Cognitive Cooperative-jamming Decision Method Based on Bee Colony Algorithm

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Abstract— For the future information warfare, a single jamming mode is not effective due to the complex electromagnetic environment. With the rapid development of cognitive radio technology, collaborative jamming based on cognitive radio, namely cognitive jamming, has attracted wide attention in the field of electronic warfare. In collaborative jamming, the problem of decision-making based on collaboration becomes one of the key issues. Traditional decision-making based on ant colony algorithm takes too many iterations, which cannot always ensure the probability of optimization. Against the issue, this paper proposes a cognitive cooperative-jamming decision method based on bee colony algorithm, which searches the global optimum solution according to the process of the honey bee group looking for high quality sources. In the case of lack of prior condition, the proposed algorithm generates fitness function according to jamming effect. Then by the rule of greed, jamming decision matrix is decided according to jammer task allocation form. The role of bees in the proposed algorithm are changed between collection and observation, which is benefit to improve the convergence speed. By this way, it can improve the speed of convergence and find an optimal decision making scheme in the scenario with multiple jammer and multiple radar. Simulation results show that the proposed decision-making method can find the optimal decision scheme with the best jamming effect and has a fast convergence speed comparing with decision-making based on ant colony algorithm. The application of bee colony algorithm in the field of cooperative-jamming decision provides a new idea for jamming decision making.

1. INTRODUCTION

In modern warfare, electronic warfare is gradually replacing the traditional mode of warfare and becoming the main form of war. Cognitive technology developed rapidly after the concept of cognitive radio emerged in 1999. Cognition refers to the process of information processing and processing of intelligent objects to receive, transform, simplify, synthesize, store, extract, reconstruct, concept formation, judge and solve problems. Many military generals use cognitive radio as the key development project for the ability of autonomous environment perception and real-time optimization of work parameters of cognitive technology. On this basis, cognitive radar and cognitive confrontation successively appear [1].

Cognitive confrontation is a closed loop learning processing system based on dynamic knowledge base of perception-recognition-decision making-action-perception, and it is used in order to improve the combat effectiveness of electronic equipment under complex electromagnetic environment [2]. Decision allocation of the cooperative jamming resources is the core link of operational command in the closed-loop learning processing system, and its an integral part of the whole cognitive confrontation system. It is the key target of cooperative jamming decision to adopt the appropriate decision scheme for jamming resource to get the best jamming effect. The cooperative jamming decision problem is a nonlinear integer combinatorial optimization problem, and the resulting decision scheme is exponentially consistent with the number of interfering resources. Traditional optimization algorithms include enumeration, Hungary and so on. Wu Gang et al. [3] used Hungary algorithm for radar jamming resource allocation; Gu Wen [4] improved Hungary algorithm and used it for target assignment problem. However, it still has great limitations because the objective function must be linear and subject to the dimension of the problem. In recent years, some intelligent algorithms, such as genetic algorithm and ant colony algorithm, have been used to solve the problem. Gao Bin et al. [5] use genetic algorithm to allocate interference resources. Although it is better than traditional algorithms, it still faces problems such as complex coding and poor searching ability. Gu Xueqiang et al. [6] adopted ant colony algorithm. He Fan et al., [7] proposed to use improved ant colony algorithm to solve this problem, which improved the search speed and optimization ability of the algorithm. Zhang Yunhao [8] proposed a method based on immune algorithm, and proved its effectiveness. Zhang Zhe and [9] proposed improved niche genetic algorithm to deal with jamming resource, which improved the premature and poor convergence of the traditional genetic algorithm. Wang Lingxiao [10] proposed the ant colony algorithm based on simulated annealing mechanism, which improved the speed of convergence of the traditional ant colony algorithm. The use of intelligent algorithms greatly improves the efficiency of solving jamming decision problem, but most intelligent algorithm still can be greatly improved because of the complex parameters. This paper proposes a method of introducing bee colony algorithm into cooperative interference decision problem, which makes the process of cooperative jamming decision-making more suitable for modern cognitive confrontation for its advantages of few basic parameters and fast convergence speed. The simulation results show that the bee colony algorithm has fewer iterations and faster convergence speed and also has better searching ability in the cooperative jamming decision problem.

2. THE MODEL OF COOPERATIVE JAMMING DECISION TASK

Suppose the number of jammer is m, and the number of enemy radar is n. The cooperative jamming decision model is shown in Figure 1.

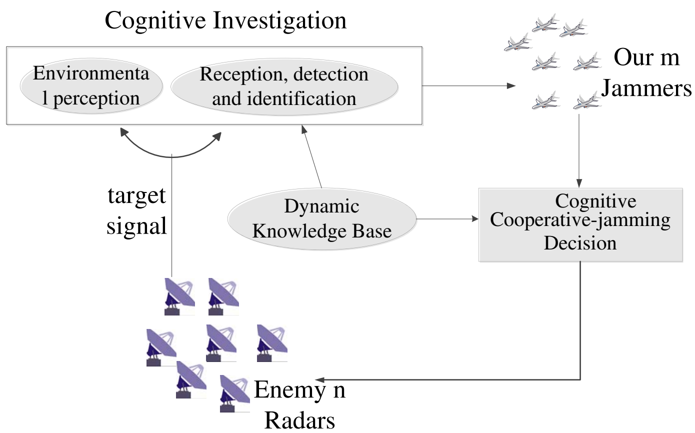

Figure 1: The model of cooperative jamming decision in cognitive confrontation.

Since the core target of cooperative jamming decision is to adopt the appropriate decision scheme to improve the jamming effect to be best, we can treat maximum jamming effect as evaluation criteria. We use fuzzy multi-attribute evaluation method to evaluate interference effects. The assessment procedure is as follows:

(1) Select indicators to evaluate interference effectiveness and build index sets. Set the evaluation index as $R = \{R_1, R_2, \ldots, R_t\}$, t is the number of evaluation index.

(2) Determine the influence degree and importance factors ω of each index by past experience value. $W = \{\omega_1, \omega_2, \ldots, \omega_t\}$

(3) Determine the membership function of each index, and calculate the membership function value of the target under each evaluation index. In this model, we have m jammers, and the enemy has n radars, then the jamming effect of each jammer i to the single radar under each evaluation index is as follows $I_i = \{I_1, I_2, \ldots, I_t\}$, $i = 1, 2, \ldots, m$: t is the number of evaluation index, I_t is the jamming effect of jammer i under the evaluation index t.

(4) Do fuzzy calculations for the jamming effect membership matrix of each jammer i to a single radar and weight of each index to get jamming effect of jammer i to radar j. Then the jamming effect matrix Q is:

$$Q = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1n} \\ q_{21} & q_{22} & \cdots & q_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ q_{m1} & q_{m2} & \cdots & q_{mn} \end{bmatrix} \tag{1}$$

We can see the jamming effect of single jammer i to single radar i through jamming effect matrix Q. The process of cooperative jamming decision is equivalent to distribute the m jammers to n radars to get the maximum jamming effect. The resulting objective function is:

$$E = \max \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} \omega_j q_{ij} \tag{2}$$

Among them, E is the jamming effect of a decision scheme, x_{ij} is the decision variable, $x_{ij} = 0$ means jammer i does not jam radar j, $x_{ij} = 1$ means jammer i jams radar j. $m * n x_{ij}$ constitute decision matrix X, ω_j indicates the importance of radar j, q_{ij} represents the jamming effect of jammer i to radar j.

Since the number of radars that can be jammed at one time is limited, and there is a limit to the total number of jammers and radars, we have the following constraints on the target function:

$$①x_{ij} = 0 \quad \text{or} \quad x_{ij} = 1 \qquad ②\sum_{i=1}^{m} x_{ij} = 1, \mathrm{j} = 1, 2, \ldots, n \qquad ③\sum_{j=1}^{n} x_{ij} <= \alpha_i, \mathrm{i} = 1, 2, \ldots, m \tag{3}$$

Among them, ① indicates whether jammer i jams radar j, ② indicates that one radar can be jammed only by one jammer, ③ indicates one jammer can jam α_i radars most at one time.

3. BEE COLONY ALGORITHM

The artificial bee colony algorithm is a swarm intelligence optimization algorithm proposed by Karaboga, a scholar of Turkey in 2005. The optimization search process of this algorithm simulates the process of honey bee colony looking for excellent nectar. During the bee collection process, employed foragers will jump in the dance area "swing dance" to share information about food source to onlookers after they gathering nectar, then onlookers will be attracted as probability by the profitability of food source. The nectar amount of food source will decrease after it is exploited a certain number of times, then the bees will give up the food source and turn to search new one. According to the bee's honey collecting behavior, we introduce employed foragers, onlookers and scouts in to bee colony algorithm. Each solution of the problem corresponds to a food source. Profitability corresponds to the nectar amount of food source, used to describe the quality of solution. The flow chart of the bee colony algorithm is shown in Figure 2.

The steps of using bee colony algorithm for cooperative jamming decision are as follows:

(1) Initialize bee populations, and there are three population parameters:

① The total number of bees: N (general definitions of employed foragers and onlookers for each $N/2$);

② Maximum iterations: $maxCycle$;

③ The single largest number of search for each food source: $limit$.

At this time, all bees are scouts with no prior information. Randomly generate N interference decision matrices X overall situation corresponding to N food sources, the jamming effect of every decision scheme is its profitability.

$$X_k = [x_{ij}]_{m \times n} i \in [1, m], j \in [1, n], k \in [1, N] \tag{4}$$

(2) Divide all bees into employed foragers and onlookers according to the jamming effect of every decision matrix X in step (1). Among them, the $N/2$ bees with higher E value are employed foragers, and the other $N/2$ bees are onlookers. Onlookers select employed foragers to follow according to the probability P of the E value of the former $N/2$ decision matrix.

$$P_i = \frac{fitness_i}{\sum\limits_{i=1}^{N/2} fitness_i} \tag{5}$$

(3) Every employed forager searches for new decision matrix around the old one and calculate its profitability. If it is greater than the old, then replace it according to the greedy criterion. Search formula is:

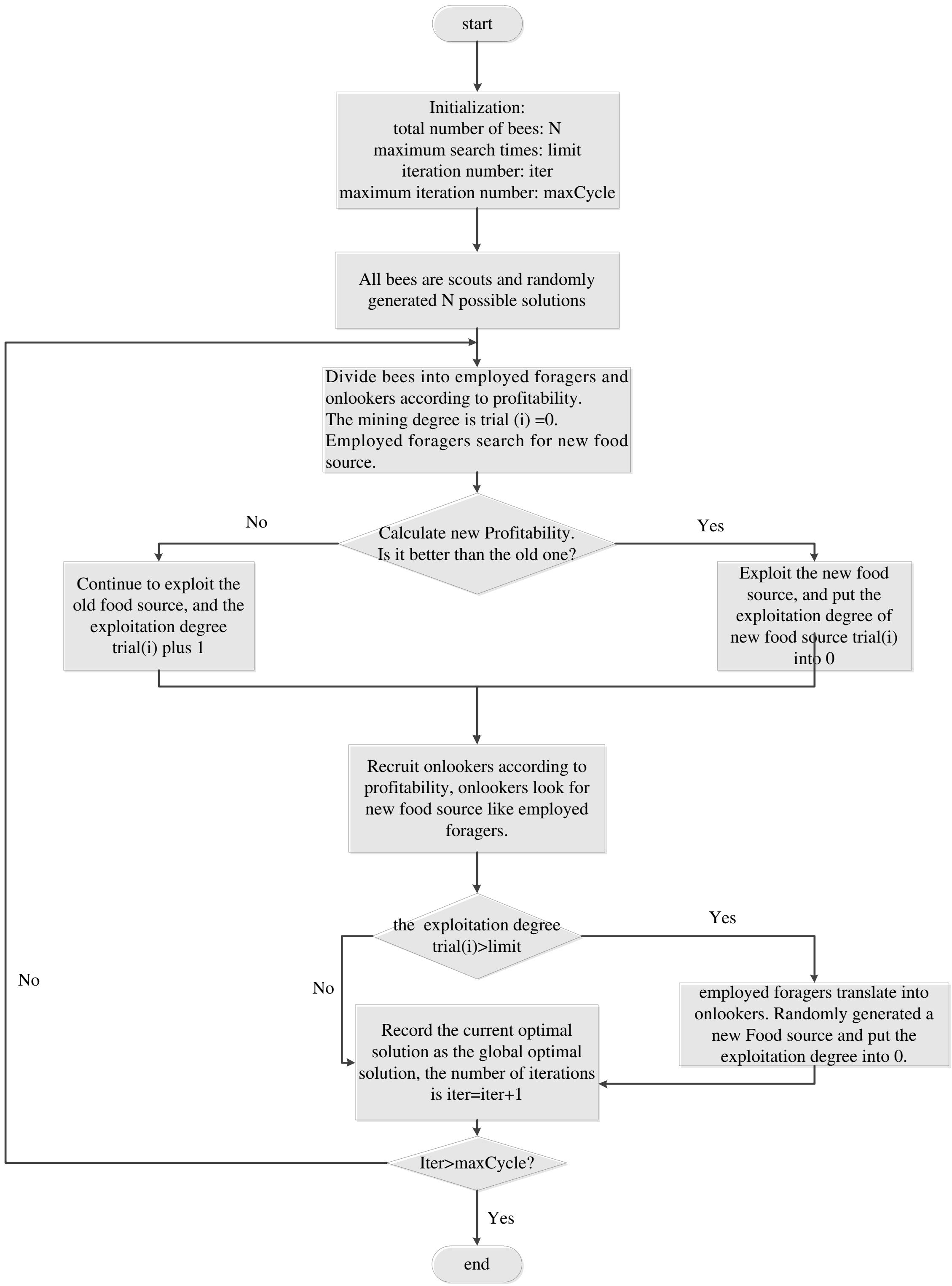

Figure 2: The flow chart of the bee colony algorithm.

$$X_k{}' = \left[x_{ij}{}'\right]_{m\times n}, i \in [1, m], j \in [1, n], k \in [1, N/2] \tag{6}$$

$$\left\{\begin{array}{l} x'_{irand1} = x_{irand2} \\ x'_{rand2} = x_{irand1} \end{array}\right. \quad i \in [1, m] \tag{7}$$

$rand1$ and $rand2$ are unequal random integers between $[1, n]$.

(4) Onlookers change the distribution mode of jammer of decision matrices corresponding to employed foragers to get a new decision matrix after they selecting them to follow. Like step (3).

(5) If employed foragers and onlookers search more than limit times for a decision matrix and find no decision scheme with better profitability, give up this decision matrix, turn the role of the bee into scouts and generate a new decision matrix that satisfies the constraints randomly.

(6) Records the decision matrix of the maximum E and turn to step (2), until the maximum iteration number maxCycle is satisfied. The decision matrix makes the profitability maximal is the decision scheme with the best jamming effect.

4. SIMULATION ANALYSIS

Suppose the number of our jammer is $m = 10$, and the number of enemy radar is $n = 10$. Their importance is as follows:

$$P = \begin{bmatrix} 0.4 & 0.8 & 0.6 & 0.9 & 0.7 & 0.4 & 0.7 & 0.3 & 0.6 & 0.8 \end{bmatrix} \tag{8}$$

Due to fuzzy multi-attribute evaluation method, one to one jamming effect matrix of jammer i to radar j is:

$$Q = \begin{bmatrix} 0.26 & 0.42 & 0.36 & 0.60 & 0.51 & 0.24 & 0.43 & 0.19 & 0.37 & 0.48 \\ 0.38 & 0.75 & 0.58 & 0.86 & 0.66 & 0.38 & 0.67 & 0.28 & 0.58 & 0.76 \\ 0.20 & 0.39 & 0.43 & 0.50 & 0.30 & 0.28 & 0.50 & 0.13 & 0.44 & 0.48 \\ 0.33 & 0.60 & 0.37 & 0.65 & 0.54 & 0.25 & 0.43 & 0.24 & 0.37 & 0.57 \\ 0.39 & 0.78 & 0.59 & 0.89 & 0.68 & 0.40 & 0.69 & 0.29 & 0.59 & 0.80 \\ 0.26 & 0.59 & 0.32 & 0.54 & 0.41 & 0.22 & 0.38 & 0.20 & 0.32 & 0.51 \\ 0.34 & 0.60 & 0.41 & 0.74 & 0.63 & 0.28 & 0.48 & 0.26 & 0.41 & 0.62 \\ 0.12 & 0.14 & 0.34 & 0.34 & 0.21 & 0.22 & 0.40 & 0.06 & 0.35 & 0.29 \\ 0.33 & 0.73 & 0.43 & 0.71 & 0.55 & 0.29 & 0.50 & 0.26 & 0.42 & 0.65 \\ 0.30 & 0.64 & 0.34 & 0.62 & 0.49 & 0.23 & 0.40 & 0.24 & 0.34 & 0.56 \end{bmatrix} \tag{9}$$

In bee colony algorithm, set the total number of bees is $N = 20$, among them, the number of employed foragers and onlookers are both $N/2 = 10$; $maxCycle = 400$; $limit = 800$ to ensure that every food source can be fully exploited. Every jammer of us can jam 1 target at a time, and each radar is only jammed by one jammer. Use matlab program to obtain the cooperative-jamming decision matrix as follows:

$$X = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix} \tag{10}$$

The decision scheme is shown in Table 1:

Table 1: Jamming decision scheme.

Identifier of enemy radar	3	4	7	1	10	6	5	9	2	8
Identifier of our jammer	1	2	3	4	5	6	7	8	9	10

The jamming effect is 3.5070 under this decision scheme, the same as enumeration method. The convergence property of the objective function is shown in Figure 3 and Figure 4:

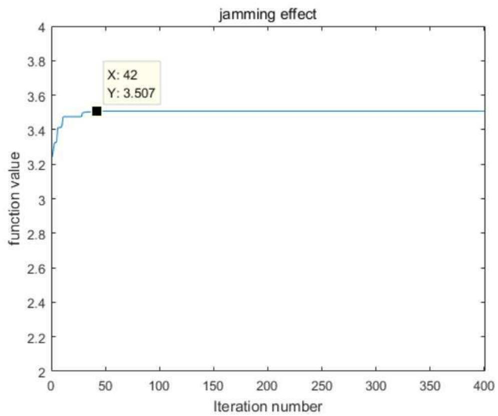

Figure 3: Bee colony algorithm optimization process convergence diagram.

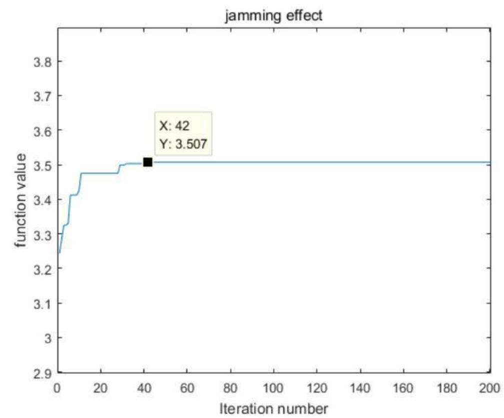

Figure 4: Local enlarged drawing.

As we can see from Figure 3 and Figure 4, the algorithm converges to the optimal value in the 42 generation, and the objective function value reaches to the optimum value through several steps. It shows that the algorithm runs in a very good global search process, reducing the probability of falling into the local optimum, and the algorithm's optimization ability has been well guaranteed.

The algorithm runs 50 times to find the average result. Compare the result with the result got by ant colony algorithm and ant colony algorithm with simulated annealing mechanism under the same conditions. The results are shown in Table 2:

Table 2: Comparison of bee colony algorithm, ant colony algorithm and its improved algorithm.

	bee colony algorithm	Ant colony algorithm with simulated annealing mechanism	ant colony algorithm
The average number of iterations in the optimal decision	47	78	93
The time needed to iterate once	0.004203	0.004633	0.004434
The time needed for the optimal decision scheme	0.1975	0.3613	0.8557
The probability to get the optimal scheme	46/50	49/50	36/50
Maximum jamming effect	3.5070	3.5070	3.5070

The three algorithms can be iterated to obtain the optimal decision scheme as Table 2 shows. Bee colony algorithm is better than ant colony algorithm and is not as good as the ant colony algorithm with simulated annealing mechanism in optimization probability, but it can guarantee the optimization ability under larger probability. The most important thing is that the bee colony algorithm is far better than the other two in search speed, not only the time needed for the single iteration is less, but also the number of iterations is greatly reduced, so that the time required to obtain the optimal decision scheme is greatly reduced, and the speed of optimization is greatly improved. In a comprehensive way, the performance of bee colony algorithm is better than the other two. Change the deployment of jammer and radar and carry simulation under the same conditions to validate the stability of the algorithm. The simulation results show that the bee colony algorithm has higher stability for it can guarantee the optimization ability and the searching speed under different strategy deployment.

5. CONCLUSION

In this paper, the decision method of cooperative jamming decision is studied, and the fuzzy multi attribute evaluation method is used to evaluate the jamming effect, and a new method is introduced to make jamming decision. The simulation results show that the bee colony algorithm is applied to jamming decision field, which greatly improves the searching speed of the algorithm, reduces the optimal decision time, at the same time, ensures the optimization probability.

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