.26	96.29	106.25
CS-STAP(dB)	36.36	46.32	56.33	66.32	76.32	86.30	96.33	106.31
BA-STAP(dB)	36.50	46.35	56.32	66.33	76.26	86.29	96.27	106.30



(a) STAP (b) FA-STAP (c) CS-STAP (d) BA-STAP

FIGURE 2. Three-dimensional pattern under 1 single-tone interference

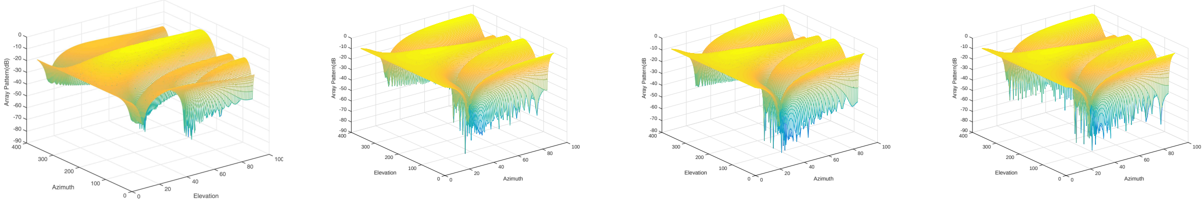
The Table 1 clearly demonstrates that the SINR improvement with FA, CS and BA is greater than the SINR improvement without meta-heuristic algorithms, augmenting with the increase of INR. From Figure 2, we can see that the beam pattern of three algorithms has a distinct difference, and the anti-interference result is not the best.

In the second example, we assume 5 single-tone interferences to disturb satellite navigation system respectively in $(40°, 50°)$, $(60°, 250°)$, $(50°, 60°)$, $(30°, 120°)$ and $(30°, 80°)$. Each INR is 30dB. Table 2 shows the difference of the SINR improvement with FA, CA and BA. Figure 3 displays three-dimensional and two-dimensional array patterns under 5 interferences.

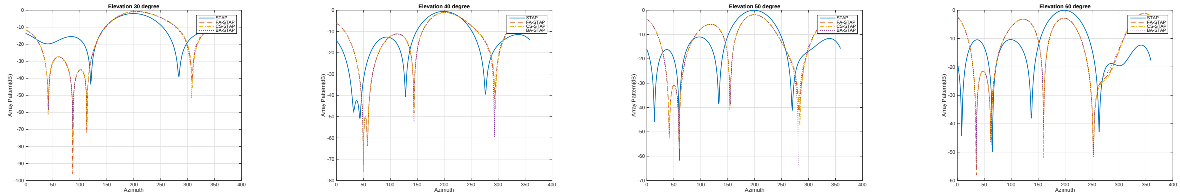
TABLE 2. SINR improvement under 5 single-tone interferences

Algorithm	STAP	FA-STAP	CS-STAP	BA-STAP
SINR Improvement(dB)	35.80	48.25	48.30	48.26

From Table 2, we can know that the value with meta-heuristics is 13dB more than the value just by STAP. Thus, FA, CS and BA play a significant part in improving SINR. It is shown from Figure 3(a) to Figure 3(d) that the performance for suppression of interference is poor, but the five nulls cannot be distinguished in three-dimensional patterns. In Figure3(e) to Figure 3(h), we can see the null of elevation $30°$ has deviation. The depth of nulls are over -50dB in elevation $50°$ and $60°$, and the depth of nulls are over -70dB in elevation $30°$ and $40°$. The largest depth of null is -96dB in $(30°, 80°)$. Besides, the main lobe does not reach the requested value and the beamwidth is wider than before. But the anti-interference result of STAP with meta-heuristics is better than the original STAP in each elevation.



(a) STAP (b) FA-STAP (c) CS-STAP (d) BA-STAP



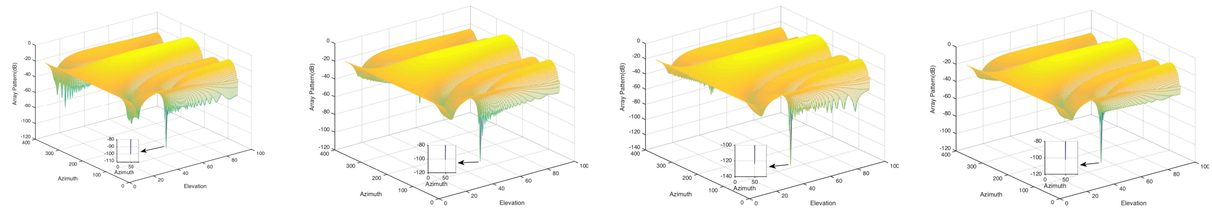
(e) 30 (f) 40 (g) 50 (h) 60

FIGURE 3. Patterns under 5 single-tone interferences

4.2. **Wideband noise interference.** In the third example, we set a wideband noise interference, the bandwidth is within the bandwidth of target signals, in $(40°, 50°)$ disturbs satellite navigation system to receive desired signal in $(50°, 200°)$. Table 3 shows the SINR improvement versus INR performance of the compared algorithms under one wideband noise interference. Three-dimensional beam patterns are presented in Figure 4.

TABLE 3. SINR improvement versus INR under 1 wideband noise interference

INR(dB)	20	30	40	50	60	70	80	90
STAP(dB)	34.27	44.25	54.90	64.69	74.89	84.70	95.61	102.79
FA-STAP(dB)	36.44	46.31	56.34	66.33	76.34	86.39	96.36	106.46
CS-STAP(dB)	36.43	46.32	56.41	66.38	76.38	86.35	96.41	106.35
BA-STAP(dB)	36.41	46.32	56.33	66.35	76.39	86.37	96.38	106.39



(a) STAP (b) FA-STAP (c) CS-STAP (d) BA-STAP

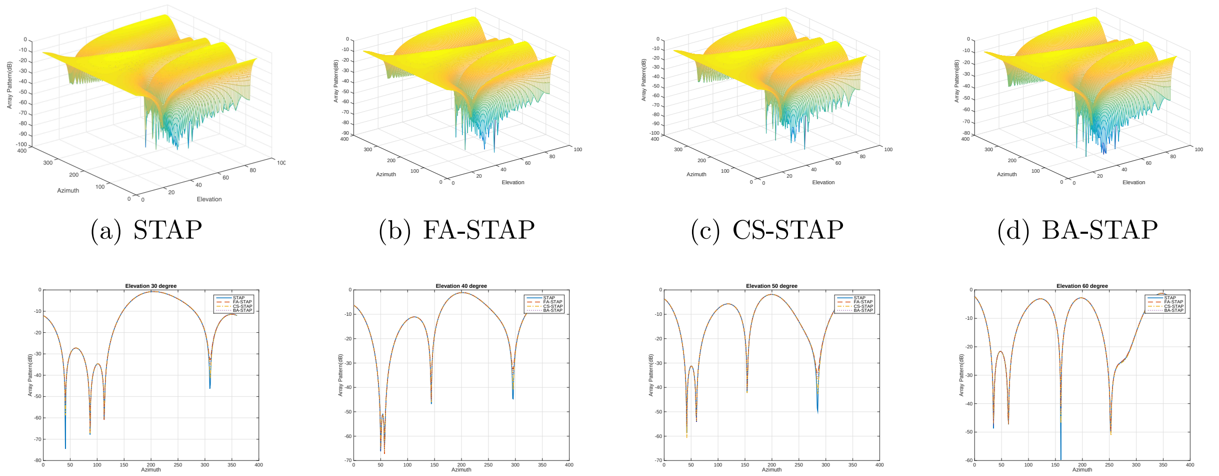
FIGURE 4. Three-dimensional pattern under 1 wideband noise interference

It is noted that the SINR improvement is similar to the result of the first example, which means the optimizing result is better than that un-optimized one in Table 3. Figure 4 proves that the non-interfering nulling by STAP with optimization algorithms is less than original STAP, and there is almost no null shifting.

In the forth example, 5 wideband noise interferences degrees of which are the same as interferences of the second example to disturb satellite navigation system. The INR is 30dB. Table 4 illustrates SINR improvement results of four algorithms. In Figure 5, patterns under 5 wideband noise interferences are displayed.

TABLE 4. SINR improvement under 5 wideband noise interferences

Algorithm	STAP	FA-STAP	CS-STAP	BA-STAP
SINR Improvement(dB)	39.18	48.35	48.36	48.39



(a) STAP (b) FA-STAP (c) CS-STAP (d) BA-STAP

(e) 30 (f) 40 (g) 50 (h) 60

FIGURE 5. Patterns under 5 wideband noise interferences

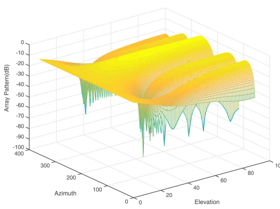
Table 4 presents that three values with meta-heuristics are similar to each other and about 10dB more than the value only by STAP. From Figure 5(e) to Figure 5(h), two-dimensional patterns under 5 wideband noise interferences are showed, and the five nulls can be distinguished obviously. The depth of five nulls are −68dB, −60dB, −66dB, −54dB and −50dB respectively. Furthermore, we can see that sidelobes are close to the main lobe which is a little wide.

4.3. **Single-tone interference and wideband noise interference.** In the third simulation, we assume a STAP with 3 single-tone interferences, degrees are $(40°, 50°)$, $(50°, 60°)$ and $(30°, 80°)$, and 2 wideband noise interferences degrees of which are $(60°, 250°)$ and $(30°, 120°)$. The INR of five interferences are all 30dB. Table 5 displays SINR improvement results of four algorithms under hybrid interferences. Then three-dimensional and two-dimensional patterns of four algorithms are showed in Figure 6.

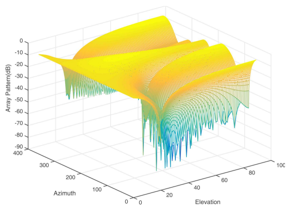
TABLE 5. SINR improvement under 5 interferences

Algorithm	STAP	FA-STAP	CS-STAP	BA-STAP
SINR Improvement(dB)	38.55	48.34	48.38	48.40

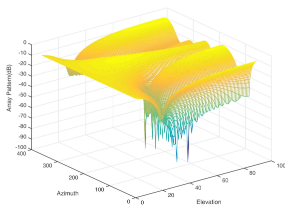
It can be observed that SINR improvement values of this simulation are close to before simulations, which means that there is always the best result after using meta-heuristic algorithms. In Figure 6, it is proved that the beamforming of our algorithms is greater than original STAP algorithm. However, there are still some questions, like null shifting and high sidelobes. From Figure 6(e) to Figure 6(h), we can see that the depth of nulls of BA-STAP algorithm that respectively are −64dB, −60dB, −53dB and −50dB are equal to other algorithms in $(30°, 80°)$, $(50°, 60°)$, $(60°, 250°)$ and $(30°, 120°)$. In $(40°, 50°)$, the depth of null of BA-STAP algorithm is −80dB, and the depth of FA-STAP and CS-STAP are −63dB.



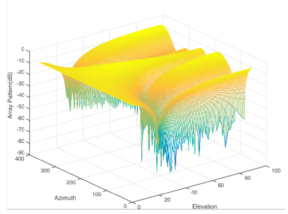
(a) STAP



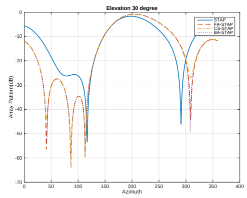
(b) FA-STAP



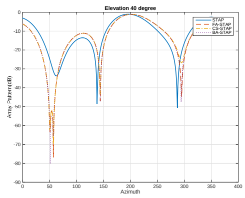
(c) CS-STAP



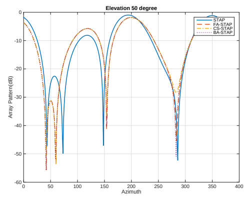
(d) BA-STAP



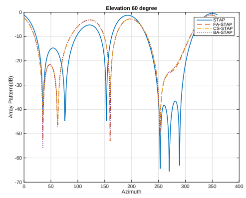
(e) 30



(f) 40



(g) 50



(h) 60

FIGURE 6. Patterns under 5 interferences

4.4. **Time analysis.** The last experiment is done to show time analysis about three meta-heuristics. Firstly, we take one condition, one single-tone interference of which the degree is same as the first example, as an example to demonstrate results of the SINR improvement after optimization with respect to the varying numbers of iterations from 10 to 90 for each run in Figure 7. And the number of populations is 10. Secondly, Figure 8 plots the SINR values from the variation of populations from 10 to 90 with 10 times iteration. Table 6 presents running time of different iterations and populations. In Figure 7, Figure 8 and Table 6, the INR is 30dB and the SNR is −20dB. Other parameters shown at the beginning of section 4 are the same as the first example.

As Figure 7 and Figure 8 show, SINR improvements do not change as the number of iterations and populations increase. For this reason, in the next example running times of different iterations and populations compare each other. It is clear that the running time of 10 times or 10 populations is much less than what of 90 times or populations in Table 6. Accordingly, we can choose the least times and populations. Moreover, running time of the STAP with BA is the minimum of the three.

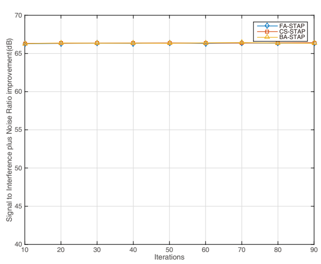


FIGURE 7. SINR versus iterations

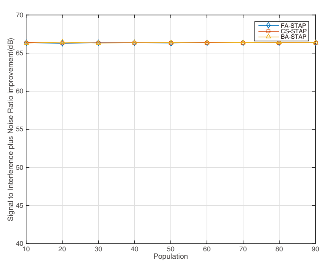


FIGURE 8. SINR versus populations

5. **Optimization algorithm based on the time delay unit.** In this section, we set the time delay unit to be the variable of meta-heuristics and research the improvement of SINR by using optimization algorithms. We assume that SNR is −20dB. Other parameters of meta-heuristics are the same as parameters of section 4.

Table 6. Running time of different iterations and populations

Algorithm	10 populations		10 times	
	10 times(s)	90 times(s)	10 populations(s)	90 populations(s)
FA-STAP	6.96	143.86	6.96	112.33
CS-STAP	7.50	102.03	7.50	103.33
BA-STAP	3.52	27.56	3.52	49.07

5.1. **Simulation performance of one interference.** Firstly, we consider that two situations, one single-tone interference and one wideband noise interfernce, disturb satellite navigation system when INR is 30dB. The degree of interference and desired signal are still $(40°, 50°)$ and $(50°, 200°)$ respectively. Table 7 shows the SINR improvement performance under 1 interference.

Table 7. SINR improvement under 1 interference

Algorithm	STAP	FA-STAP	CS-STAP	BA-STAP
Single-tone interference(dB)	25.44	46.25	46.20	46.26
Wideband noise interference(dB)	35.79	46.19	46.23	46.25

From Table 7, we can see that the SINR improvement with meta-heuristic algorithm is better than that un-optimized one. And all results of optimization algorithm are unaffected by the type of interference. Besides the results of algorithm based on the time delay unit is similar to the results of Table 1 and Table 3 with 30dB INR.

5.2. **Simulation performance of five interferences.** Secondly, we presume 5 interferences(INR = 30dB) to disturb satellite navigaton system, including single-tone interference, wideband noise interference and mixed interference (3 single-tone interferences and 2 wideband noise interferences). All degrees are same as degrees of section 4. Table 8 presents the difference of the SINR improvement with three kinds of interference.

Table 8. SINR improvement under 5 interferences

Algorithm	STAP	FA-STAP	CS-STAP	BA-STAP
Single-tone interference(dB)	35.80	48.24	48.30	48.28
Wideband noise interference(dB)	38.29	48.20	48.25	48.31
Mixed interference(dB)	38.29	48.26	48.28	48.30

It can be observed that SINR improvements of optimization algorithm reach 48dB, which means optimization algorithms with time delay unit variable can improve effectively SINR improvement. By comparing results of section 5 and section 4, we can know that optimization algorithms of different variable have similar results that SINR improvements are about 48dB under 5 interferences. Above all, algorithms with time delay unit variable can get a great optimized result which is similar to the result of algorithms with SNR variable. Meanwhile, the beamforming result of section 5 is similar to it of section 4. Because this paper mainly focuses on the improvement of SINR, we will not present the beam pattern in this section.

6. **Conclusions.** In order to improve the different SINR between input SINR and output SINR, FA, CS and BA meta-heuristics based on a STAP anti-interference technique is proposed in this paper. As it is shown in the above results, optimization effect of three algorithms is obvious, meanwhile, SINR improvement results with three meta-heuristics

are similar to each other, but the running time of those is totally different. In addition, array patterns have high sidelobes, null shifting and wide main lobe after optimizing by meta-heuristics. In future, reducing main lobe beamwidth and the relative height of sidelobes will be designed for beamforming stability.

Acknowledgment. This research was supported partially by National Natural Science Foundation of China 61301201Heilongjiang Postdoctoral Research Foundation LBH-Q140 39.

REFERENCES

[1] L. E. Brennan, D. J. Piwinski, and F. M. Staudaher, Space-time adaptive processing algorithm performance evaluation, *Adaptive Antenna System Symposium*, pp. 105–110, 1992.

[2] S. Werner, M. With, and V. Koivunen, Householder Multistage Wiener Filter for Space-Time Navigation Receivers, *IEEE Transactions on Aerospace and electronic systems*, vol. 43, no. 3, pp. 975–988, 2007.

[3] X. J. Wang, L. Huang, and L. N. Bao, Research on Space-time Adaptive Anti-interference Algorithm of Per-saterllite Constraint, *Journal of Navigation and Positioning*, vol. 3, no. 2, pp. 57–61, 2015.

[4] X. Wang, H. Y. Wang, and B. N. Pei, MIMO-OFDM radar waveform design for improving the detection performance of STAP, *Proc. of IEEE Int'l Conf. on Signal Processing, Communications and Computing*, pp. 1–4, 2016.

[5] C. Doroody, T. S. Kiong and S. Darzi, SINR Improvement Using Firefly Algorithm (FA) for Linear Constrained Minimum Variance (LCMV) Beamforming Technique, *Proc. of Int'l Conf. on Computer, Communications, and Control Technology*, pp. 441–445, 2015.

[6] S. Arora, S. Singh, A conceptual comparison of firefly algorithm, bat algorithm and cuckoo search, *Proc. of Int'l Conf. on Control Computing Communication & Materials*, pp. 1–4, 2013.

[7] D. P. Maya, A. C. Kandiyil, Blind inter carrier interference compensation in MIMO SC-IFDMA system using firefly algorithm, *AEU-International Journal of Electronics and Communications*, vol. 70, no. 6, pp. 857–865, 2016.

[8] A. Nasir, M. Maqsood, Correction for Beamforming in Array Antenna Using Firefly & Harmony Search Algorithm, *Proc. of the 12th Int'l Conf. on High-Capacity Optical Networks and Enabling/Emerging Technologies*, pp. 1–4, 2015.

[9] Q. Yao, Y. L. Lu, Efficient Beamforming Using Bat Algorithm, *Proc. of 2016 IEEE MTT-S Int'l Conf. on 2015 International Numerical Electromagnetic and Multiphysics Modeling and Optimization*, pp. 1–2, 2016.

[10] H. K. Kwan, J. J. Liang, Minimax Design of Linear Phase FIR Filters using Cuckoo Search Algorithm, *Proc. of the 8th Int'l Conf. on Wireless Communications & Signal Processing*, pp. 1–4, 2016.

[11] A. Mukherjee, J. Biswas, Design of Higher order FIR Low Pass filter using Cuckoo Search Algorithm, *Proc. of the 8th Int'l Conf. on Communication and Signal Processing*, pp. 0936–0941, 2016.

[12] A. Elahi, T. S. Khattak, I. M. Qureshi, and N. Gul, Application of Differential and Cuckoo Search Algorithms in Reduction of sidelobes, *Proc. of the 19th Int'l Conf. on Multi-Topic Conference*, pp. 1–5, 2016.

[13] L. B. Fertig, Analytical Expressions for Space-Time Adaptive Processing (STAP) Performance, *IEEE Transactions on Aerospace and electronic systems*, vol. 51, no. 1, pp. 42–53, 2015.

[14] X. S. Yang, Firefly Algorithm, Stochastic Test Functions and Design Optimisation, *International Journal of Bio-Inspired Computation*, vol. 2, no. 2, pp. 78–84, 2010.

[15] K. N. A. Rani, F. Malek, Symmetric Linear Antenna Array Geometry Synthesis using Cuckoo Search Metaheuristic Algorithm, *Proc. of the 17th Asia-Pacific Conference on Communication*, pp. 374–379, 2011.

[16] S. Mirjalili, S. M. Mifjalili, and X. S. Yang (eds.), Binary bat algorithm, *Springer-Verlag, Neural Computing and Applications*, vol. 25, no. 3, pp. 663–681, 2014.