Routing Algorithm of Congestion Control for Aeronautic Swarm Network

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Abstract —Aeronautic swarm network based on aeronautic operations is a new type of network scenario. Currently, aeronautic swarm network is facing the network congestion problem that needs to be solved urgently, which will bring new challenges to the research of its routing protocol. Through in-depth analysis of the causes and effects of network congestion problems, we proposes an routing algorithm of congestion control for aeronautic swarm network. According to the characteristics of aeronautic swarm network, load evaluation indicators are designed for the nodes, links and sub-nets respectively and used as parameters of the routing algorithm to achieve network congestion control. This algorithm solves the problem of network congestion in the aeronautic swarm network effectively and improves the real-time performance of data forwarding.

Index Terms—Aeronautic swarm, congestion control, routing algorithm，OLSR

I. Introduction

The aeronautic swarm [1] inspired by the behavior of biological swarm can have dozens to hundreds of aeronautic platforms. And there are various types of aeronautic swarm platforms, such as E-3 early warning aircraft, reconnaissance aircraft and UAVs (Unmanned aerial vehicle), which can simultaneously perform multiple tasks [2]. In order to realize real-time and reliable communication during the mission process, a large-scale aeronautic swarm network is constructed by various types interconnecting members of the aeronautic swarm [3]. Platforms that perform the same task in an aeronautic swarm typically build a task sub-net for information sharing, which may result in the presence of one or more sub-nets in an aeronautical swarm network. Therefore, a aeronautic swarm network is complex and heterogeneous network and requires complex functions such as routing protocol [4].

On the one hand, the burstiness of tasks in aeronautic swarm network causes unpredictable changes in network load conditions. For example, bursting high-bandwidth demand services in aeronautic swarm network will result in other types of services failing to allocate sufficient bandwidth resources, causing network congestion and reducing network transmission performance. Task changes, on the other hand, also cause network load conditions to change with the task. For example, a platform which performs battlefield environment monitoring task will establish a sub-net with other platforms after the target is found and achieves the target coordinated tracking and positioning. In this process, the services generated by the platform are changed from relatively single battlefield situation information to large-scale and multiple-type information such as target detection and co-location. When there are a large number of information transmission requirements, continuous network congestion is caused by network resources (including link bandwidth, storage space etc.) and platform data processing and forwarding capabilities limited [5], [6]. In addition, different service transmission priority differences cause delay requirements to be differentiated. For example, fire control and guidance data streams have higher priority than voice streams, and priority is required to ensure the transmission of fire control and guided data streams. At the same time, in order to make the continuous control command of the command platform reach the target platform in order, a certain delay guarantee is needed. For example, to ensure that the UAV formation command and coordination information arrives at the formation in an orderly manner, the UAV formation is guided to perform continuous tactical actions (Fig. 1) and requiring low latency guarantee. The demand differentiation for delays in different services complicates network congestion problem.

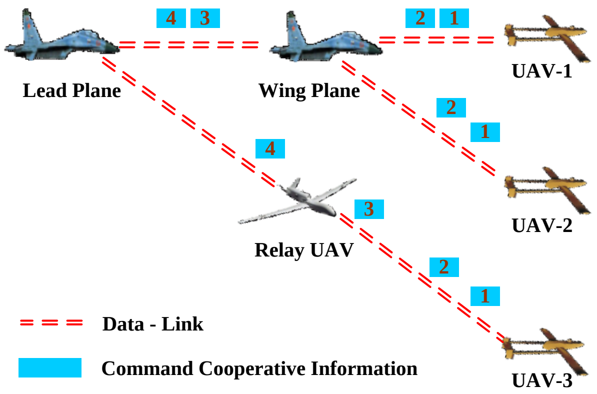

Fig. 1. UAV collaboration control information distribution

Manuscript received March 10, 2019; revised August 7, 2019.
This work was supported by the National Natural Science Foundations of CHINA No. 61472443.
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doi: 10.12720/jcm.14.9.813-818

The network congestion challenge faced by aeronautic swarm will reduce the real-time performance of routing protocols [7], [8] and also affect task implementation and performance improvement. Therefore, there is an urgent need to solve the problem of aeronautic swarm network congestion [9], [10].

II. Related Work

As a new application scenario, aeronautic swarm have just begun to study the problem of network congestion. The existing network congestion control methods are mainly for traditional application environments such as wireless MESH networks. For example, in paper [11], the problem of network performance degradation caused by wireless MESH network congestion is considered. The hop count and cross-layer information are used to optimize the routing process, and the node load and packet arrival rate are used as performance evaluation indicators. The strategy named LBCL-AODV is proposed based on AODV. In the literature [12], the software-defined network [13]-[15] ant colony optimization load balancing algorithm is proposed. The load balancing degree is used as the objective function to redefine the ant colony algorithm parameters and operations, set the network data flow and plan its optimal transmission path. In the article [16], the DLB (Dynamic load balance) algorithm is proposed for the east west traffic stability of the data center network. When the link starts to block, the algorithm performs the source-side virtual machine migration for the larger stable flow, so as to avoid the problem that the stable flow is too concentrated and the data center network load is balanced. Although the existing results cannot be directly used in aeronautic swarm network, they still provide valuable experience for the study of network congestion in this context.

This paper designs a routing algorithm of network congestion control for aeronautic swarm network. On the basis of analyzing the congestion problem of aeronautic swarm network, by evaluating the load status of nodes, links and sub-nets, the evaluation indicators is used as the algorithm input to realize network congestion control and improve the real-time performance of OLSR routing protocol.

III. Network Load Assessment

The aeronautic swarm network can be abstracted into a network topology $G(E, V)$, where V is a set of nodes and E is a set of links. Aeronautic swarm task processes, such as swarm probing, are usually done collaboratively by multiple different types of platforms. This small-scale mission formation constitutes the communication sub-nets of aeronautic swarm. The information exchange process in the sub-net generates a large amount of service data, which has a significant impact on network congestion. Therefore, the division of sub-nets in an aeronautic swarm network is very important for network congestion control. The sub-net is divided as shown in Fig. 2.

Sub-netting: During aeronautic swarm mission, manned aircraft coordinates and commands the formation consisted by multiple platforms to complete different tactical actions. Therefore, the command platform acts as a sub-net center node and its one-hop neighbor to form a sub-net node set. Then the closed area formed by multiple nodes in the sub-net is used as the sub-net coverage.

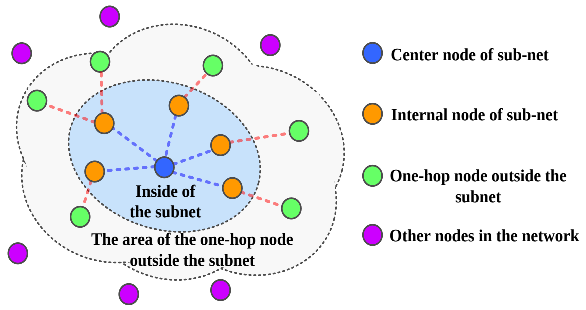

Fig. 2. schematic diagram of sub-netting

By modeling abstract nodes, links and sub-nets, the aeronautic swarm network is simplified to the network topology $G(E, V)$. Load metrics are defined for nodes, links and sub-nets respectively to quantify node, link and sub-net load levels. Quantification of the network load level is implemented in three ways above, which will provide parameter inputs for this routing algorithm of network congestion control.

A. Node Load Evaluation

Let the total amount of data received by the node i from the link receiving port corresponding to the neighbor j in the period T is *Receive_Bytes_j*. Let k be the number of neighbors of node i, then node i counts the amount of data received from k neighbors. So node i receives the total amount of data in the period T as *Receive_Bytes*.

$$Recieve\_Bytes = \sum_{j=1}^{k} Recieve\_Bytes\_j \quad (1)$$

Let *Initial_Bytes* be the amount of data that has not been processed in the previous period T by node i. Then the load *Node_Load* of node i in the current period T is calculated as shown in equation (2).

$$Node\_Load = Initial\_Bytes + Recieve\_Bytes \quad (2)$$

If *Initial_Bytes* is not 0 byte, the node i will process *Initial_Bytes* and *Receive_Bytes* in turn during period T.

Table I: Aeronautic Swarm Network Node Classification

Node Category	Class A	Class B	Class C
Typical Representation	Early Warning Aircraft	Fighter Platform	UAV
Platform Size	Large	Medium	Small

Data Storage and Processing Capabilities	Strong	Medium	Weak
Load Limit	*Node_Loadmax_A*	*Node_Loadmax_B*	*Node_Loadmax_C*
Load Threshold	$Node\_Loadth\_A$	$Node\_Loadth\_B$	$Node\_Loadth\_C$

As shown in Table I above, the various types of aeronautic swarm platforms lead to differences in node load capabilities, such as UAVs, fighters and early warning aircraft, which data storage and processing capabilities vary widely. In order to fully consider this factor, aeronautic swarm platforms are divided into categories A, B and C.

Set *Node_Loadmax* as the load limit based on the load capacity of node and *Node_Loadth as* the load threshold when the node is under high load.

$$NL = \frac{Node\_Load}{Node\_Loadmax} \tag{3}$$

The node load normalized value NL is used as the node load indicator. The calculation process of NL is as shown in equation (3) and the range of NL is(0,1). The node load threshold NL_th is calculated as shown in equation (4).

$$NL\_th = \frac{Node\_Loadth}{Node\_Loadmax} \tag{4}$$

When NL is between the threshold NL_th and 1, it indicates that the node has a high load and congestion control needs to be implemented.

B. Link Load Evaluation

It is assumed that the node *i* transmits data amount *Trans_Bytes* from the link corresponding port in the period T and the received data amount is *Receive_Bytes*. Node *i* counts the amount of data transmitted and received from the port every period T. Then the link load *Link_Load* in the period T is calculated as shown in equation (5):

$$Link\_Load = Trans\_Bytes + Recieve\_Bytes \tag{5}$$

Set *Link_Loadmax* as the link load capacity upper limit and *Link_Loadth*the as the load threshold. The *Link_Load* normalized value is used as the link load indicator *LL* and the calculation of *LL* is as shown in equation (6).

$$LL = \frac{Link\_Load}{Link\_Loadmax} \tag{6}$$

where *LL* takes a value range (0, 1) and sets *LL_th as* the link load normalization threshold, which is calculated as shown in equation (7).

$$LL\_th = \frac{Link\_Loadth}{Link\_Loadmax} \tag{7}$$

When the *LL* is between the thresholds *LL_th* and 1, the link is in a high load state and congestion control is required.

C. Sub-net Load Evaluation

The sub-net where the task formation is located in the aeronautic swarm is usually easy to transmit a large amount of service information, such as cooperative detection information. This makes the link on which information sharing between sub-net members depend occupies and extreme the sub-net load, so the sub-net load depends mainly on its internal link load level.

When the link load in the sub-net is relatively uniform and the average load is low, the sub-net load is light; when the link load in the sub-net is uneven or the average load is high, the sub-net load is heavy. Let α be the sub-net load evaluation factor, and the calculation of α is as shown in formula (8).

$$\alpha = \frac{(\sum_{k=1}^{M} LL\_k)^2}{M \bullet \sum_{k=1}^{M} (LL\_k)^2} \tag{8}$$

To reflect the sub-net congestion characteristics and load level, the sub-net load indicator is designed to be *AL*, and the calculation process is as shown in formula (9).

$$AL = \frac{1}{e^{-\frac{1}{M}} - e^{-1}} \bullet (e^{-\alpha} - e^{-1}) \tag{9}$$

The value of *AL* is on the range of [0,1), *LL_k* is the normalized load of the *k-th* link and *M* is the number of links participating in the evaluation in the sub-net. The larger the *AL* value, the heavier the sub-net load and vice versa.

IV. Routing algorithm Design

In order to realize the network congestion control of aeronautic swarm and improve the real-time performance of OLSR protocol, a congestion control routing algorithm with three load indicators as input is designed.

Due to the lack of data diversion mechanism for large-scale networks to cope with network congestion, OLSR protocol needs routing algorithms to achieve data diversion. This routing algorithm selects a low-load optimal path and forwards the packet, so that the network congestion state is alleviated. The algorithm provides a specific data diversion scheme for each node in the network and calculates the packet forwarding alternative path to make the data packet arrive at the destination node correctly, thereby completing the network congestion control process.

The specific steps of this algorithm are as follows:

Step1: Node *i* calculates load indicator *NL* of the node *i* and the link load indicator *LL* associated with *i* as described in Section 3.1 and Section 3.2.

Step2: The node *i* adds its own ID and its load indicator *NL*, the ID of the *i*-related link, its load indicator *LL* and the ID of the sub-net to the reserved field of its TC (Topology Control) message. Then node *i* broadcasts the TC message.

Step3: During the TC broadcast, the MPR of the last hop node forwards the TC message until the TC message is propagated to all nodes.

Step4: After receiving the TC message, the node extracts the information recorded in the reserved field and obtains the node load *NL* and the link load *LL*, then calculates the sub-net load *AL* according to Section 3.3. Therefore, the node will grasp the load status corresponding to all nodes, links and sub-nets in the network.

Step5: After packet arrives, the current node (maybe not node *i*) judges according to the existing routing table:

a. If the next hop node of the packet is the destination node, it is forwarded according to the existing original routing table path.

b. If the next hop node of the packet is a congested node and is not the destination node, the next hop node replacing the current routing table path is calculated according to the TC message in the OLSR protocol and then packet is forwarded.

The specific process of the alternative path calculation is as follows: According to the OLSR principle, the current node (maybe not node *i*) receives the TC message of each MPR node in the network during the topology convergence process. This message TC includes the neighbor set of each MPR node. Therefore, the node uses the link state algorithm to perform hop-by-hop iteration calculation from the destination node along the source node direction and finds multiple routing paths from the source node to the destination node. Then it selects the alternate path and next hop node on this path to forward the packet.

Step6: It is found through calculation that the packet is forwarded along the original routing table path if there is no suitable alternative path.

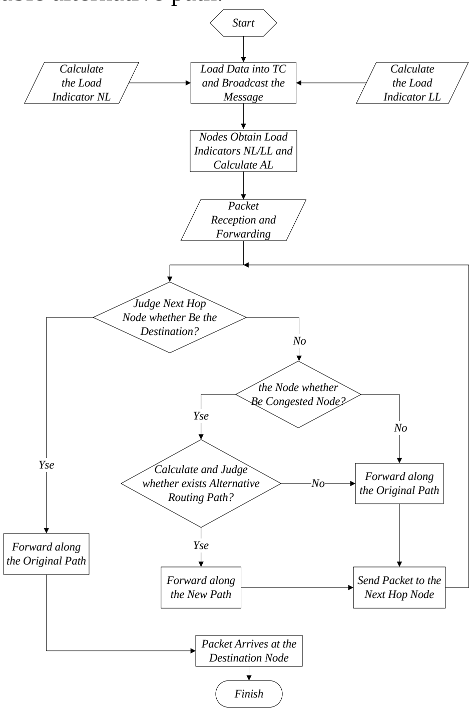

Fig. 3. congestion control routing algorithm

The whole process of congestion control routing algorithm is shown in the Fig. 3 above. After forwarding along the original path or using an alternate path, the packet will arrive at the destination node along the low-load optimal path to complete the packet routing process.

V. Simulation Analysis

In this paper, OLSR protocol is used as performance verification protocol to verify the performance of the routing algorithm of congestion control for aeronautic swarm network. Normalize the load cap definition by node, link and sub-net and set the *NL*, *LL* and *AL* load caps to 1. Set the simulation parameters as shown in Table II:

TABLE II: SIMULATION PARAMETERS

parameter	***value***
scene size	$1200\times1200km^2$
number of nodes	50~120
communication radius R	200*km*
***load status evaluation period* T**	5s
Load threshold	0.8

The node initiates the routing algorithm of congestion control. When *NL*, *LL* and *AL* are above the load threshold, the node re-routes the routing path for the data packet. Before and after congestion control, the simulation relates the Number of Nodes in the network to the End-to-End delay and Packet Arrival Rate are as follows.

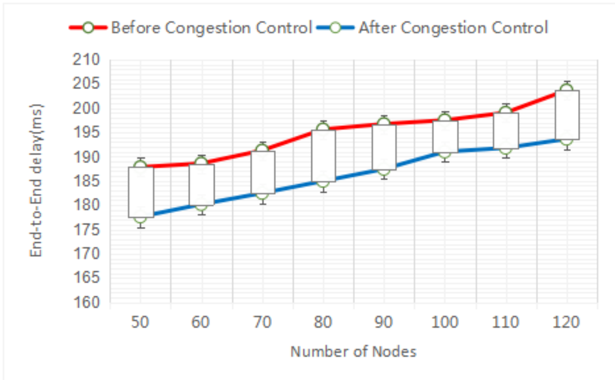

Fig. 4. Number of nodes - end-to-end delay

Fig. 4 shows the relationship between the number of nodes and the end-to-end delay. In both cases, the end-to-end delay increases with the number of nodes and the delay before congestion control is larger overall. The increase in the number of nodes leads to frequent information interactions in the network, such as packet flooding and increased channel competition; At the same time, the uneven load causes excessive congestion of some nodes, links, areas and blocks the packet forwarding path, resulting in an increase in end-to-end delay. After congestion control, the high-load nodes, links and sub-nets number are reduced so that packets can be processed, forwarded and reduced. And the internal business interactions of the sub-net are affected by external information.

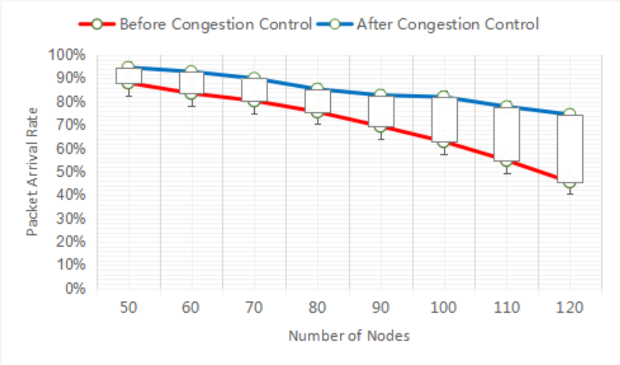

Fig. 5. Number of nodes - packet arrival rate

Fig. 5 shows the relationship between the number of nodes and the packet arrival rate. In both cases, the packet arrival rate decreases with the number of nodes and the packet arrival rate is higher overall after congestion control. Uneven network load causes excessive congestion of some nodes, links and sub-nets. At the same time, the number of nodes increases, the number of packets in the network increases and the packet loss during packet forwarding also increases significantly, which resulting in the decrease in packet arrival rate. After congestion control, the high-load nodes, links and sub-nets are reduced. So the packet forwarding path is effectively and smoothly reach the destination node.

The simulation results show that the congestion control routing algorithm in this paper can greatly improve the real-time performance of the OLSR protocol in the aeronautic swarm network environment. And this algorithm can extent meet the real-time performance requirements of aeronautic swarm network.

VI. Conclusion

To solve the network congestion problem faced by aeronautic swarm network, this paper designs the congestion control routing algorithm. Firstly, define the load metric to quantify the load on nodes, links and sub-nets. Secondly, the routing algorithm of congestion control is designed and the three load indicators are used as the parameter inputs of the algorithm. Finally, the routing algorithm is implemented during the running of OLSR protocol to implement network congestion control. The simulation shows that the network congestion control routing algorithm solves the network congestion problem currently faced by the aeronautic swarm network and improves the real-time performance of OLSR protocol.

Acknowledgment

This work was supported in part by the National Natural Science Foundations of China (61472443).

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