



Cross Layer Method of Reliable Transmission in UAV Ad Hoc Network Based on Improved Ant Colony Algorithm

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Abstract. In order to improve the quality of communication between UAVs, a cross layer reliable transmission method based on improved ant colony algorithm is proposed in this study. According to the free space attenuation model, the threshold of signal strength for receiving messages from neighbor nodes is defined. Then, the improved ant colony algorithm is used to calculate the path stability between the source node and the destination node, so as to perceive the stability of the reliable transmission path of UAV ad hoc network. The running speed of the buffer area is calculated according to the cache queue length of UAV ad hoc network, and the congestion in the transmission process is detected. Finally, through the energy consumption and transmission balance mechanism, improve the routing process of data transmission between UAV formations to achieve reliable transmission of UAV ad hoc networks. The experimental results show that this method can effectively reduce the transmission outage probability. With the increase of data transmission rate and UAV speed, lower average delay and higher delivery success rate can be obtained.

Keywords: Improved Ant Colony Algorithm · UAV Ad Hoc Network · Reliable Transmission · Communication Protocol · Cross Layer Method

1 Introduction

At present, the application of UAV has covered many fields such as civil, industrial production and military. Moreover, UAVs have become an indispensable and important part of modern warfare. They are mainly used for tasks such as reconnaissance and surveillance, intelligence collection, communication relay, and rapid strike on the battlefield. The modern battlefield has the characteristics of high confrontation, wide coverage, and large amount of information [1].

When multiple UAV formations perform tasks cooperatively, they can exchange mission planning, flight status, intelligence information and other data with each other through UAV self-organization network to improve UAV formation's perception of real-time situation and achieve the overall effectiveness of multiple UAVs performing tasks independently. In UAV self-organization network, each UAV is treated as a node [2].

Reference [3] proposed a multiple access control (MAC) protocol supporting mixed service transmission. Aiming at the QoS requirements of mixed services, the protocol adopts multi-channel random access strategy for the highest priority services, and multi-channel free busy access strategy for the remaining priorities. It controls the access rights of non timeout packets in real time according to the threshold and channel occupancy, and provides QoS guarantee capability for each priority service through a multi priority backoff mechanism based on channel free busy awareness. Reference [4] proposes a multi priority single threshold access control (MSAC) protocol. By designing a channel load statistics time correction mechanism and a channel access control mechanism based on a single threshold, more accurate channel load statistics and load control based on data packets can be achieved, so that the system channel carrying capacity matches the actual channel load and maximizes the use of channel resources. Reference [5] proposed a cross layer optimization technology for using multiple description coding (MDC) to improve the QoS of video streaming applications in multi radio wireless mesh networks (WMN). WMN is an emerging technology used to connect various types of networks to the Internet.

With the development of science and technology, the use of UAVs has evolved from the initial single-machine mission to the formation of multiple UAVs to complete tasks collaboratively. Due to the dynamic characteristics of UAV formation, the rapid changes in network topology, the rapid changes in the wireless channel environment, and the scarcity of network bandwidth have caused the traditional layered architecture to encounter new difficulties and challenges in improving network performance. Optimization provides a broad space. Introducing a cross-layer design to optimize UAV network architecture, while maintaining the separation between layers, it allows the protocols of different layers to share the state information of the network, which is conducive to the optimization of intra-layer and inter-layer operations, and achieves effective allocation of network resources. Improve the comprehensive performance of UAV self-organizing network.

Based on the above research background, this paper uses the improved ant colony algorithm to design a cross layer method for the reliable transmission of UAV ad hoc network, so as to meet the quality requirements of communication between UAVs. The general research ideas are as follows:

- (1) According to the free space attenuation model, the threshold value of signal strength for receiving messages from neighboring nodes is defined.
- (2) The improved ant colony algorithm is used to calculate the path stability between the source node and the destination node in the ad hoc network.
- (3) The running speed of the cache area is calculated according to the length of the cache queue in the ad hoc network, and the congestion in the transmission process is detected.
- (4) Through the energy consumption and transmission balance mechanism, the data transmission route selection process is optimized to achieve reliable transmission of UAV in the ad hoc network.

2 Design of Cross-Layer Method for Reliable Transmission of UAV Ad Hoc Network

2.1 Perceive the Stability of the Reliable Transmission Path of UAV Ad Hoc Network

In UAV ad hoc network, due to the rapid movement speed of UAV and the different task allocation of each UAV, the network topology changes rapidly, and the phenomenon of link interruption is very common. Therefore, in order to avoid the degradation of network performance caused by link interruption, a link stability evaluation method is proposed. It can not only comprehensively evaluate the stability of a link, but also predict and delete the links that may be interrupted in advance by receiving the signal strength of Hello messages and establishing a long-term monitoring mechanism for them [6], which overcomes the shortcomings of previous methods and improves the network performance. At the same time, in order to avoid the impact of GPS positioning error or external interference on the method, this paper does not use the location information of nodes.

In the reconnaissance process of UAV formation on the battlefield environment, due to the different needs of the mission, the formation is often composed of different types of UAVs, so the speed, antenna gain and maximum transmission power of each platform are different. Therefore, this paper improves the data packet of Hello message, including source node address, node congestion, antenna gain, transmission power, and moving speed.

According to the free space attenuation model, the signal strength p_{ri} of the Hello message received by the current node from the neighbor node i at distance d is:

$$p_{ri} = p_t g_t g_r \left(\frac{\gamma}{4\pi d} \right)^2 \quad (1)$$

where, γ is the wavelength of the radio wave, g_r is the gain of the receiving antenna, g_t is the gain of the transmitting antenna, and p_t is the Hello message transmission power of the neighbor node.

Assume that the coverage of the antenna is a circular area of radius r . In a circular area of radius r , the average distance between two mobile nodes is $0.9054r$. Therefore, this paper defines the critical value of signal strength for receiving Hello messages from neighbor nodes as:

$$p_l = p_t g_t g_r \left(\frac{\gamma}{4\pi \cdot 0.9054r} \right)^2 \quad (2)$$

The current node can calculate the critical value of the received signal strength according to the known information of the node and the information contained in the Hello message of the neighbor node, and compare it with the measured signal strength to evaluate the stability of the reliable transmission link of UAV ad hoc network for the first time. The process is as follows:

$$K_i = \begin{cases} 0, & p_{ri} \leq p_l \\ 1 - \frac{p_l}{p_{ri}}, & p_{ri} > p_l \end{cases} \quad (3)$$

The value of K_i represents the stability of the reliable transmission link of the i UAV ad hoc network at the current moment. The larger the value of K_i , the better the stability of the link, but it does not exceed 1. When K_i is 0, the link is identified as an unstable UAV ad hoc network reliable transmission link, and is deleted from the storage area. In order to maintain the real-time nature of the K_i value, it needs to be updated continuously, and the update time interval T is:

$$T = \frac{r - 0.9054r}{v_1 + v_2} \quad (4)$$

where, v_1 is the maximum moving speed of the current node, and v_2 is the maximum moving speed of the neighbor node. Because the types of neighbor nodes are different, the corresponding T is also different. By using this time interval to update the K_i value, it can ensure that no neighbor node in the storage area has moved out of its communication range within time T . It effectively uses the storage space of the node and provides a reliable choice for the route discovery phase. It effectively solves the defect of fixed Hello message cycle.

The above process only evaluates the stability of the reliable transmission link of UAV ad hoc network at a certain moment, and does not establish a long-term mechanism to comprehensively evaluate the stability of the reliable transmission link of UAV ad hoc network. Therefore, this paper estimates the mobility of neighbor nodes according to the changes of the Hello message signal strength at different times [7], and deletes the neighbor nodes with strong mobility in the storage area of the current node.

According to the above process, Biannemei-Chebyshev inequality can be obtained:

$$p\{|X - E(X)| < \phi\} \geq 1 - \frac{\overline{\mu}(X)}{\phi^2} \quad (5)$$

where, X is a discrete variable, $E(X)$ is the mathematical expectation of X , $\overline{\mu}(X)$ is the variance of X , and ϕ is any positive number.

When $\overline{\mu}(X) = 0$, there is $p\{|X - E(X)| < \phi\} = 1$, which means that the variable X is equal to its expected value, and it also means that the smaller the variance of the variable X is, the closer the variable X is to its expectation, and the smaller the variation of the variable X is.

According to multiple measurements of variable X , its variance $\overline{\mu}(X)$ can be obtained as follows:

$$\overline{\mu}(X) = \left(\sum \frac{X_k^2}{N} \right) - \left(\sum \frac{X_k}{N} \right)^2 \quad (6)$$

Taking the value of K_i at different times as the measured value of variable X multiple times, and substituting it into formula (6), we can get:

$$\text{var}(K_i) = \left(\sum_{i=1}^n \frac{K_i(X)^2}{N} \right) - \left(\sum_{i=1}^n \frac{K_i(X)}{N} \right)^2 \quad (7)$$

The mobility of a neighbor node can be obtained by formula (7). The smaller the value of $\text{var}(K_i)$, the less obvious the neighbor node's movement is, and the more stable

the i link is. This method only judges the mobility of neighbor nodes in the current node's storage area.

To sum up, the specific process of judging the stability of the reliable transmission link of UAV ad hoc network is as follows: each node numbers the neighboring nodes that enter the scope of this node $0.9054r$, and writes them into the storage area, and according to the formula (3), calculate the stability K_i of each link at the current moment. When the K_i value of a link is 0, the storage area will delete the link. When a link obtains two consecutive K_i s that are not 0, the node mobility of the link is judged, and as long as K_i is not 0, the node mobility of the link is always judged. When $\text{var}(K_i)$ of a link exceeds the preset threshold value var_l three times, it indicates that the neighbor node has strong mobility, and it also indicates that the link is unstable. Therefore, the link is deleted from the storage area of the current node. At the same time, in order to save storage space, this paper defines that only the K_i values of the last five moments are stored in the node storage area.

In the route discovery stage, it is usually necessary to select the most stable route to transmit data, so it is necessary to comprehensively quantify the stability of a current link. This paper proposes a comprehensive quantification method for the stability of a current link, as follows:

$$Q_i(t_m) = \frac{K_i(t_m)}{e^{\text{var}_m(K_i)}} \quad (8)$$

where, $Q_i(t_m)$ is the comprehensive stability of the i link at time t_m , $K_i(t_m)$ is the K_i value at time t_m , and $\text{var}_m(K_i)$ is the $\text{var}(K_i)$ value at time t_m . At this moment, when a neighbor node enters the storage area of the current node for the first time, the value of $\text{var}(K_i)$ is empty. In this method, let $\text{var}_m(K_i) = 1$ at this moment. Moreover, the larger the $Q_i(t_m)$ value, the higher the comprehensive stability of the reliable transmission link of UAV ad hoc network.

Each routing control packet contains a value of W . The source node sends a forward ant and sets the initial value of W to 1. When the forward ant moves in the network, every time it passes an intermediate node, it multiplies the link stability Q_i between the intermediate node and the previous hop node by the current W value [8] to get a new W value. When the ant reaches the destination node, the stability of the path from the source node to the destination node can be obtained:

$$W = \prod_{j=1}^n Q_i^j \quad (9)$$

In the formula, Q_i^j is the stability of each link passed by the forward ants in the route discovery process, and n is the number of nodes passed by the forward ants.

2.2 Congestion Detection in Reliable Transmission Process of UAV Ad Hoc Network

In the process of information transmission, although UAV will continuously send the transmitted data information to its next hop UAV, UAV will also continuously receive

the transmitted data information from the previous hop UAV. When the overall rate at which the drone receives data information is much higher than the rate at which it is sent, the load on the nodes increases, which will cause congestion on the transmission path. By detecting the length of UAV's cache queue, the speed at which its cache area is fully loaded is calculated [9]. When the speed of UAV cache reaches full load is positive, and the faster the speed is, the easier it is for UAV cache to overflow, the more likely it is to cause congestion, and the higher the congestion degree of UAV; The slower the speed is, the lower the congestion of UAV; When the cache reaches full load at a negative speed, it means that the current available cache space of UAV is larger and no congestion will occur.

Use L_{all} to represent the length of the buffer area, L_0 to represent the length of the buffer queue at the current moment, and there must be $L_{all} \geq L_0$. When $L_{all} = L_0$, the buffer area is full and congestion occurs. According to the DropTail principle, the data packets that arrive later will be discarded. Therefore, to avoid this situation, it is detected in advance that the buffer area is about to be full, and the This status information is fed back to the source drone to control the rate at which the source drone sends data packets.

When $L_{all} > L_0$, the buffer area is not full. The input rate Λ_{in} and output rate Λ_{out} D of a UAV data packet can be obtained through the time information provided by the MAC layer. The calculation formula is:

$$\Lambda_{in} = \frac{1}{T_{in}} \quad (10)$$

$$\Lambda_{out} = \frac{1}{T_{out}} \quad (11)$$

Among them, T_{in} is the time interval between the arrival of two adjacent data packets, and T_{out} is the time interval from when the data packet is ready to be transmitted to when ACK packet is received to confirm the successful reception, including processes such as contention, backoff waiting, data transmission, and collision retransmission.

T_{in} and T_{out} need the time information recorded by the MAC layer and get it through calculation, but the data transmission is random. If the result is recorded only once, it is obviously not convincing. Therefore, the weighted iterative average method is used to reduce the error caused by the randomness of data transmission. The specific method is as follows:

$$T_{in}(n) = \sigma T_{in}(n-1) + (1-\sigma)[t_{in}(n) - t_{in}(n-1)] \quad (12)$$

$$T_{out}(m) = \varsigma T_{out}(m-1) + (1-\varsigma)[t_{sck}(m) - t_{ready}(m)] \quad (13)$$

where, $T_{in}(n)$ and $T_{in}(n-1)$ are the average time interval between the arrival of the second data packet calculated by weighted average when the n and $n-1$ data packets arrive at UAV respectively, $T_{out}(m)$ and $T_{out}(m-1)$ represent the average processing time calculated by weighted average when the m and $m-1$ data packets arrive at UAV successfully from the time they are ready to be transmitted to the next hop, and $[t_{in}(n) - t_{in}(n-1)]$ represents the actual recorded time interval between the n and $n-1$ data packets arriving at UAV, $[t_{sck}(m) - t_{ready}(m)]$ is the m data packet actually recorded.

It is the processing time from the time when it is ready to be transmitted to the time when it is successfully received by the next hop UAV. σ and ζ are weight coefficients. In order to reduce the measurement error, $\sigma = \zeta = 0.2$ is taken in this paper.

In the process of data transmission, there may be no data transmission for a long time or due to congestion, which will cause $T_{in}(n)$ and $T_{out}(m)$ to approach infinity, which is not expected. Therefore, it is necessary to eliminate the infinite values in $T_{in}(n)$ and $T_{out}(m)$. , reducing the error, the detection value ϑ can be expressed as:

$$\vartheta_1 = \frac{t_{in}(n) - t_{in}(n-1)}{Et_{in}} \quad (14)$$

$$\vartheta_2 = \frac{t_{tick}(m) - t_{ready}(m-1)}{Et_{out}} \quad (15)$$

where, Et_{in} is the expected time interval between two adjacent data packets arriving at UAV, and Et_{out} is the expected processing time from the time when they are ready to be transmitted to the time when they are successfully received by the next hop UAV. Therefore, dividing the actual value by the expected value can determine whether there is no data transmission for a long time or transmission failure due to congestion.

2.3 Realization of Reliable Transmission Across Layers of UAV Ad Hoc Network

In view of the large amount of data transmission between UAVs, only the adaptive power control mechanism cannot guarantee the reliable transmission of data. It is necessary to reasonably select the route of data transmission according to the status of the data link. The following is an analysis of routing selection from the perspectives of energy consumption and transmission balance to realize cross-layer transmission.

H_T represents the energy consumption of UAV i transmitting α -bit data through the data link, and its expression is:

$$H_T = \begin{cases} \alpha \times E_{elec} + \alpha \times \partial_{fs} \times d^2, & d \leq R \\ \alpha \times E_{elec} + \alpha \times \partial_{amp} \times d^4, & d > R \end{cases} \quad (16)$$

$$H_R = \alpha E_{elec} \quad (17)$$

The energy consumption of the source drone is $H_s = H_T$, the energy consumption of the destination drone is $H_d = H_R$, and the energy consumption H_p of the relay drone p can be expressed as:

$$H_p = H_R + H_T \quad (18)$$

where, E_{elec} is the energy loss of transmitting and receiving unit bit information, α is the number of bits, and d is the distance between two UAVs. The power of electromagnetic wave will decrease with the increase of the distance between UAVs. Therefore, ∂_{fs} and ∂_{amp} are the power consumption coefficients of power amplification circuits for free space model and multipath fading model respectively [10].

Every time a drone is passed, an H value will be calculated and recorded in the routing table of the drone. In the N hop from the source UAV to the destination UAV, the energy factor of this link can be obtained by the following formula:

$$H_{std} = H_s \times H_d \times \prod_{n \in N-2} H_n \quad (19)$$

H_{std} of the above equation is used as the energy based link selection standard. For multiple links to the same destination UAV, select the link with the lowest H_{std} value as the data transmission link.

Definition U_{ik} represents the transmission factor of data k ($k \in \{A, B, C\}$) at UAV i , which is used to describe the load situation at UAV i . ML_i represents the maximum load space at UAV i , and PL_{ik} represents the load of UAV i processing data k . where PL_i is jointly determined by UAV i and neighboring UAVs, and its expression can be expressed as:

$$PL_i = SL_i(x) + NL_i \quad (20)$$

$$SL_i(x) = SL_i(x-1) \times \xi + SQ_i \times (1 - \xi) \quad (21)$$

$$NL_i = SL_{i+1} \quad (22)$$

where, $SL_i(x)$ represents the current load of UAV i , $SL_i(x-1)$ represents the load of UAV i at the last moment, SQ_i represents the MAC layer queue length of current UAV i , NL_i represents the load of UAV i 's neighbor, and also the load of UAV itself at the next hop, ξ ($\xi \in [0, 1]$) [0, 1] is the smoothing factor, and ξ is taken as 0.2 in this paper.

If data A is generated at UAV i , the current communication channel is completely preempted, and other data is not selected to be transmitted through UAV at this time. Let its transfer factor $U_A = 1$.

The transfer factor of data B can be expressed as:

$$U_{iB} = \frac{L_{iB}}{M_i} \times (1 - U_{iA}) \quad (23)$$

Multiply $1 - U_{iA}$ after $\frac{L_{iB}}{M_i}$ to avoid continuing to select this UAV to transmit data B if data A is generated. $U_{iA} = 1$ means that data A almost completely occupies UAV i link. If $U_{iA} = 0$ means that data A is not generated at UAV i and data B is transmitted normally.

The total transmission factor U_{stdB} on the link from the source UAV to the destination UAV can be expressed as:

$$U_{stdB} = \prod_{i \in N} U_{iB} \quad (24)$$

The transfer factor of data C can be expressed as:

$$U_{iC} = \frac{PL_{iC}}{ML_i} \times (1 - U_{iB}) \quad (25)$$

The reason for using this form is similar to that before. If there is no data A and B transmission at UAV i , then U_{iA} and U_{iB} are equal to 0. The total transmission factor U_{stdC} on the link from the source UAV to the destination UAV can be expressed as:

$$U_{stdC} = \prod_{i \in N} U_{iC} \quad (26)$$

U_{stdk} considers the link conditions of data transmission. The smaller the value of U_{stdk} is, the smaller the transmission load of the link is. Selecting such a link can avoid congestion and reduce large delays and high packet loss rates.

Under the adjustment of priority function, the priority of data C is gradually increased. When the priority of data C is higher than that of data B , only the subscripts of formula (23), (24), (25) and (26) need to be exchanged; When the priority of data C is cancelled, the subscript can be called back.

The values of U and H are both 0 when no data is sent from the source drone, which can ensure that the source drone has enough energy and cache to process the message.

To sum up, it can be concluded that the data $k(k \in (A, B, C))$ is transmitted on a certain link, based on the joint weight expression of energy and transmission balance:

$$W_{stdk} = \begin{cases} \alpha \times e^{-H_{std}} + \beta \times e^{-U_{stdk}}, & k \in B, C \\ \alpha \times e^{-H_s \times H_d} + \beta \times e^{-1}, & k \in A \end{cases} \quad (27)$$

In the formula, α and β are the weights of the two determinants, and $\alpha + \beta = 1$ is taken as $\alpha = 0.1$ and $\beta = 0.9$.

An additional area is added in the Hello message to store the U and H values. A drone loads its U and H values into the Hello message before sending Hello to the next-hop drone. When the drone receives the Hello message, it takes out the U and H values in the Hello message to update the routing table, calculates the W value, and selects the path with the largest W value to transmit data.

Once the distance between two UAVs is less than the safety distance, the data A with the highest priority will be generated. At this time, the data link between them is occupied, and the data with low priority cannot be transmitted on this link. For the transmission of the other two types of data, other links are selected for transmission according to the updated transmission information of the relevant links, and priority adjustment function is used to avoid the phenomenon of “starving” of low priority data and make full use of bandwidth resources.

3 Experimental Comparative Analysis

3.1 Set the Experimental Parameters

Simulate the information transmission of UAV self-organizing network, and set the simulation scenario that multiple UAVs are distributed in a 50 km x 50 km square area. Other parameter settings are shown in Table 1.

Table 1. Experimental parameters

Parameter	Size	Parameter	Size
MAC protocol	IEEE802.11	RTS threshold/byte	550
Agent type	TCP	Transmission type	FTP
Data packet	[64,10000]	Channel rate (M/b)	1
SIFS/ μ s	10	DIFS/ μ s	50
Antenna type	Omnidirectional antenna	Interface queue type	Drop Tail
UAV flight speed (m/s)	20~70	Communication range	8
Simulation time/s	1000	Number of drones	30

3.2 Analysis of Results

In order to verify the superiority of the method in this paper, the cross-layer method based on supporting mixed service transmission described in reference [3] and the cross-layer method based on multi-priority single-threshold access described in reference [4] are compared. After applying different methods, the performance of break probability varying with signal noise ratio (SNR) is shown in Fig. 1. It can be seen from Fig. 1 that the outage probability decreases with the increase of the signal-to-noise ratio. The outage probability of the method in this paper is lower than that of the cross-layer method based on supporting mixed service transmission and the cross-layer method based on multi-priority single-threshold access. About 42% and 63%. This is because this method uses improved ant colony algorithm to perceive the stability of the reliable transmission path of UAV ad hoc network, selects the communication mode with the best channel

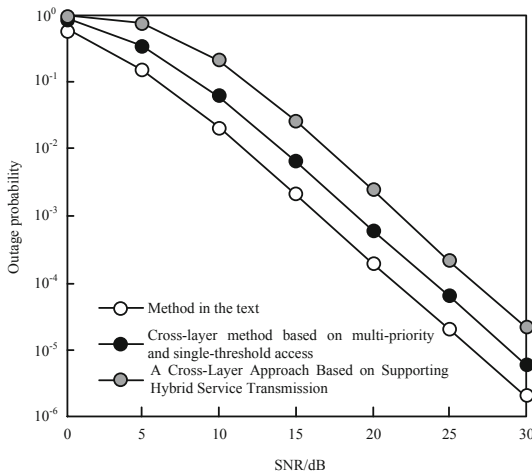


Fig. 1. Performance of outage probability as a function of signal-to-noise ratio

conditions for data transmission, and also uses dynamic congestion detection in advance in congestion control to effectively reduce interruption.

After applying different methods, the performance change of packet delivery success rate with connection data transmission rate is shown in Fig. 2. It can be seen from Fig. 2 that the packet delivery success rate of the method in this paper is about 6% and 9% higher than that of the cross layer method based on supporting mixed service transmission and the cross layer method based on multi priority single threshold access under the same conditions.

In this method, congestion is predicted according to the time when packets enter the cache queue during data transmission, and the sliding window of the source UAV is controlled in advance to reduce congestion, thus improving the success rate of packet delivery to a certain extent.

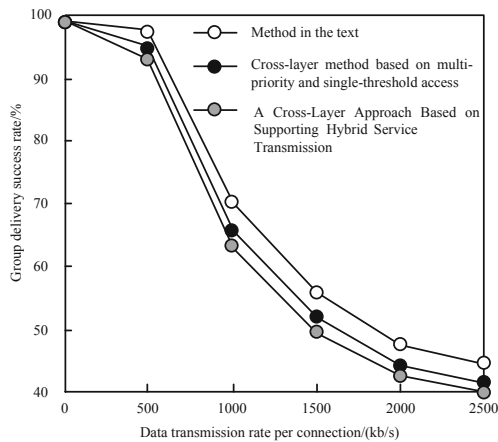


Fig. 2. Performance of packet delivery success rate versus connection data transmission rate

The performance change of packet delivery success rate with the maximum rate of UAV is shown in Fig. 3. It can be seen from Fig. 3 that with the increase of the maximum rate of UAV, the possibility of link interruption between UAVs also increases. The method in this paper is about 7% and 11% higher than the cross layer method based on supporting mixed service transmission and the cross layer method based on multi priority single threshold access respectively. This is because in the process of data transmission, the method in this paper will select a more appropriate data transmission mode according to the channel conditions, and make congestion prediction, which will slow down the decline of the packet delivery success rate to a certain extent.

The performance change of average delay with the maximum rate of UAV is shown in Fig. 4. As can be seen from Fig. 4, with the increase of the maximum speed of UAV, the average delay of the method in this paper is respectively higher than that of the cross-layer method based on supporting mixed service transmission and the cross-layer method based on multi-priority single-threshold access under the same conditions. The layer method is about 12% and 18% lower.

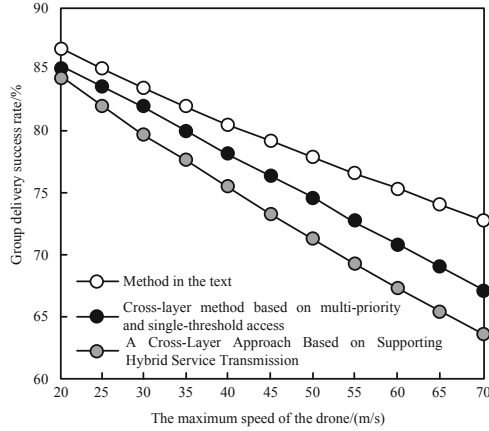


Fig. 3. Performance of packet delivery success rate with the maximum rate of UAV

With the increase of the maximum speed of UAV, it is not only necessary to ensure congestion control during data transmission, but also to minimize the number of link interruptions so that data can be transmitted quickly. The method in this paper is based on this idea, taking the interruption and congestion control into account to ensure the stability of UAV self-organized network communication.

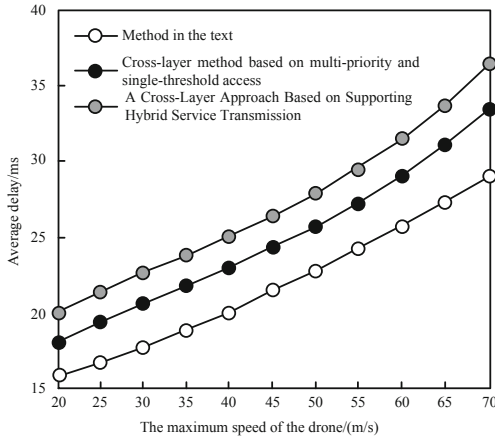


Fig. 4. Performance of average delay versus maximum UAV rate

4 Conclusion

In this paper, the improved ant colony algorithm is applied to the design of reliable transmission cross-layer method of UAV ad hoc network. The improved ant colony algorithm is used to calculate the path stability between the source node and the destination node of the ad hoc network. According to the calculation results and the running

speed of the ad hoc network buffer, the congestion in the transmission process is detected. Finally, through the energy consumption and transmission balance mechanism, the route selection process of data transmission between UAV formations is improved to achieve reliable transmission.

The experimental results show that this method can improve the performance of UAV ad hoc network to a certain extent and ensure the reliability of communication. However, there are still areas to be optimized in this study. In the future research, we will consider the throughput in the data transmission process, optimize cross-layer cooperation, and improve the network throughput on the basis of ensuring the original delay and delivery success rate.

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