The Cognitive Communication based Anti-jamming Method for UAV Swarm Communication

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Abstract. The communication environment of intelligent UAV swarm is complex and easy to be interfered by various electromagnetic signals. An anti-jamming method of UAV swarm communication based on cognitive communication is proposed to realize the communication networking function of UAV swarm in certain interference environment. The main approaches include spectrum sensing in electromagnetic environment, anti-jamming based intelligent decision making, and series typical anti-jamming techniques such as adaptive interference and signal separation, dynamic spectrum access, high reliability waveform enabled.

1. Introduction
The intelligent wireless communication network system based on environment awareness is an important application field of UAV swarm communication anti-jamming technology. It can sense the external environment and use artificial intelligence technology to learn from the environment. By changing some parameters (such as transmission power, carrier frequency and modulation technology) in real time, its internal state can adapt to the statistical changes of the received wireless signal, so as to achieve the purpose of highly reliable communication and effective use of spectrum resources at any time and any place. The environment sensing ability of the communication system enables it to capture or perceive information from the wireless environment, so that it can identify the unused spectrum resources in specific time and space, and select the most suitable spectrum and working parameters. Cognitive communication anti-jamming technology requires that the communication system can adjust the working parameters of the transmitter without modifying the hardware part and without interrupting the work. It can be carried out at the beginning of transmission or in the process of transmission. It is the specific performance of cognitive radio communication system to adapt to the dynamic wireless environment.

Reference [1] makes a visual analysis of battlefield electromagnetic situation from multiple perspectives. The method of electromagnetic environment visualization in Artillery Battlefield is given in reference [2]. In reference [3], the communication parameter adjustment method combining genetic algorithm and simulated annealing is proposed and compared. In reference [4], a swarm based dynamic multichannel network strategy is introduced and a spectrum cognitive interference routing algorithm is proposed. In reference [5], a dynamic network coding technique in weak communication environment is proposed. In reference [6], an artificial intelligence communication anti-jamming system based on radial basis function neural network algorithm is designed. In reference [7], the intelligent anti-jamming communication technologies such as interference recognition and waveform reconstruction are analyzed. In reference [8], two intelligent anti-jamming decision engines are simulated and the results are analyzed.
2. Spectrum sensing of UAV swarm communication to electromagnetic environment

2.1. Distributed electromagnetic environment cooperative detection
Based on the mechanism, process and algorithm of distributed task collaborative allocation, the dynamic allocation of detection tasks is carried out in a unified way, so as to achieve the purpose of fast acquisition of all frequency, spatial and domain electromagnetic environment signals.

Based on the distributed network collaboration, make full use of the electromagnetic environment detection resources on the platform of the collaborative network to allocate the detection area, frequency band and target, so as to achieve the full-time, wide area and wide spectrum cooperative detection effect. The following figure shows the cooperative detection of distributed electromagnetic environment.

![Distributed electromagnetic environment cooperative detection](image)

2.2. Field location and identification of multi UAV cooperative radiation sources
Based on the communication network cooperation of multiple UAVs, multi-sensor intelligence data fusion can be realized. Through situation sharing and data fusion, the confidence of target attribute discrimination, threat level assessment and activity situation awareness can be improved. The direction finding technology of amplitude comparison method, interferometer and MUSIC are studied.

First, a feature database of target radiation sources is established. Then, the signal recognition algorithm is designed, and the template in the template database is used to quickly compare, match and identify the extracted target features. Based on the network cooperation, the enemy radiation sources are cooperatively positioned to improve the positioning accuracy and shorten the positioning convergence time. It also has the ability to quickly identify and coordinate with the target, and it can achieve real-time situation information acquisition and sharing.

2.3. The knowledge base of electromagnetic radiation source and the construction of spectrum map form the electromagnetic situation of battlefield
Through the acquisition, analysis, prediction and classification of the electromagnetic environment elements of UAV swarm, the electromagnetic radiation source knowledge base is formed. Through sensing the electromagnetic field data around the target from time domain, frequency domain, spatial domain, energy domain and other aspects, and also through processing and analysis, using the spatial discrete inversion electromagnetic field distribution technology, the dynamic electromagnetic field is displayed and visualized, which forms the battlefield electromagnetic situation and multi-dimensional spectrum map.

3. Cognitive decision based on genetic algorithm
The UAV swarm intelligently can sense the electromagnetic environment, obtain the battlefield electromagnetic situation and spectrum map, and finally conduct intelligent decision-making for communication anti-jamming.
As shown in the following figure, this paper conducts research on anti-jamming intelligent decision-making technology based on cognitive results. Real-time monitoring of the spectrum environment of the battlefield, achieving interference avoidance or elimination through active and passive methods, and improving the comprehensive anti-jamming capability of swarm communication. Active evasion mainly adjusts the system transmission parameters in real time according to the electromagnetic environment, realizes frequency domain avoidance by changing the frequency hopping pattern, or improves the anti-jamming tolerance by changing the modulation and coding mode, the symbol width, and the length of the spreading code. Passive cancellation mainly aims at different interference types, using adaptive notch or fractional Fourier transform to eliminate the influence of interference signals on the system.

![Diagram](image-url)

**Figure 2. Intelligent anti-jamming decision.**

On the basis of accurate estimation of spectrum situation, this paper uses genetic algorithm to solve the problem of cognitive parameter configuration and improve the anti-jamming ability and spectrum utilization. An improved algorithm combining simulated annealing algorithm with genetic algorithm is proposed, which can greatly improve the search efficiency of the algorithm without changing the genetic algorithm. By controlling whether to accept the new individuals after crossover and mutation of genetic algorithm, the shortcomings of genetic algorithm are improved. The combination of simulated annealing algorithm and genetic algorithm improves the effectiveness of cognitive decision engine. For the implementation of genetic algorithm, the scheme first uses parameter coding to connect n communication parameters (modulation mode, center frequency, symbol rate, bandwidth, transmission time percentage, etc.) in frequency hopping anti-jamming system into chromosomes, as shown in the figure below. Then the objective function is obtained as:

![Chromosome](image-url)

**Figure 3. Chromosome of genetic algorithm.**

The objective function is:

\[ f' = f^{10} = (\sum_{i=1}^{n} w_i f_i)^{10} \]  

As a measure mechanism of chromosome fitness, genetic algorithm is characterized by survival of the fittest and survival of the fittest. Individuals with high fitness are left to the next generation, and those with low fitness are eliminated, so cross exchange genes to generate new individuals; variation can enhance the global search ability of genetic algorithm by increasing individual diversity. In order to make up for the deficiency of the efficiency of genetic algorithm, the simulated annealing algorithm is introduced to decide whether to accept the new individuals after the crossover operation. The objective function values of pre-crossing chromosome are expressed as \( f_{\text{old}} \) and \( f_{\text{old}} \), and the
objective function values of post-crossing chromosome are expressed as \( f_{1\text{new}} \) and \( f_{2\text{new}} \). \( P \) is the probability of whether a new chromosome will replace a crossed chromosome, as follows:

\[
p = \begin{cases} 
1 & \Delta f < 0 \\
\exp(-\Delta f / T_g) & \Delta f \geq 0 
\end{cases}
\] (2)

\[
\Delta f = (f_{1\text{old}} + f_{2\text{old}} + f_{1\text{new}} + f_{2\text{new}}) / 4 - f_{1\text{new}}(f_{2\text{new}})
\] (3)

\( T_g \) is the temperature, and the temperature attenuation function is as follows:

\[ T_g = T_0 \alpha^{g-1} \] (4)

where \( T_0 \) is the initial temperature, and \( G \) is the evolution algebra, \( 0 < \alpha < 1 \).

According to the above formula, with the increase of evolution algebra \( g \), \( T_g \) decreases gradually, so the probability of accepting new individuals with lower value than the expected objective function decreases. In the early stage of algorithm evolution, most new individuals can be accepted to expand the value space. While in the middle and late stage of algorithm evolution, the possibility or probability of accepting new individuals with higher value than the expected objective function is greater.

4. Anti-jamming mode of cognitive communication

After obtaining the spectrum environment information, the swarm communication system takes active defense or evasion measures according to the interference characteristics to improve the communication quality and reliability. The measures include adaptive interference signal and separation, gradual dynamic spectrum access, parameter automatic control, high reliable waveform self enabling.

4.1. Adaptive interference and signal separation

When the communication system is affected by narrow-band interference, resulting in some frequency points being affected, the cognitive communication system can extract the characteristic information of the interference signal, such as modulation mode, power size, etc. At the receiving end, the interference signal is separated by adaptive notch or matched filter. And the impact of the interference is reduced to improve the communication quality.

When using adaptive interference and signal separation, it is assumed that \( n \) of \( m \) frequency points are interfered. The probability of \( n \) frequency points demodulation error caused by interference is \( p_i \) respectively, and the frequency points can be demodulated correctly after using interference and signal separation, then the anti-jamming gain of dry signal separation is:

\[
G_f = 10 \log \left( \frac{m}{m - \sum_{i=1}^{n} p_i} \right)
\] (5)

4.2. Gradual dynamic spectrum access

The communication system is interfered by some frequency bands, which results in some frequency points seriously affected. If the number of affected frequency points does not exceed \( 1 / 3 \) of all the frequency points, the cognitive communication system can optimize the frequency hopping pattern. The affected frequency points in the frequency hopping pattern are replaced by other frequency points in the frequency set to avoid the interference actively. If the frequency point of the interference changes dynamically, the frequency hopping pattern will change accordingly, so as to realize the dynamic spectrum access and improve the communication quality.

In the process of frequency hopping pattern optimization, only some disturbed frequency points in
the pattern are replaced, and no significant changes are made to the frequency hopping pattern. Because of the uniform probability of frequency points in the pattern, more than 2/3 of the changed pattern is the same as the original pattern, which is a gradual process. The advantage of keeping the pattern gradual change is that the nodes in the communication system that do not optimize the pattern in time can still receive and receive messages in the network normally, but the communication quality is not high, which is the same as the effect when the whole network does not change the pattern in the case of partial band interference.

When using gradual dynamic spectrum access, assume that \( n \) of 51 frequency points are seriously interfered, where \( n \leq 17 \). The interference causes the demodulation error of \( N \) frequency points, then the anti-jamming gain of gradual dynamic spectrum access is:

\[
G_a = 10 \log \left( \frac{51}{51 - n} \right)
\]  

(6)

4.3. **High reliability waveform autonomous operation**

High reliability waveform includes long code spread spectrum and high redundancy channel coding. When all or most of the frequency points of the communication system are seriously affected, the frequency hopping gain disappears. At this time, the hopping speed can be reduced or even the fixed frequency can be used, the pulse interval time can be reduced, and the pulse duration can be increased. When the baud rate of the channel is unchanged, a longer spread spectrum code can be used for frequency expansion communication, and the spread spectrum gain can be increased to resist strong interference. For example, the communication system currently uses 32-bit code to expand 5-bit original information. If the length of spread spectrum code is increased and the original information of \( 2^k \)-bit spread \( k \)-bit is used \((k > 5)\), the increment of spread spectrum gain is:

\[
G_k^* = 10 \log \left( \frac{2^k}{k} \right) - 10 \log \left( \frac{32}{5} \right) \approx 10 \log \left( \frac{2^k}{k} \right) - 8
\]  

(7)

At present, the communication system uses RS (31,15) channel coding, and the coding efficiency is 1/2. Using a higher redundancy coding method, reducing the coding efficiency, it can obtain a greater error correction ability, thus improving the anti-jamming ability. Assuming that the new coding rate is \( r \), \( r < 1/2 \), the increment of spread spectrum gain is:

\[
G_k^* = 10 \log \left( \frac{1}{r} \right) - 10 \log \left( 2 \right) \approx 10 \log \left( \frac{1}{r} \right) - 3
\]  

(8)

Therefore, the total anti-jamming gain of high reliability waveform is:

\[
G_w = G_k^* + G_r^* \approx 10 \log \left( \frac{2^k}{k} \right) + 10 \log \left( \frac{1}{r} \right) - 11
\]  

(9)

The high reliable waveform greatly improves the anti-jamming ability, at the cost of the decrease of the transmission rate, which is as follows

\[
R = 0.2kr2^{-k}
\]  

(10)

![Figure 4. Estimated anti-jamming gain and decrease ratio of signal transmission rate.](image)

Cognitive communication system nodes can use high reliable waveform transmission independently without informing the receiver. Therefore, communication system nodes need the dual-
mode receiving ability. Dual mode reception refers to that the communication system node can receive and process high reliable waveform while receiving conventional waveform.

5. Conclusion
This paper discusses the anti-jamming technology of UAV swarm based on cognitive communication, which can detect, locate and identify the communication signals in the electromagnetic environment, and construct the electromagnetic situation map and spectrum map according to the knowledge base of radiation sources. An innovative genetic algorithm based intelligent cognitive decision-making is proposed to choose the appropriate communication anti-jamming technology. Finally, several typical cognitive communication anti-jamming technologies are given and compared.

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