Research on multi-address autonomous access technology of uav cluster data link based on priority statistics

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Abstract. As a uav cluster that can change the future combat situation, its data link has the requirements of high speed, low delay, dynamic networking and large network capacity. In this paper, a priority statistics based multi-address autonomous access technology for uav cluster data link is studied. Firstly, the channel load is detected and predicted by time-frequency analysis for different priority services. Then, multi-node information fusion is adopted for multi-address decision-making. Finally, the designed technology is simulated by Qualnet software. The simulation results show that the proposed multi-address autonomous access technology based on priority statistics can effectively reduce in-network channel collisions and realize low-delay transmission of high-priority services.

1. Introduction

Unmanned aerial vehicle swarm refers to several networked small or micro uavs that use distributed control technology to fly in the same mode and perform the same or similar missions [1]. In the process of cooperative engagement, in order to ensure the safety of formation flight, unmanned aerial vehicle cluster internal needs through commands that frequent exchange of tactical data link network, location information and status information to quickly adapt to the environment, reasonable planning path, efficient to complete the task, the cluster data link determines the performance of the interactive real-time, integrity and reliability of the information [2,3]. As one of the key technologies to support the networked communication capability of uav cluster data link, multi-address technology stipulates the way to share wireless channel resources within the cluster, and its performance directly affects the performance of the whole network.

Traditional network multi-address technology is given priority to with scheduling classes agreement, use the TDMA MAC protocol implementation more multi-node channel access [4,5]. Although the traditional networking multiple access technology is easy to realize in engineering, it cannot dynamically network, is difficult to expand the network scale, and has high data delay, so it cannot meet the low delay transmission requirements in the collaborative operation of uav cluster. The existing low delay AD hoc network multiple access technology generally adopts the access based on competition mechanism, and the typical representative is the TTNT [6-8] of the us army. However, although this technology can realize low delay transmission, it has the inherent deficiency of channel collision.

In order to meet the requirements of uav cluster data link very low end to end delay, high speed dynamic flexible network and large network capacity. This paper presents an autonomous access
technology for uav cluster data link based on priority statistics. Firstly, detect and predict channel load by time-frequency analysis for different priority services. Then, use multi-node information fusion to make multiple access decision. The probability of channel collision is reduced and the network throughput and channel utilization are increased.

2. Design of multi-address autonomous access mode

According to the different ways of channel access, the existing wireless AD hoc network multi-address autonomous access technology can be divided into the following two categories: fixed allocation class multi-address access technology based on reservation mechanism and random class multi-address access technology based on competition mechanism. Although fixed allocation class multiple access technology, such as TDMA technology, has great advantages in throughput, its high delay is not suitable for the mobile variable network such as uav cluster data link. In order to solve this problem, this paper adopts SPMA (competitive class multi-address access) technology based on priority statistics. Since there is no need to pre-allocate time slots or reserve time slots for nodes, it is only necessary to decide whether the nodes are connected to the network according to the network busy degree, thus the access delay of multi-channel access can be greatly reduced. Furthermore, in order to solve the problem that multi-node simultaneous transmission in the traditional SPMA technology leads to the increase of delay and the decrease of channel utilization, the state of the whole uav cluster data link network is evaluated through periodic detection before sending, and then reasonable scheduling is carried out. While the possibility of collision is greatly reduced, different information priorities are classified to realize low-delay transmission of high-priority information.

According to the different requirements of the missions, the information that needs to be interactive in the cooperative operation of uav cluster can be divided into the following three categories:

1. high-priority information: real-time tactical instructions, which are characterized by higher real-time requirements and less information;
2. middle-priority information: battlefield situation information, which is characterized by general real-time requirements and general information;
3. low-priority information: image voice information, which is characterized by low real-time requirements and large amount of information.

Since the priority is oriented to information type, the status of different nodes in uav cluster is the same. The priority of channel occupied by them is determined by the data type to be sent at the front end of the sending queue of each node. The channel access process of different nodes is shown in figure 1.

![Figure 1. channel access process of different nodes.](image)
Due to the low requirement of access delay of uav cluster data link system, if the current transmission is low-priority information, the current information transmission will be interrupted and high-priority transmission will be carried out once time-sensitive and moving targets appear. Set different transmission priorities for different information to ensure that the highest priority data is transmitted as it comes.

For high-priority information, it is necessary to ensure a very low delay. Therefore, simple and fast high-threshold energy detection is adopted, which does not need to consider the transmission of low-priority information. The access method adopts a non-cooperative sharing mechanism to ensure the fast and efficient access of high-priority information. For medium and low priority information detection in order to guarantee a better detection performance, adopts double threshold energy detection, in which the priority information USES the energy level of double threshold detection, low priority information using two levels of double threshold detection, when the network load is bigger, can be independent retreat algorithm based on priority to low, medium priority information retreat, reduce the network load.

3. Realization of multi-address autonomous access technology
The channel load is the basis of the multi-access autonomous access technology to judge the node access channel or random retreat, which largely determines the performance of the multi-access technology. In this paper, the busy degree of channel is detected and predicted by time-frequency analysis.

3.1. Detection scheme
Different priority information has different requirements on detection performance and detection time, and corresponding methods should be adopted to detect channel occupied state according to different priorities. The specific implementation is as follows:

(1) high-priority information: energy detection

Energy detection does not need prior information and has the advantages of small computation, fast speed and high detection performance. Although the performance of energy detection is poor at low SNR, energy detection is suitable for high priority information because high priority information still has good detection performance in low SNR environment. The detection process is shown in figure 2 below.

\[
y(n) \rightarrow (\cdot)^2 \rightarrow \frac{1}{\sigma^2} \sum_{i=1}^{n}(\cdot) \rightarrow h_i < \lambda < h_i
\]

**Figure 2.** Energy detection process diagram.

(2) middle-priority information: double threshold cooperative energy detection

When middle-priority information is used for channel occupancy state detection, the detection performance is poor due to interference of high-priority information signal. In this paper, the dual-threshold collaborative energy detection is adopted to improve the reliability of channel occupancy detection, reduce the probability of high-priority information leakage, and effectively improve the detection performance.

(3) low-priority information: two-level-double threshold collaborative detection

When the occupied state of low priority information channel is detected, it will be interfered by high and medium priority information signals at the same time. In order to improve the detection performance, in addition to the priority of using double threshold detection technology together, also USES two levels of detection: first, using energy detection awareness and to quick search of the entire bandwidth, determine the presence of high, medium priority signal, if does not exist in high, medium priority signal bandwidth, the direct transmission of information; If the statistics exceed the threshold, there may be high and medium priority signals, and then the second level detection of the channel is carried out by the cyclic stationary method to improve the detection performance. Compared with the
detection scheme of medium priority information, the detection scheme of low priority information has higher robustness and better performance, but requires the longest detection time. The working principle of two-stage detection is shown in figure 3.

![Figure 3. Schematic diagram of two-level detection method.](image)

The schematic diagram of the second level detection using the cyclic stationary detection method is shown in figure 4.

![Figure 4. Schematic diagram of cyclic stationary detection method.](image)

There are two conditions for receiving signals $x(t)$, namely $H_0$ and $H_1$

$$H_0: \quad x(t) = n(t)$$

$$H_1: \quad x(t) = s(t) + n(t)$$

$n(t)$ is thermal noise and $s(t)$ is useful signal.

$x(t)$ is assumed to be a zero-mean random process, which is considered to be periodic, and its autocorrelation function is:

$$c_{xx}(t, \tau) = E(x(t)x(t + \tau))$$

the corresponding Fourier sequence is:

$$c_{xx}(t, \tau) = c_{xx}(\tau) + \sum_{\alpha \neq 0} C_{xx}(\alpha, \tau)e^{j2\pi \alpha t}$$

$$C_{xx}(\alpha, \tau) = \lim_{Z \to \infty} \frac{1}{Z} \frac{Z}{2} c_{xx}(t, \tau)e^{j2\pi \alpha t} dt$$

$\alpha$ is the cycle period, $\psi$ is the range of values that cycle period can take on, $C_{xx}(\alpha, \tau)$ is called the period-dependent equation.

for a fixed delay $\tau$, $c_{xx}(t, \tau)$ can get two parts

$$c_{xx}(t, \tau) = CC + PPC$$

$$PPC = \sum_{\alpha \neq 0} C_{xx}(\alpha, \tau)e^{j2\pi \alpha t}$$ is the time dependent part, $CC = c_{xx}(\tau)$ is the continuity part and has independent time. Although $CC = c_{xx}(\tau)$ exists in $H_0$ and $H_1$, but it is not related to $PPC = 0$. When the periodic frequency of $x(t)$, $\alpha \neq 0$, in the case $H_0$, $PPC = 0$, in the case $H_1$, $PPC \neq 0$. By calculating whether PPC is 0, we can detect the occupancy of various priority information channels.

Define the time correlation function as $\overline{c_{xx}}(t, \tau) = c_{xx}(t, \tau) - c_{xx}(\tau)$, instead of $c_{xx}(t, \tau)$,

$$H_0: \quad \overline{c_{xx}}(t, \tau) = 0$$

$$H_1: \quad \overline{c_{xx}}(t, \tau) \neq 0$$
\[ H_1 : \quad \tilde{c}_{in}(t, \tau) \neq 0 \]  

In the case of given delay, the load state of low-priority information channel is detected by detecting whether \( \tilde{c}_{in}(t, \tau) \) is zero.

### 3.2. Information is sent for autonomous decision-making

In order to realize the low-delay transmission of time-sensitive information in the cluster and meet the requirements of weapon coordination and joint attack, an autonomous decision-making scheme of multi-node information fusion is designed. According to the detection results of channel occupancy, the scheme makes independent decisions on whether to send information to the outside world: the high-priority information has the absolute priority to use the channel, and when the high-priority information is transmitted to the outside world, the sub-priority information cannot be accessed and must be avoided. When channel occupancy is low, sub-priority information access is allowed. The accuracy of channel occupancy detection results of a single node is not high, and the reliability of detection can be effectively improved by combining the results of channel occupancy detection of multiple nodes. When the sub-priority information is sent to the channel, the signal energy of the channel is divided into several different levels. The principle of autonomous decision-making scheme for information transmission is shown in figure 5.

![Figure 5. Schematic diagram of autonomous decision-making scheme for information transmission.](image)

### 4. Performance simulation

The number of nodes in the network is 200, among which each node communicates with a certain probability \( P \), and the node priority is set to different priority, so as to simulate the designed data link multiple access technology. The simulated AD hoc network of uav is composed of 30 nodes, which are evenly distributed in a square area of 15000m×15000m. The duration of the simulation experiment was 1000s. Each simulation experiment was conducted for 20 times, and different seed values were selected for each simulation experiment. The value range of seed was 1~20.
Figure 6. data flow at 6 seconds.

Figure 6 is the network data flow diagram of simulation 6s. It can be seen that in the case that the information cannot reach the jump range in the propagation process, the path planned by multiple access autonomous access technology is used and other nodes are used for relay. Figure 7 is the network data flow diagram of simulation 8s. Compared with 6s, the bandwidth of the 8s network information transmission is decreased, the network load is reduced, and the low-priority information is transferred after it is retreated, thus reducing the probability of network information collision.

Figure 7. data flow at 8 seconds

5. Conclusion
This paper proposes an autonomous access technology for uav cluster data link based on priority statistics, which detects and predicts the busy degree of the channel through time-frequency analysis, and adopts the autonomous decision scheme of multi-node information fusion to send information, thus reducing the collision probability of the channel. The simulation results show that the multi-access technology designed in this paper can better solve the multi-access problem of uav cluster data link networking.
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