RESEARCH ON INTER-SATELLITE COMMUNICATION SYSTEM OF FRACTIONATED SPACECRAFT

Qing Chen(1)**, Jinxiu Zhang**(2)**, Shengchang Lan**(3) **and Zhigang Zhang**(4)
(1)(2)(4) *Research Center of Satellite Technology, Harbin Institute of Technology, Mailbox 3012, No. 2 Yikuang Street, Harbin 150080, CHINA.+86-14745152519, qing.c.hit@gmail.com*
(3) *Department of Radio Science and Engineering, Aalto University, Espoo,02150. lansc1015@gmai.com*

Abstract: *Fractionated spacecraft has the limitation of energy on board, then energy saving strategy is of great importance. Besides, fractionated spacecraft is oriented with mission, and that its efficient completion of tasks should also be considered. This paper focus on the energy-efficient routing protocol., synthesizes the lifetime maximization routing algorithm and mission's demand strategy, and presents an intelligent energy-efficient strategy.*

Keywords: Inter-communication System, Clustering Algorithm, Fractionated Spacecraft.

1. Introduction

In recent years, extensive efforts have been lucubrated on fractionated spacecraft. As a fully functional spacecraft, fractionated spacecraft meets some challenges, such as frequent information exchange among sub-spacecrafts, dynamic variation of network topology, frequent link switching, short duration of effective routing time and etc. The wireless ad hoc network is a self-organized, peer-to-peer, multihop network without any fixed infrastructure. The properties of simplicity, fast deployment and strong survivability of the network make it capable of being used in fractionated spacecraft networks.

2. Improved Clustering Algorithm

Fractionated spacecraft is in some sense different from traditional Ad Hoc network, every sub-spacecraft's orbit is mainly fixed, which means every node in the network have the whole relative location model. To optimize network management, it is necessary for an appropriate clustering algorithm to maintain the network structure. So this paper propose a clustering algorithm to divided network into several parts with optimized neighbor set (ONS) and Minimum ID algorithm.

In the Minimum ID algorithm, the network is clustered according to unique ID of each node which is defined before the final topology is formed. The advantages of this algorithm are small amount of calculation, easy implementation, fast convergence. But in cluster maintenance stage, nodes frequently broadcast packets which increase the burden of entire network.

2.1 Optimized Neighbor Set

The figure below shows node A's neighbor node distribution, and the largest dotted circle is node A's transmission coverage with maximum power. When node A transmit data to C, if the situation meets $P_{AC} > P_{AB} + P_{BC}$, node B is power efficient neighbor and node C is power non-efficient neighbor.

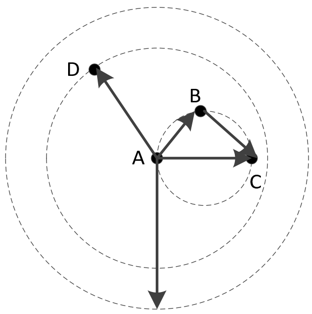


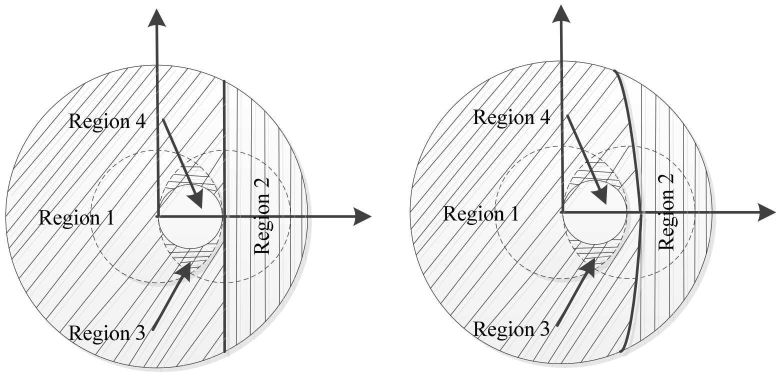
Figure 1 IEEE802.11 Power Non-efficient Diagram

Each node establishes its own optimal neighbor set (ONS), and the nodes in ONS meet the following conditions:

$$\forall j \in ONS(i), P_T(i, j) \le P_T(i,u) + P_T(u, j), u \in NS(i), u \ne j$$

Where, $P_T(i,u)$ means the minimum appropriate communication power, NS(i) indicates the neighbor set when transmission with largest power, and ONS(i) is optimized neighbor set.

Then, according to the geometric relations the maximum coverage of node i can be divided into four sub-regions, shown as the figure below.



$(a)\ P_R = O(P_T / d^2)$ $(b)\ P_R = O(P_T / d^4)$

Figure 8 Region Division of Node i Coverage

Therefore, when node i establishes the optimal neighbor set, it can arbitrarily choose a random neighbor node, exclude the corresponding node which also locates in region 2 out of ONS(i), then repeat the former step, and finally find the power efficient neighbor set.

2.2 Comprehensive Judgment Model

Due to the requirement of consideration of 3 essential factors whose weight is not the exact value, this paper introduces fuzzy comprehensive judgment model to evaluate the score of each node. Comprehensive judgment model is an mathematical model in fuzzy mathematics.

There exists three factors, according to the judgment of one object: the set of m factors: $U = \{u_1, u_2, \cdots, u_m\}$, the set of n scores: $V = \{v_1, v_2, \cdots, v_n\}$, when judging the factor $u_i (i = 1, 2, \cdots, m)$, from set U to V, it can get a fuzzy set $(r_{i1}, r_{i2}, \cdots, r_{in})$ based on V through a fuzzy mapping $f : U \to F(V)\ u_i \mapsto (r_{i1}, r_{i2}, \cdots, r_{in})$

Then, the judgment matrix R is

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{21} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & & r_{mn} \end{bmatrix}$$

In order to identify differences effects of each factor, the weight fuzzy set $A = (a_1, a_2, \cdots, a_m)$ is used to build the model as follows:

$$A \cdot R = B = (b_1, b_2, \cdots, b_n)$$

$$A = (a_1, a_2, \cdots, a_m), \ \sum_{i=1}^{m} a_i = 1, \ a_i \geq 0$$

$$R = (r_{ij})_{m \times n}, \ \ r_{ij} \in [0,1]$$

$$b_i = \sum_{i=1}^{m} a_i r_{ij}, \ \ j = 1, 2, \cdots, n$$

Where, b_j is the judgment function.

Comments V={cluster header, neutral, non-cluster header}, and $A_1(x), A_2(x), A_3(x)$ represent the membership function of "cluster header", "neutral", "non-cluster header".

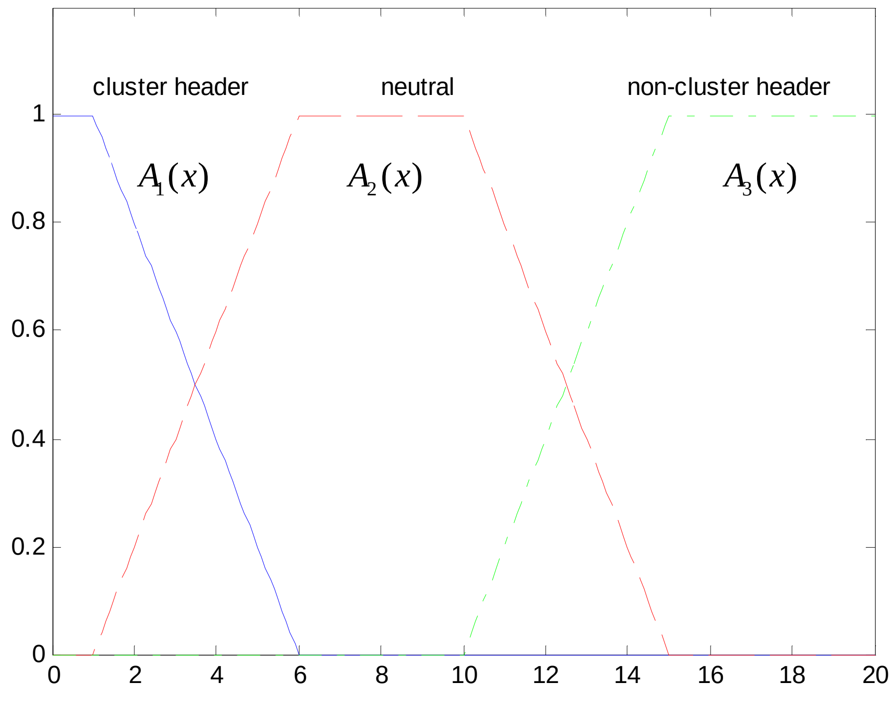


Figure 2 Node degree membership function

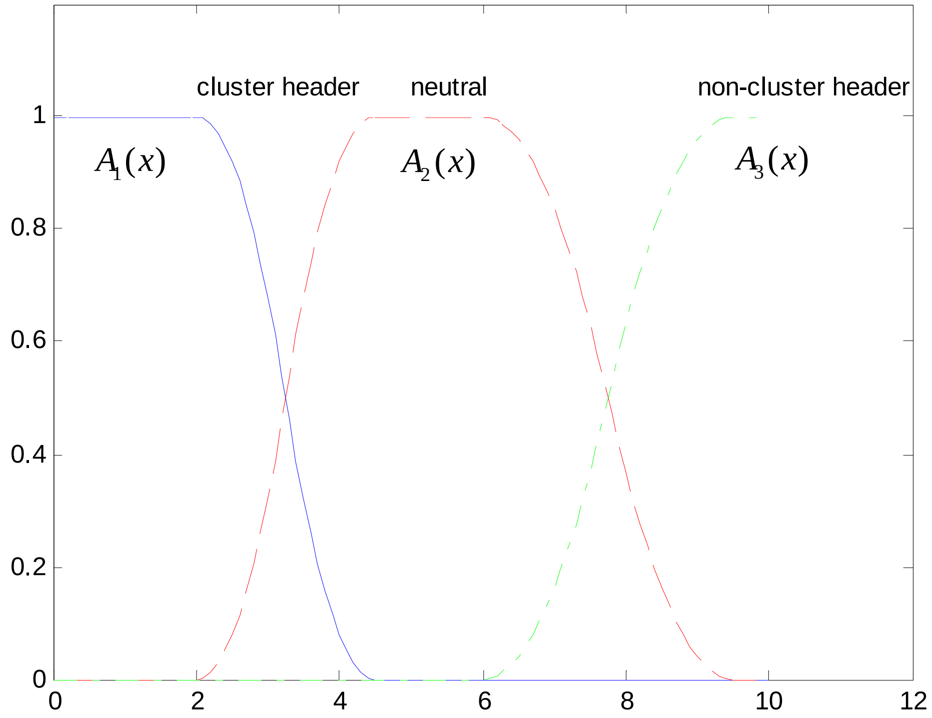


Figure 3 Energy consumption membership function

Suppose the score's vector of comments is $C=(c_1,c_2,\cdots,c_n)$ and then, the final score is

$$S=\frac{\sum_{i=1}^{n} b_i c_i}{\sum_{i=1}^{n} b_i}$$

2.2 Algorithm Structure

Compared to traditional weighted algorithms, that using the Minimum ID algorithm as the basic structure avoid a large number of weight calculation, and improve the efficiency of clustering. After the initial clustering, weight is calculated in each cluster and managed by the cluster header. This structure of algorithm make full usage of the sub-network in each cluster, decrease the network burden and ensure the whole network stability when the topology of the fractionated spacecraft is changed.

Then, the structure of improved clustering algorithm is as follow:

Step 1: distribute the integer number (starting with 1) to all the nodes, then divide the whole network into several clusters by using the Minimum ID algorithm.

Step 2: update every node's Optimized Neighbor Set. When the ONS updating timer come to the end, every node broadcast and receive the labeling signal.

Step 3: Calculate score of electing cluster header. By using the comprehensive judgment model, each node can get a score depend on the consideration of relative node degree and residual energy.
Step 4: Re-elect cluster header.
Step 5: Update member and gateway.
Step 6: Re-calculate the new time (period), then, repeat process 2~6.
Step 7: When topology of the nodes is changed, all the nodes are re-clustered through the Minimum ID algorithm.

3 Simulation

The topology of the Fractionated Spacecraft in our simulations is derived from the Simple and Compound Module concept of the OMNeT++ framework. The architecture of a Node is depicted in Figure 4. Each layer of the node is represented as a Simple Module of OMNeT++. The different layers of the Node have gates to the other layers of the Node to form the Node stack. A simple module with Wireless Channel functionality is used to communicate with these compound modules through multiple gates.

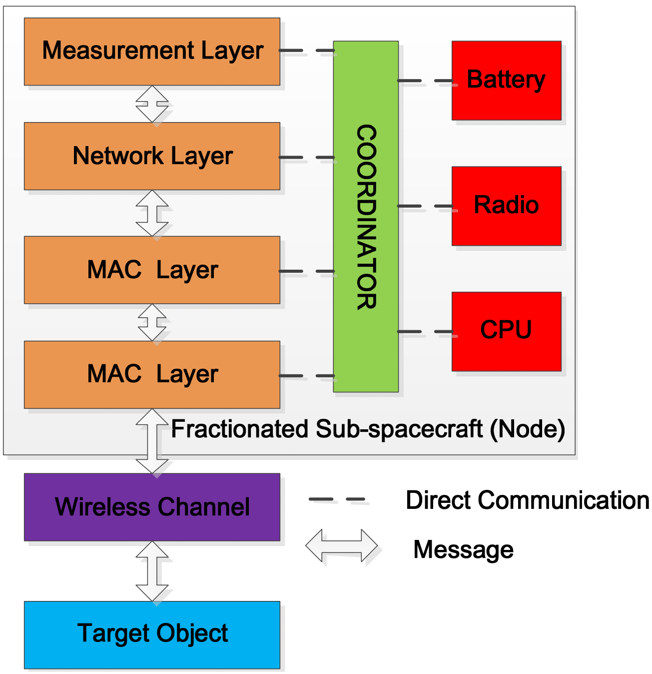


Figure 4 Basic Structure of the Node in Simulator Structure

In the $1000m \times 1000m$ area, it has 10 nodes, randomly distributed. Each node has a velocity of $15m/s$ The maximum transmission power is $200mW$, receiving sensitivity is $-84dBm$ and the attenuation index of radio propagation is 2. Then, the topologies are as follows:

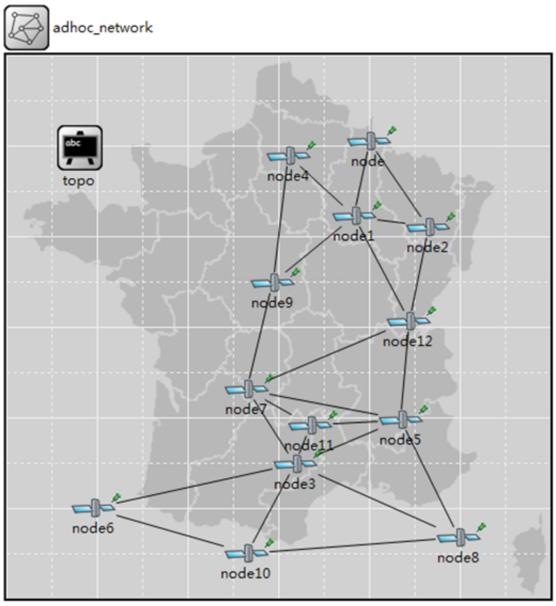


Figure 5 Full power topology

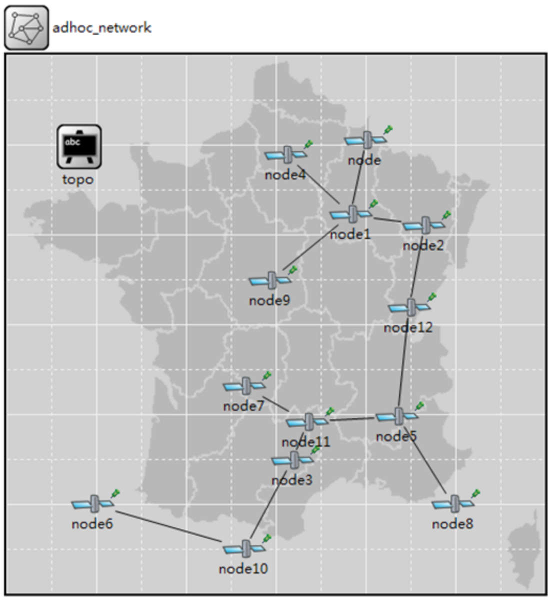


Figure 6 Improved clustering algorithm topology

After the realization fo simulation, results are shown in table 1 below.

Table 1 Received data by different clustering algorithm

Node (Target)	Received Data	Average	Variance
Minimum ID algorithm	65	1.754	0.593
Traditional weight clustering algorithm	83	1.761	0.811
Improved clustering algorithm	101	1.801	1.183

From the table above, the improved clustering algorithm shows the best performance and have the largest average and variance, highest data receiving rate. This illustrate the improved algorithm guarantee better connectivity and system's stability, compared to other algorithms in the same situation.

4. Conclusions

Fractionated spacecraft requires a new inter-communication network system. This paper focuses on the improved clustering algorithm which introduces the concept of ONS and comprehensive judgment model. Finally, this paper proposes the intelligent improved energy-efficient routing protocol and compared to other clustering algorithms, through simulation on OMNeT++, proves the better performance of the new algorithm, which means it meets the demand of fractionated spacecraft better. During the simulation, only energy consumption and node degree are considered and more work need to be done in the future.

5. Acknowledgments

The authors thank the great support from the national high technology research and development program (2013AA120603), and Research Center of Satellite Technology in Harbin Institute of Technology.

6. References

[1] C.Y. Chong, S.P. Kumar. Sensor networks: Evolution, Opportunities, and Challenges. Proceedings of the IEEE, 2003,91(8):1246-1256.

[2] K. Weniger and M. Zitterbatt, “Address autoconfiguration in mobile ad hoc networks: current approaches and future directions,” IEEE Network, pp. 6–11, Aug 2004.

[3] Yao Chen. Research on Topology Control Algorithm for UAV Ad Hoc Networks[D]. National University of Defense Technology of China. 2009.

[4] P. Karn, “MACA-A new channel access method for packet radio,” in Proceedings of ARRL/CRRL Amateur Radio 9th Computer Networking Conference, (London, Ontario, Canada), pp. 134–140, Sep 1990.

[5] Tianming Zhang. Research for Adhoc Networks Route Protocol[D]. University of Science and Technology of China. 2009.