# The Clustering Algorithm of UAV Networking in Near-space

LIU Kesheng#1, ZHANG Jun#2, ZHANG Tao#3

# School of Electronics and Information Engineering, Beihang University
Beihang University, Beijing 100191, China

1liukesheng@buaa.edu.cn

2 buaazhangjun@vip.sina.com

3zhtao73@163.com

***Abstract*—Considering the features of UAV(Unmanned Air Vehicle) networking in near-space, such as low network performance, ineffective communication capability of UAV clusters and the difficulty to manage UAV while it is out of sight, this paper proposes a Space-Earth-Based integrated—"Calculate on the ground, Adjust in the space" thought to design a "Clustering Algorithm of UAV Networking in Near-space". The mathematical analysis and simulation results show that this algorithm can effectively improve the stability and flexibility of near-space clusters, economize the systematic expense, guarantee the movable networking ability of nodes in the space by reducing the calculation of nodes, and realize the clustering and networking of nodes in near-space environment the ability of which is limited.**

## I. INTRODUCTION

Recently, along with the continuous evolution of UAV technologies [1] and the increasing application requirements, it is a hotspot and developing research direction to build one or multiple mission groups by a number of UAVs to complete various complicated missions synergistically.

At present, UAV networking technology faces two problems as followed. It is difficult to establish networks among UAVs, and maintain over-the-horizon communication in UAV networks. To solve the problems above, it is an effective way to utilize UAV networking based on the near-space communication system.

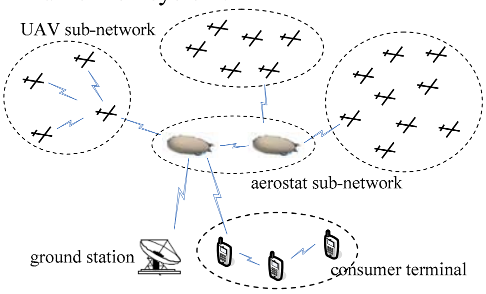


Fig.1 UAV networking in near-space communicate system

Near-space[2] communication system is composed of one or several aerostat nodes in the region of 20-100 kilometers above the earth. In it, as shown in Fig.1, UAVs connect the aerostat sub-network through wireless link. Via this sub-network, UAVs, UAV groups and the ground manage center can communicate cooperatively. It can effectively realize the networking management and relay transmission among UAVs, and solve the difficulty of networking and the problem of over-the-horizon communication. It is an effective approach to realize UAV networking.

In the process of communication, UAV nodes are normally divided into several clusters by a clustering algorithm. Each cluster chooses one node as the cluster head, and the others as the cluster members. The cluster head communicates with aerostats directly or indirectly as the represent of the whole cluster, and on the other hand, it also broadcasts the data and control information to other cluster members. In this way, it can not only guarantee that some of cluster heads can connect with aerostats, which can effectively use the channel resources of aerostats, but also guarantee logical clustering and appropriate cluster head electing, and more cluster heads can stay in the communication area of aerostats in a long time by reasonable algorithms. At the same time, adopting clustering algorithm can also facilitate network management, reduce the costs of communication and routing, and optimize the network performance.

Presently, the research of the clustering algorithms in MANET is comparatively mature, including lowest-ID algorithm [3][4], highest degree algorithm [5], largest weight algorithm [6], Max-Min D-Cluster Formation [7] and MMWN (Mobile Multihop Wireless Network) structure [8]. But all these algorithms are for Ad-hoc ground networks. For the UAV networking based on the near-space communication system, these algorithms sometimes are not effectively available, because of the system characteristics of high mobility of nodes and the limited platform processing ability. Therefore, the appropriate clustering algorithms are required to meet the demands of near-space UAV networking.

## II. CLUSTERING ALGORITHMS OF NEAR-SPACE UAV NETWORKING

Aiming at solving the key problem of near-space UAV networking---UAV network clustering algorithm, this paper will propose a clustering algorithm of near-space UAV networking, adopting the Space-Earth-Based integrated thought— "Calculate on the ground, Adjust in the space". According to the result of path planning, the ground stations calculate the initial cluster planning in advance. And the aerostat nodes adjust the cluster in real-time based on the specific circumstances (the change of nodes position). According to the connecting states, UAV nodes validate the

978-1-4244-2193-0/08/$25.00 ©2008 IEEE

final result of clustering and finish the process of network clustering. Through the cooperated processing among the ground stations, the aerostat nodes and the UAV nodes, the ability of air nodes dynamical networking can be guaranteed while the computation of aerostats and UAV nodes is reduced. And this effectively realized clustering and networking of high-speedy UAV nodes under limited-computation in the near-space environment.

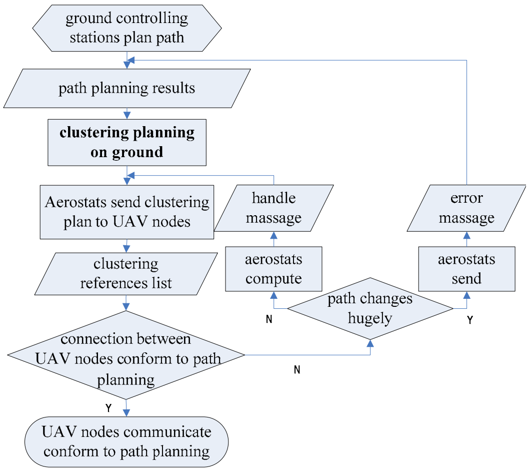


Fig.2 General technological process of UAV Networking Clustering Algorithm in Near-space

Fig.2 is the general technological process of this algorithm. In the algorithm, the key point is clustering planning on the ground, which requires huge computation. Because it can be completed by ground stations with rich resources, not only can it raise the computation speed, and increase the clustering velocity greatly, but also can reduce the computation of UAV nodes and information transmit control. Therefore, the proposed algorithm can save the air channel resources greatly.

### A. Ground Clustering Planning

The ground controlling stations can learn about the scheduled aviation data of UAV nodes in future mission period through path planning, and receive the air network topology structure real-timely. Ground clustering planning first calculates initial clustering plan according to geography information. Considering the stability of clusters, the peculiar factor of near-space was added into traditional largest weight algorithm. It can optimize clusters and choose the cluster head, and maintain the clusters continuously in near-space networks.

#### a Initial Clustering Based On Geography Information[9]

First, according to the 3-Dimension coordinates of the UAV nodes, the network district is divided into different areas. These areas are firm-sized and non-intersect 3-Dimensional cuboids. It makes sure that the node number in each area is between the upper and lower bounds of the cluster size. And then breadth-prior search [10] algorithm is utilized to confirm the connecting branch number of each area. If the sizes of all these connecting branches in cluster were in the bound of the size of cluster at this time, the initial clustering is finished. Otherwise it moves into the circulation of merging and splitting connecting branches until the size of all connecting branches in each cluster is in the region of the size of clusters.

#### b Improved Largest Weight Algorithm To Optimize Clustering and Choosing The Cluster Head

Considering the specialties of near-space networks, this paper utilizes path-planning results to create optimal matrix. It can optimize the initial clustering plan, and formulate the final clustering result. Then, the peculiar factor of near-space is applied into traditional largest weight algorithm, and utilized the improved largest weight algorithm to choose one cluster head for each final cluster. The steps are detailed as follows:

a) Create Optimal Matrix According to the path-planning result

Ground Stations plan and monitor UAV aviation data by path system, and obtain the path-planning data. The ground clustering planning system makes these scattered data to continuous functions about absolute time *t*, which is facile to create optimized matrix.

According to the requirement of the largest weight algorithm, three matrixes are defined:

• Connecting Endurance Time Matrix among Node to Node $[A_{ij}]$ $(A_{ij} = T_{ij}(t))$. It is a symmetric Matrix, whose diagonal elements are 0, and other elements which represent the endurance time of each connecting among UAV nodes are functions of the absolute time *t*.

When the distance between node to node is not bigger than the effective communication radius *r*, it can be considered that the two points- *i, j*- are kept in connection. Based on this principle, we can get the coordinates, moving speed, moving direction of each node in near-space network through ground controlling station planning, and then we can calculate the connection endurance time among node to node $T_{ij}(t)$ [11][12]:

$$T_{ij}(t) = \frac{-(ab+cd+ef)+\sqrt{(a^2+c^2+e^2)r^2+(ab+cd+ef)^2-(a^2+c^2+e^2)(b^2+d^2+f^2)}}{a^2+c^2+c^2}$$

In which,

$$a = v_i(t)\cos\varphi_i(t)\cos\theta_i(t) - v_j(t)\cos\varphi_j(t)\cos\theta_j(t)$$

$$b = x_i(t) - x_j(t)$$

$$c = v_i(t)\cos\varphi_i(t)\sin\theta_i(t) - v_j(t)\cos\varphi_j(t)\sin\theta_j(t)$$

$$d = y_i(t) - y_j(t)$$

$$e = v_i(t)\sin\varphi_i(t) - v_j(t)\sin\varphi_j(t)$$

$$f = z_i(t) - z_j(t)$$

$(x_i(t), y_i(t), z_i(t))$ and $(x_j(t), y_j(t), z_j(t))$ are coordinates of node *i* and *j*, respectively. $v_i(t)$ and $v_j(t)$ are average moving speeds, $\theta_i(t)$, $\theta_j(t)$ and $\varphi_i(t)$, $\varphi_j(t)$ are moving directions of nodes *i* and *j* respectively $(0 \le \theta_i(t), \theta_j(t) < 2\pi \ 0 \le \varphi_i(t), \varphi_j(t) < 2\pi)$.

• Nodes Degree Matrix $[B_{ij}]$ $(B_{ij} = B_{ij}(t))$. It is a column matrix in which each element is the function of absolute time *t* for the node degrees of each UAV nodes.

• The connection endurance time matrix between nodes and aerostats $[C_{ij}]$ $(C_{ij} = To_{ij}(t))$.It is an *n***m* matrix (*n* is the number of UAV nodes, *m* is the number of aerostats), $To_{ij}(t)$ is the peculiar circumstance of $T_{ij}(t)$ when one node among them is in static state.

b) Utilizing Optimizing Matrix to optimize the primary cluster, and then end clustering

Considering the cluster stability, ground clusters utilized three optimizing matrix to optimize the initial clustering result.

When clustering planning on the startup time $t=a$ of certain mission section, we need to consider the stability of initial clustering from $t=a$ to $t=a-m$ period of time. According to three optimizing matrixes, we conduct research on continuous function of relevant matrix element. If in most periods of time clusters are continuously changed because of certain node, the node will be kicked out of this cluster in advance. Then, the above process will be repeated every b period of time (b<m), but the updating of clustering planning is not necessary every time. To guarantee the stability of clustering, it only needs to update clustering planning when $t=a+n*b$ ($n$ is a natural number, depended on necessity).

c) Choosing the Cluster Head

According to the requirement of the clustering system performance and environmental circumstance of the network, we can calculate the weight matrix $[Q] =a*[A]+b*[B]+c*[C] +d*[E]$ (remnant energy matrix) ( a+b+c+d=1, and a>b,c,d) of each cluster, and adopt the relevant node of the largest $[Q]$ as the head of this cluster.

$[A]$ is connection endurance time element between nodes and nodes. The network is mobile, and the node which is selected to be the cluster head must reduce its influence on clustering structure during the process of mobility, so that it can reduce the control volume of business, and reduce the costs made by continuously established clusters and choosing cluster heads.

$[B]$ is the node degree element, which is mainly aimed at seeking the best trade-off between cluster number and average hops in clusters, and avoiding increasing the number of nodes in cluster rapidly while choosing the node that has the larger node degree as the cluster head, which may lead into the rapid reduction of throughput of each node in cluster and the seriously detrimental influence on the whole performance of system.

$[C]$ is the connection endurance time element between node and aerostat. Because the problems of how to connect into a large amount of disperse UAV nodes through limited accessing points are needed to be solved. Therefore, when choosing the cluster head, we should decide whether each cluster can make their cluster heads become the accessing points to the aerostats or not. If several cluster heads are not in the coverage areas of aerostats, it need to transmit information indirectly depend on other cluster heads.

After the choosing of cluster heads of each cluster, the clustering planning on ground is finished. Aerostats will send the clustering planning to UAV nodes. Then the proposed algorithm moves into section of cluster adjustment on air.

### *B. Cluster Adjustment on air*

#### *a Receiving ground clustering reference and interactively validating information*

The clustering reference information sent by the ground station is a list containing several lines, including the relevant information of all the $K$ clusters on air in a future mission period. The structure is shown in Table 1.

TABLE 1 CONSULT LIST OF CLUSTERING ON THE GROUND

| *L NO.* | *n LID* | *n MID* | *n MW* | *nCHT* | *n CHL* |
|---|---|---|---|---|---|

Where, *L No*. stands for the sequence number of the line (Line NO.), *n* LID stands for ID of the cluster head of cluster $n$ ($n=1...k$), *n MW* stands for the weight of largest weight algorithm of all members in cluster *n*, *n CHT* stands for the time when cluster *n* changed its state, *n CHL* stands for the line sequence number of the clustering information in the list after cluster *n* has changed its state

After receiving the clustering reference information on ground, UAV nodes will use the interactive confirm message with other nodes to decide how to utilize clustering reference on ground. The structure of this confirmed information is very simple, which is beneficial to save the bandwidth resources. It is shown in Table 2

TABLE 2 STRUCTURE OF CONFIRM MESSAGE

| *N ID* | *N CP* |
|---|---|

Where, *N ID* stands for ID of sending node N, *N CP* stands for whether the sending node moves conform to path planning, whose value is 0 or 1. *N CP=0* stands for moving conform to the path planning, while *N CP=1* stands for not conform to the path planning because of specific condition.

#### *b Clustering Communication According to the results of clustering reference on ground or real-time clustering*

When the UAV node M receives the acknowledgement message that the sending node N conforms to the path planning and N ID is in the ground clustering reference list n MID, the node M can communicate within its cluster and between different clusters according to ground clustering reference.

When the UAV node M received the messages that the sending node N does not conform to the path planning, the node M will send Wrong Message to ground selectively through aerostats, meanwhile UAV node N will report the changed path information to ground through aerostats. At this time, aerostats will selectively transmit Wrong Message to ground according to the magnitude of node N path changing. For the larger magnitude of the path changing, aerostats will transmit Wrong Message to ground and wait for the ground to update the ground clustering reference; otherwise, they will send Handle Message to node M after proper calculating and processing and directly update the ground clustering reference list of each moving node on air. If node N temporarily changes its moving path under specific condition, and returns to the former path after the mission completed, node N is considered with small magnitude of path changing; if it changes its path and does not return to the former one, node N is considered with huge magnitude of path changing.

If the magnitude of node N path changing is huge, we will do real-time clustering through communication with neighbor nodes according to the algorithm of “with member nodes leaving cluster” and “with new nodes joining into cluster” in the process of ground clustering, and then send the real-time clustering results to ground, to update ground clustering reference.

## III. Algorithm Simulations

For the aim of validating the correctness of Clustering Algorithm of UAV Networking in Near-space and superiority of performance, simulation experiment is performed in the scene which contains 2 aerostat nodes and 100 UAV nodes in the range of 800km*500km. In the simulation, we set the aerostat nodes to be immobile, and the distance between adjacent aero-stat noedes is 300km; For UAV nodes, we schedule their mission paths in advance, and set their moving speed to be 0.6 mach and transmission radius to be 150 km.

This paper compared the near-space clustering algorithm with traditional mobile self-organized network clustering algorithm which is directly available on air, and simulated for 100 times. The cluster size range are separately (5,15), (10,25), (15,35), (20,40). The average UAV nodes channel resource occupancy percentage $p$ of the proposed algorithm and traditional algorithm is:

$$p = \frac{\text{The average UAV nodes channel resource occupancy of near - space clustering algorithm}}{\text{The average UAV nodes channel resource occupancy of traditional mobile self - organized network clustering algorithm}}$$

Here, we define the channel resource average occupancy as the average percentage of the consuming channel resources of all the UAV nodes which are used to establish clusters and choose cluster heads occupying all the channel resource of that node.

The result was shown in Figure 3:

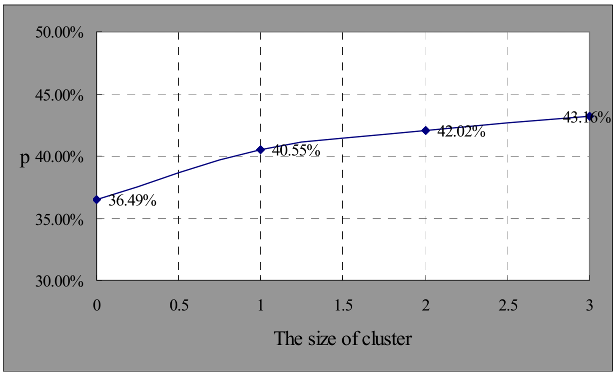


Fig.3 Contrast between two algorithms at average route resource occupancy

In fig.3, abscissa 0,1,2,3 stand for the cluster size of (5,15), (10,25), (15,35), (20,40) in correct order.

It is clear that the near-space clustering algorithm is apparently superior to the clustering algorithm of mobile self-organized network-oriented on air in the average occupancy percentage of channel resources, whose magnitude is around 40%. It saves the consumption of system resource at the cost of the data transmission of air-to-ground through path-planning information. Currently we can know that, with the accretion of cluster size, the information used for clustering confirming are interactively increased in clusters in the near-space clustering algorithm, and the information transmission for cluster reconstructing are increased. This may make the average occupancy percentage of UAV nodes channel resource increase a little, but cannot lead to rapid increase.

## IV. Conclusions

Utilizing near-space communication system which is an efficient approach to realize UAV networking, can effectively realize the networking management and relay transmission of UAV nodes, thereby solving the problems of poor capability of networking, efficient communication and over-the-horizon communication among UAVs. This paper aims at solving the key problem in near-space UAV networking---UAV networking clustering algorithm. It adopts the Space-Earth-Based integrated thought - “Calculate on the ground, Adjust in the space” to design a “Clustering Algorithm of UAV Networking in Near-space”. Then through the cooperated processing among the ground stations, aerostat nodes and UAV nodes, UAV clustering and networking in near-space environment can be achieved.

Through the simulation and validation, the average occupancy percentage of UAV nodes channel resources based on this algorithm is nearly 40% of that directly using the clustering algorithm of mobile self-organized network-oriented on air. This algorithm can effectively raise the stability and flexibility of near-space clustering, reduce the system costs, and guarantee the ability of dynamic networking of air nodes by reducing the calculation complexity of aerostats and UAV nodes. Also, the proposed solution can effectively realize clustering and networking of UAV high-speedy nodes with limited-computation in the near-space environment.

## References

[1] Ding Lijun, Hu Yinbiao. The Development and Trend of UAV[J], Winged Missiles, 1999(10):6～9. [In Chinese]

[2] He Yanfeng, The Military Applications of the Near-space Platform[J], Defence Science Technology, 2007,6: 32～35. [In Chinese]

[3] D. J. Baker, A.Ephremides. The architectural organization of a mobile radio network via a distributed algorithm. IEEE Trans. Comm. ,November 1981, COM-29(11):1694～1701

[4] C. R. L in, M. Gerla. Adaptive Clustering for Mobile Wireless Networks. IEEE Journal on Selected Areas in Communications, 1997,15(7):1265～1275.

[5] GERLAM, TSAIJ. Multicluster, mobile, multimedia radio network [J]. Wireless Networks, 1995,1(3):255～265.

[6] G. Chen, et al. Connectivity Based k-hop Clustering in Wireless Networks. Proceedings of the 35th Hawaii International Conference on System Sciences, June, 2002.

[7] A. D. Am is, et al. M ax-Min D-Cluster Formation in Wireless Ad-Hoc Networks. Proceedings of IEEE IN FOCOM ’2000, March 2000.

[8] R. Ramanathan, M. Steenstrup. Hierarchically organized, multihop mobile wireless networks for quality of-service support. Mobile Networks and Applications, 1996, 3 (1): 110～119.

[9] Wu Di, Li Qing. A Clustering Algorithm Based on Global Positioning System for Ad-Hoc Networks[J], Computer Engineering and Applications, 2005(14):138～152. [In Chinese]

[10] Yan Weimin, Wu Weimin. Data Structure[M], 1995,166～167. [In Chinese]

[11] Su W, Lee SJ, Gerla M. Mobility prediction in wireless networks. In : 21st Century Military Communications Conference Proceedings, Vol 1 ,2000. 491～ 495.

[12] Chellapa R, Jennings A, Shenoy N. A comparative study of mobility prediction in fixed wireless networks and mobile ad hoc networks. In:IEEE International Conferenceon , Vol 2 , 2003: 891～895.