A Review of Routing Algorithms Based on Multi-Layer Satellite Networks

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Abstract. Compared with single layer satellite network, satellite distribution of multi-layer satellite networks in the double layer or multilayer orbital plane, combines all the advantages of engaging subjects of the satellite, therefore contains its low vulnerability, good robustness, high stability, high spectrum efficiency and system throughput, channel characteristics such as large capacity, in the satellite network is a very promising direction. Multilayer satellite network also has some inevitable disadvantages, that is, the number of nodes and the number of links is large, so it has the characteristics of frequent changes in network topology, which requires higher routing algorithm. There are many researches on routing algorithms based on multi-layer satellite networks at home and abroad. This paper introduces the general situation of multi-layer satellite network, classifies the existing routing algorithms of multi-layer satellite network according to different standards, analyzes several typical routing algorithms in detail, points out the advantages and disadvantages, and summarizes the future development trend.

1. Introduction

With the rapid development of the Internet, the expansion of human communication range and the rapid increase of network communication service data, the ground communication network is not enough to meet the growing needs of people. The satellite network can not only make up for the incomplete coverage of the ground network, but also provide basic services for emergency communication, reduce the unreliability of communication services and create favorable conditions for personnel rescue. Therefore, as a supplement to the ground network, satellite network communication has been widely concerned in recent years. Compared to traditional ground communication network, satellite network communication system has smaller ground limit, flexible networking, wide coverage, high reliability and good service quality in certain circumstances, can use the link bandwidth higher many advantages, through the network of satellite system can achieve full coverage of the surface of the earth, to the global users with reliable communication services. A satellite network consists of several satellites in different orbits. It includes various types of constellations, such as GEO(Geostationary Earth Orbit), MEO(Medium Earth Orbit), and...
LEO (Low Earth Orbit). In the study, we divide them into two categories: single-layer satellite network and multi-layer satellite network.

Specifically, the multi-layer satellite network makes the whole network more flexible, diverse and more resistant to destruction through the intersecting of satellites between different layers.

2. Multi-layer satellite network system

Multilayer satellite network usually consists of LEO satellites, MEO satellites and GEO satellites. According to the current research status, the major network structures include LEO/MEO two-layer satellite network [1], LEO/GEO two-layer satellite network [2-3] and LEO/MEO/GEO three-layer satellite network [4].

As shown in Figure 1 below, we can divide the network into two autonomous regions: the ground network and the satellite network. The ground network is connected to the satellite network via low-orbit communications, with the UDL line. Multi-layer satellite network has the advantages of each layer of satellites, and satellites in different layers cooperate with each other to make the overall performance of the network more powerful. Specifically, the multi-layer satellite network makes the whole network more flexible, diverse and more resistant to destruction through the intersecting of satellites between different layers.

The GEO layer has only one geosynchronous orbit with a single satellite evenly distributed. There are $N_G$ orbits in the MEO layer, and there are $N_M$ satellites in each orbital plane at equal intervals. There are totally $N_M \times M_M$ MEO satellites. The number of orbits in LEO layer is $M_L$, and the number of satellites in each orbit is $N_L$, so that there are all $N_L \times M_L$ satellites, and the number of satellites in different layers is satisfied $N_G \ll N_M \times M_M \ll N_L \times M_L$. There are two kinds of full-duplex links in the backbone of multi-layer satellite network. One is IOL, which is responsible for connecting GEO, MEO and LEO satellites and undertaking the task of information interaction between layers. The other is ISL, which is responsible for data interactions between satellites in the same layer.

![Fig.1 Multilayer satellite network architecture](image)
Taking LEO satellite constellation as the backbone network and combining with the architecture of medium and high orbit satellite diversion control has many advantages. It is the main research direction of the future satellite communication network. How to make use of the advantages of each layer of satellites to achieve reasonable traffic distribution and improve the throughput of the whole network is one of the key contents of routing algorithm research in multi-layer satellite networks.

3. Research on routing algorithm of multilayer satellite networks at home and alive

The design of inter-satellite routing protocol for multi-layer satellite network must fully combine the characteristics and advantages of satellite network to overcome the difficulties of inter-satellite routing implementation caused by the complexity of space-based environment. At present, the research on inter-satellite routing protocols for multi-layer satellite networks at home and abroad, on the basis of various multi-layer satellite network structural models, different inter-satellite routing protocols are proposed for different network structural models. HSRP [5] (HSRP: Hierarchical Satellite Routing Protocol (Hierarchical Satellite Routing Protocol) is proposed on the basis of LEO/MEO two-layer constellation network structure model, as shown in Fig. 2. The specific process is as follows: Firstly, each LEO satellite node sends HELLO packets periodically to each other to obtain the topology state information of its neighbor nodes. Secondly, through the interlayer link between LEO satellite and MEO satellite, the obtained neighbor node topological state information is sent to MEO satellite. Then, MEO satellites interact with each other to collect the topological state information of LEO satellites, so that the topological structure information of all LEO satellites can be obtained and sent to each LEO satellite. Finally, each LEO satellite calculates its own routing table after receiving the topological structure of the whole network.

![Fig.2 HSRP inter-star routing protocol](image-url)
Bayhan et al. [6] proposed a QoS (Quality of Service) Routing Protocol ARPQ (Adaptive Routing Protocol for Quality of Service) for LEO/MEO double-layer satellite networks. This algorithm mainly provides QoS guarantee for time-sensitive services such as VoIP (Voice Over Internet Protocol). The main method is to conduct layered transmission and dynamic routing adjustment according to transmission delay and detected link queue utilization rate. This algorithm can provide better QoS for time-sensitive services. But the system overhead is too high.

In recent years, many traffic balancing technologies have been proposed for multi-layer satellite networks. For example, Y. Kawamoto et al. [7], in order to effectively solve transmission congestion, divided data packets into three categories according to different real-time performance, and set different routing mechanisms for each data type, which can well control packet loss rate and improve network throughput. Audah. L et al. proposed a traffic balance technology for LEO/MEO network[8], which optimized the link utilization through multi-path forwarding, and controlled the forwarded data by using the queue access system and combining with the current link information to avoid network congestion.

The Satellite Dynamic Routing Protocol (SDRP) proposed by Tuo Yanjun et al. [9] belongs to Dynamic Routing, which is also targeted at LEO/MEO Satellite network and has the capability of independent operation. It is a Routing algorithm based on virtual topology. Improve the utilization rate of network resources.

Yang Li and Yang Xiaochun et al. [10] proposed a routing algorithm VLRA based on GEO/LEO double-layer satellite network. The improved time virtualization strategy reasonably divided the operation cycle of satellite network and effectively solved the problem caused by too short time slice. The GEO/LEO layer satellite network is effectively managed by the layered management strategy. The satellite network begins to collect link-state information for routing calculation and updates in each time slice. The simulation results show the optimization results of the improved time virtualization strategy. The new algorithm has stable end-to-end delay. When the network load increases, compared with SPF and SGRP algorithms, it has lower packet loss rate and better throughput performance. Aiming at the frequent interruptions of inter-satellite links and long end-to-end delays caused by the time-varying topology of satellite networks, Zhang Taijiang and Li Yongjun et al. [11] carried out hierarchical clustering design on the GEO/LEO two-layer satellite networks and proposed an optimized temporary sequential routing algorithm HCR. In the LEO layer, HCR algorithm is used to establish multiple non-cyclic paths from the source satellite to the destination satellite. In the case of network congestion in the LEO layer, satellites in the GEO layer are used to realize layered data transmission. Compared with the traditional algorithm, the reliability and flexibility of satellite network management are improved. Wei Debin, Liu Jian et al. [12] proposed a multi-constraint QoS routing algorithm for satellite networks. By improving the heuristic function of ant colony algorithm, the link QoS information is taken as an important basis for the ants to select the next hop node, and the pheromone updating rules are optimized by combining the sorting idea and the maximum and minimum ant algorithm to obtain the optimal QoS path in line with the current service.

If Akyildiz proposed that MLSR[13](MLSR: Multi Layer Satellite Routing) inter-satellite routing protocol was proposed for LEO/MEO/GEO three-layer satellite network structure, as shown in Figure 3. The protocol uses the abstract idea of grouping to divide virtual topology. We can clearly see the characteristics of satellite coverage layer by layer from the figure, so we group the satellites of MEO layer and LEO layer, and then take the corresponding high-level satellites of GEO and MEO as group managers. At present, there are two commonly used selection methods for group
Managers. One is to select the high-level satellite with the shortest distance as the group manager based on the distance standard, and the other is to select the high-level satellite with the longest coverage as the group manager. This grouping method makes the calculation of routing table need the support of the data of the routing table of the satellite of the upper layer, so the data are calculated step by step and then sent to the next layer of satellite group.

![Fig.3 MLSR inter-star routing protocol](image)

TDRP[14-15] (TDRP: Time Division Routing Protocol) is also proposed for LEO/MEO/GEO three-layer satellite network structure, and it also uses the abstract idea of grouping to partition the virtual topology. As shown in the figure below, is the implementation framework of TDRP algorithm. It can be clearly seen that this algorithm is layered and relatively independent, so this algorithm can save a lot of time. Among them, the calculation of routing table of GEO layer is completely independent, and the routing tables within and between groups of MEO layer and LEO layer need the support of network topology and all kinds of connection data. In addition, the data support of the upper layer is also needed. Finally, the routing table calculation of each layer is completed on the star, and the routing table is sent to the respective group members.
Fig. 4 TDRP inter-star routing protocol
For satellite-ground integrated network, Zhang Hao and Wang Chunfeng[16] proposed a delay constrained routing algorithm (DCRM-CP). This algorithm establishes the contact topology between the satellite nodes and improves the performance of the satellite network compared with the traditional routing algorithm. Xu Huixiu and Li Deshi et al. [17-18] proposed a hybrid routing algorithm based on the Earth–satellite integrated network, which can predict the transmission delay of the satellite network and has good performance in terms of end-to-end delay and throughput.

4. The development trend
At home and abroad, the routing algorithm of satellite network has been deeply and extensively studied, but at the same time, the existing problems of routing algorithm of satellite network should also be found. The mechanism of pre-calculating and storing routing tables based on system cycle segmentation takes up a lot of storage space, requires the existence of central nodes, and has poor damage resistance. Once there is a link or node failure, the network performance will decline significantly, and the routing table cannot be dynamically constructed according to the change of network business traffic. The routing algorithm based on coverage region division and the routing algorithm based on virtual nodes require a very regular topology structure of the satellite network, which is only applicable to the satellite network in polar orbit, and cannot solve the problem of network performance degradation caused by the topology changes caused by satellite and link failures. Data-driven routing algorithms are often designed for specific satellite constellations, which are not universal and have poor performance under high load. Therefore, according to the characteristics of satellite network, the design of low cost, adaptive and high reliability of QoS satellite routing algorithm still needs further research.

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