Acta Technica 62 (2017), No. 6A, 321–328

Study for routing algorithm and coverage rate of nano-satellite constellation

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Abstract. According to the constellation of Nano-satellite has become development tendency. this paper studies its coverage rate and the routing algorithm for its high rate network in polar. The coverage rate of different orbit number is given. The routing protocol adapted to the high-speed network and the optimizing strategy are then illustrated. The coverage model of Nano-satellite constellation is established by sim tool kit and the high-speed network model of it is established by NS3 network simulation platform. The simulation results are shown, 12∗12 classic Sun-synchronous orbit (SSO) constellations has both a good coverage rate of three latitude area and a suitable economic cost. Optimizing routing algorithm for high rate network in polar reduces the routing overhead and optimizes the performance of the network.

Key words. Nano-satellite, coverage rate, constellation, high-rate network, routing overhead.

1. Introduction

Recent years, constellation network has become an important supplement and extension of terrestrial network due to its advantages of global seamless coverage, simple access and strong expansibility. For its low cost, small size, low power consumption, light mass, the Nano-satellite has gained wide attention. Its application is increasing. The constellation of Nano-satellite system has become development tendency. Several space demonstration tests and application studies have been carried out. Such as Flock-1 constellation [1], space Technology 5 constellation plan [2], it is hard to transmit data to the ground station from the Nano-satellite constellation in high rate data for that the resources of Nano-satellite are limited. To solve the problem, an effective scheme is to establish high-speed inter-satellite link to construct a high-speed network in polar regions, the data is routed to the satellites which will

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pass through the ground station in the high-speed network. Then the data collected on the satellites will download to the ground. Therefore, the coverage area and the routing policy in the high-speed network become the key point in the study of Nano-satellite constellation. Currently, there are few researches on microsatellite constellation, existing satellite network routing algorithm is mainly aimed at large satellite networks. WANG Z [3] studied Cross -layer design of codes for satellite multimedia broadcast. Jiang W et al [4] worked on multi-class traffic quality of service routing for low earth orbit (LEO) satellite networks. Agent-based load balancing routing for LEO satellite networks was researched by Rao Y et al [5]. Yao F et al [6] analyzed Satellite constellation of mid earth orbit (MEO) network. The application scenarios of the routing algorithm are the whole constellation. The study of the routing algorithm mainly aimed at Wireless Sensor Networks (WSN) [7]. The mainly routing algorithm used in the scenarios are Dynamic Source Routing(DSR) and Optimized Link State Routing (OLSR) [8]. While the study of Nano-satellite constellation mainly focuses on its coverage area and the routing strategy of the high rate network of cube sat cluster. CHEN Q et al [9] analyzed a taxonomy of energy efficiency strategies for cube sat cluster formation networks. Pratibha et al [10] observed the performance of OLSR and DSR Routing Protocols for WSN. This paper analyzes the coverage area of different conditions, studies the routing protocol adapted to the high rate network and, the deficiency of the protocol, provide the improved algorithm micro satellite constellation high rate transmission OLSR (MCHT-OLSR). Finally, the constellation with the best coverage rate is provided and the algorithm is fully validated by the simulation system.

2. Overview of coverage of Nano-satellite constellation

2.1. Coverage rate of Nano-satellite constellation

In the condition that the number of satellites in constellation is fixed, coverage area of the Nano-satellite constellation will be shifted as the orbit number and orbit inclination angle transformed. The factors to consider in the design of Nano-satellite constellation include the configuration of the networks satellite, the number of the orbit, and the number of satellites in each orbital plane. When the total number of satellites are fixed, the number of orbital planes and the number of satellites in each orbit are inversely related. In the condition that the number of satellites in constellation is fixed, coverage area of the Nano-satellite constellation will be shifted as the orbit number and orbit inclination angle transformed. In the next part, this paper will discuss the coverage area of the constellations under different conditions.

To analysis of Nano-satellite constellation coverage objectively, should divide the earth into low latitudes region ($-30° \sim 30°$), middle latitude region ($-30° \sim -70° \cup 30° \sim 70°$), and the high latitude region, ($-70° \sim -90° \cup 70° \sim 90°$). Since most of the world's population lives in the middle and lower latitudes, global uniform coverage takes precedence. Economic factor is another factor should be taken into consideration. As the number of satellite orbit increases, so does the cost of launch. Presuppose that the height of the orbit is 600 km. Take the classic homogeneous constellations as an example to analysis the coverage area in orbit inclination angle. Simulation of coverage area of different orbit number is done by SIM TOOL KIT (STK). In the condition of fixed number of network satellites, the coverage of the area will tend to be better as the orbital increases. Taking 144 satellite constellations as an example, studies the effective on coverage by different orbit.

The coverage rate of the Nano-satellite constellation over different orbit is shown in Fig. 1.

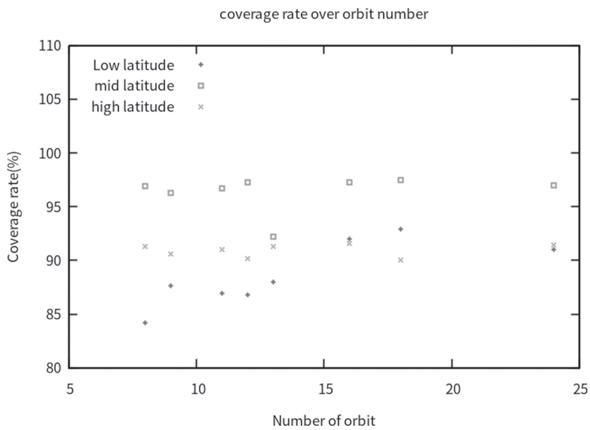

Fig. 1. The coverage over number of orbit

That means in the condition of fixed number of network satellites, the coverage of the lower latitudes will tend to be better as the orbital increases. However, as the number of satellite orbit increases, so does the cost of launch. Synthesizes all the factor above, $12 * 12$ classic SSO constellations has both a good coverage rate of three latitude and suitable economic costs.

2.2. Routing protocol for high rate network

The network in the polar region of $12 * 12$ SSO constellation is similar to Ad-hoc network, the network topological changes regularly and low infrequently. The resources on the Nano-satellite are limited. Therefore, best fit for the high rate network is Ad-hoc table-driven OLSR.

OLSR protocol needs to periodically send Hello messages and TC messages [11], the former is used to get next hop neighbor node and second hop neighbor node information to confirm MPR [12]. The later is used to maintain the routing information of the entire network [13]. When data need to be transmitted, the routing information is already available, whence there is no additional routing overhead [14]. In the condition ignoring frame collisions and various types of withdrawal, the routing overhead of OLSR is only related to network topology, sending interval of Hello ($Hello\_Int$), sending interval of TC (TC_Int), and node number of the network [15]. Suppose average number of the TC message relayed by the MPR is MPR_Num, the simulation time is set to Sim_Time, the number of Hello message is.

$$Num\_Hello = \frac{Sim\_Time}{Hello\_Int} \tag{1}$$

Since TC messages need to be relayed MPR_Num times, the TC message relayed by one node is

$$Num\_TC = \frac{Sim\_Time}{TC\_Int} \times MPR\_Num \tag{2}$$

When total number of nodes in the network is $Ntotal$, the routing overhead of OLSR ($OLSRoverhead$) is:

$$OLSR_{overhead} = \left(\frac{Sim\_Time}{Hello\_Int} + \frac{Sim\_Time}{TC\_Int} \times MPR\_Num \right) \times N_{total} \tag{3}$$

3. Advanced method

This paper provides an optimized routing protocol Nano-satellite constellation high rate transmission OLSR (MCHT-OLSR) apply to the high rate network. MCHT-OLSR changes the transmit method of Hello and TC message to reduce the overhead of routing protocol and enhance network performance. MCHT-OLSR confirms the network topology state of the node by the change of node's link set and MPR selector set. MCHT-OLSR adds a parameter score of link stability (SS) and score of MPR (SOM) in the protocol. The interval time of sending Hello in OLSR is defined to be a constant value ($Hello\_Interval$), MTCH-OLSR set Hello_Int to Hello_min when the link set is changed. And it set $Hello\_Int$ to $Hello\_c$ when hello message is sended. This paper set that $Hello\_\min = Hello\_Interval \times 0.5$, and $Hello\_c = Hello\_\min + SS$. $Hello\_c \leq Hello\_\max$, while $Hello\_\max = Hello\_\min \times 10$. In a similar way, this paper set that $TC\_\min = TC\_Interval \times 0.5$, and $Hello\_c = TC\_\min + SOM$. $TC\_c \leq TC\_\max$, while $TC\_\max = TC\_\min \times 10$. Considering the possibility of communication failure during the interval of sending a Hello or TC message, the interval in MCHT-OLSR may be greater than the actual expected value. Therefore, the protocol adds a buffer mechanism to the interval calculation. The calculation formulas are given as follow:

$$Hello\_Int = \begin{cases} (Hello\_\min + SS) \times 0.8 + Hello\_last \times 0.2 \, (0 < SS < Hello\_\max) \\ Hello\_\max \, (SS > Hello\_\max - Hello\_\min) \\ Helllo\_\min \, (SS = 0) \end{cases} \tag{4}$$

In the formula, $Hello\_last$ means the $Hello\_Int$ of the previous Hello message.

$$TC\_Int = \begin{cases} TC\_\min(SOM = 0) \\ (TC\_\min + SOM) \times 0.8 + 0.2 \times TC\_last\,(0 < SOM < TC\_\max) \\ T_{\max}\,(SM > TC\_\max - TC\_\min) \end{cases} \quad (5)$$

In the formula, TC_last means the TC_Int of the previous TC message. When all nodes in high rate network satisfy the conditions that SOM>0, SS>0, then the routing overhead will be:

$$OLSRoverhead = \frac{Sim\_Time}{(Hello\_\min + SS) \times 0.8 + Hello\_last \times 0.2} \times N_{total} + \frac{Sim\_Time}{(TC\_\min + SOM) \times 0.8 + TC\_last \times 0.2} \times N_{total} \quad (6)$$

When all nodes in high rate network satisfy the conditions that SOM=0 and SS=0, then the routing overhead will be:

$$OLSRoverhead = \frac{Sim\_Time}{Hello\_\min} \times N_{total} + \frac{Sim\_Time}{TC\_\min} \times MPR\_Num \times N_{total} \quad (7)$$

4. Results and discussion

Based on simulation, the average throughput rate of the network is show below:

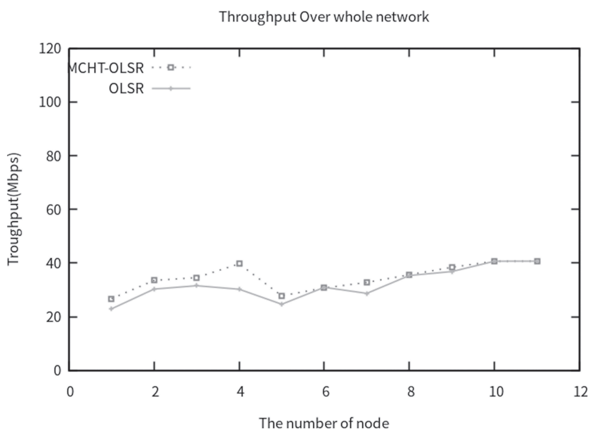

Fig. 2. Effect on Throughput of MCHT-OLSR

Fig. 2 is a diagram of the total throughput of MCHT-OLSR and OLSR algorithm when different nodes chosen as source node. When node 4 become the source node, the improvement on throughput reaches max when MCHT-OLSR is used. While node 11 become the source node, the improvement on throughput reaches minimum. The simulation results show that the average throughput rate of the network is improved when the node adopts the MCTH-OLSR protocol.

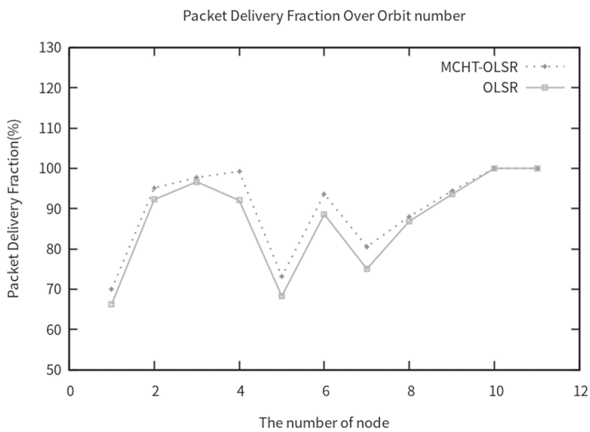

Fig. 3. Effect on packet delivery of MCHT-OLSR

Fig. 3 is a diagram of the total throughput of MCHT-OLSR and OLSR algorithm when different nodes chosen as source node. Accounting to the figure above, it is shown that the packet delivery of MCHT-OLSR is higher than the original one. The message flooding of MCHT-OLSR and OLSR algorithm is shown in the figure below:

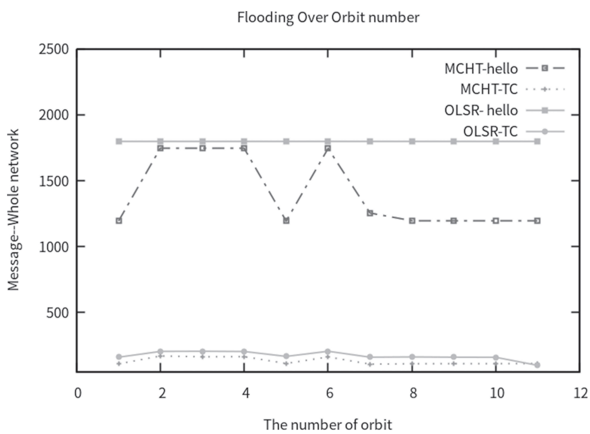

Fig. 4. The message flooding of the two protocol over time

In Fig. 4, simulation results show that routing overhead has been significantly reduced compared to OLSR, while the MCHT-OLSR is used. In the meantime, the entire performance is slightly optimized for that the throughput and the packet delivery ratio is improved than OLSR.

5. Conclusion

This paper analyzes the microsatellite constellation and the high rate network of the constellation in polar. It focuses on studying the coverage rate of Nano-satellite constellations and the routing protocol of the high rate network of $12*12$ SSO model. The routing protocol adapted to the high-speed network and its optimized strategy MCHT-OLSR are illustrated. According to the simulation result by STK and NS3, $12 * 12$ classic SSO constellations has both a good coverage rate of three latitude area and a suitable economic cost. MCHT-OLSR routing algorithm used in high rate network reduces the routing overhead significantly. Meanwhile it optimizes the performance of the network by improves the throughput and the packet delivery ratio.

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Received November 16, 2017