A Review on Routing Algorithms for Lower Earth Orbit Satellite Networks

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Abstract - *Satellite networks play a crucial role in connecting people and providing communication and information services to remote areas where other forms of communication may not be available. Low Earth Orbit (LEO) satellite networks consist of large number of satellites orbiting the earth at a low altitude, between 1,200 to 2,000 kilometers. These satellites provide near-global coverage and are used for various applications, including global communication, navigation, and remote sensing. A review of various routing algorithms for LEO satellite networks is presented in this paper. Design and implementation of routing algorithms can have a significant impact on the performance and reliability of these networks. In LEO satellite networks, routing algorithms must take into account several unique challenges, such as the dynamic and changing nature of the network, the limited bandwidth and processing power of the satellites, and the high latency and low data rates associated with communication over large distances.*

Key Words: Satellite Networks, Routing Algorithms, Lower Earth Orbit Satellites, Bandwidth, Data Rates, Software Defined Routing, Inter-Satellite Link, Dijkstra's Algorithm

1. INTRODUCTION

Advancements in technology has played a significant role in improving the standard of life of people, thereby increasing the demand on living environment. People all around the globe are using a vast multitude of smart devices, which in turn poses high demands for broadband internet connectivity. As a result, satellite networks are becoming an increasingly important part of the global communication landscape. Satellite networks are found to have various application areas like Telecommunications, Broadcasting, Internet Connectivity, Remote Sensing, Navigation, Military and Intelligence etc. Since LEO satellites are closer to the earth's surface, they can provide lower latency and higher bandwidth compared to geostationary satellites. This makes them well suited for applications such as broadband internet connectivity, which requires low latency and high bandwidth.

Routing algorithms play a critical role in LEO (Low Earth Orbit) satellite networks. They determine the best path for data to travel from its source to its destination, which is essential for ensuring efficient and reliable communication in the network. In LEO satellite networks, routing algorithms must take into account several unique challenges, such as the dynamic and changing nature of the network, the limited bandwidth and processing power of the satellites, and the high latency and low data rates associated with communication over large distances. Some of the key reasons for the importance of routing algorithms in LEO satellite networks are Dynamic Network Topology, Bandwidth and Processing Limitations, Latency and Data Rates, Energy Efficiency etc.

Routing algorithms, being a critical component of LEO satellite networks, has a significant impact on the performance and reliability of the network. Several factors like congestion, reliability, scalability, cost, security etc. need to be considered while choosing a routing algorithm, which makes it a complex decision. The choice of right routing algorithms can help LEO satellite networks meet the growing demand for global communication and information services in remote or inaccessible areas.

2. LITERATURE SURVEY

By gathering and referring to several benchmark studies, a literature review was undertaken.

The 'Link Reversal' technique was proposed by Dongni Li et al. [1] as a distributed dynamic routing system for LEO and MEO satellite networks. In this case, the main objective is to optimize the routing strategy by taking into account the periodicity and predictability of the satellite movement, which aids in automatically modifying the routes to avoid the problematic links when certain ISLs abruptly shut down. It is anticipated that every satellite node maintains a Destination Oriented Acyclic Directed Graph (DOADG), listing all other satellite nodes in the graph together with itself as the destination satellite. The ADG is changed to always be destination oriented when certain ISLs become invalid, allowing for dynamic routing. Compared to off-line routing algorithms, the primary benefit of the link revision method is its ability to automatically modify routes based on changes in topology and avoid problematic links, resulting in reduced packet overhead and quicker convergence.

Jiang Wenjuan et al. [2] proposed a connection-oriented routing algorithm for Lower Earth Orbit satellite networks. This algorithm considers both Inter-State Links (ISLs) and

Up-Down Links (UDLs), thus splitting the routing problem into 2 parts - ISL routing and UDL routing. The routing algorithm used here is the Dijkstra's Algorithm. Distance is chosen as the factor to determine link cost in UDLs' routing whereas traffic distribution is considered in the ISLs' routing and it's cost function is devised. Simulation of this algorithm in OPNET, with Iridium Network System, provided continuous communication with inter-satellite handoffs or inter-orbit handoffs.

Zhian Yang et al. [3] proposed a LEO satellite network routing algorithm based on dynamic clustering, called as Dynamic Clustering Routing Algorithm (DCRA). A dynamic clustering strategy is chosen here to dynamically adapt to the continuously dynamically adapt to the constantly changing topology and lower the cost of processing and storage in LEO satellites. Routing process is carried out after the formation of cluster centers and consists of both inter-cluster and intra-cluster routing. Simulation of this algorithm in OPNET showed that it is effective and adaptive, and can save memory.

An Ant-Colony optimization based routing algorithm, with cross layer architecture for Low Earth Orbit satellite networks was proposed by Wang Houtian et al. [4]. With cross-layer optimization, it is possible to integrate the layers of the protocol stack into a comprehensive classification framework, which helps meet the requirement of QoS in broadband satellite networks. Between the network's source and destination, mobile agents, like ants in the ant-colony system, move from one node to another to look for feasible routes and other useful information. Ant colony optimization introduce minimum bandwidth constraint and this will balance the traffic load.

Yilun Liu et al. [5] proposed a sub-optimal routing algorithm called Approximate Optimal Routing Algorithm (AORA), based on network topology for massive LEO satellite networks. Here, the source and destination gateway positions are used to determine the topology of the local network, and the number of satellites and gateways required to create the Dijkstra's algorithm's correlation matrix is reduced. The Dijkstra's algorithm's sub-correlation matrix is established by the location relationship between the source and destination gateways. Based on the source and destination gateway locations, to select a set of gateways and identify the satellites with which they can communicate, renumber the gateways and create the sub-correlation matrix. The main correlation matrix is used to determine the value of the sub-correlation matrix. The values of the matrix are updated in real time in response to network traffic conditions to select the best load balancing route. The use of sub-correlation matrix helps to reduce the computational complexity of Dijkstra's algorithm.

Yonghu Zhu et al. [6] proposed Software Defined Routing Algorithm (SDRA) in LEO Satellite Networks. The key idea is to use software-defined networking (SDN) to divide the satellite network into control and data plane. Through a standard interface between the controller and satellites, the SDN architecture allows for flexible management and configuration of the network resources. In order to implement distributed control and centralized management of the entire network in real time, a software defined satellite networking architecture with a master controller and several slave controllers is created. As switches, the satellites only have to forward data in accordance with the flow table and notify the controllers about the network status. Calculating routing is the responsibility of controllers. Through fine-grained centralized management of the satellite network, the controllers can select the best routing path and enhance the network's QoS performance. The proposed algorithm has improved performance in terms of end-to-end delay, packet dropping probability, and network throughput in addition to achieving a better traffic distribution and reduces the queuing delay by nearly half.

A load-balancing segment routing technique for traffic return in LEO satellite networks was proposed by Wei Liu et al. [7]. The light and heavy load zones are split in this manner dynamically based on the relative position relationship between the gates and the reverse slot. In order to reduce congestion and increase network throughput, various zones employ different routing rules. Routing rules are based on the minimum weight path as determined by the congestion index in the heavy load zone and the pre-balancing shortest path algorithm in the light load zone. Following that, segment routing is used to implement consistent forwarding in every zone. While the heavy load zone's routing strategy differs from the light load zone, one of the outermost circle satellite nodes inside the heavy load zone is included in the routing pathways of the satellite nodes that pass through it. Nodes on satellites only travel through the high load zone; they never go through the light load zone. The suggested approach demonstrated improved load balancing performance when it was implemented on the LSN with varying traffic distributions, unit service values, and sizes.

Lu Zhang et al. suggested a routing algorithm based on connection status information for LEO satellite networks [8]. The suggested algorithm is divided into three stages: the phase for establishing the topology, the phase for calculating routing, and the phase for responding to link failures. Information about the satellite link state and logical topology is gathered via hello packets. In order to compute the proper routing in real-time, one can ascertain the hop count, direction, and priority of both horizontal and vertical transmission by combining the logical topology with actual location data. A deluge of satellite failure data is transmitted, enabling the transmitting satellite to choose the best backup route in case of an outage. This guarantees, in the event of a link failure, a smaller end-to-end delay, a higher delivery rate, etc.

Jiang Liu et al. [9] load balancing routing strategy for LEO satellite networks by using a Selective Iterative Dijkstra's Algorithm (SIDA). A Selective Shunt Load Balancing strategy (SSLB) is proposed to solve the link congestion problem in low latitude LEO networks. This strategy diverts the traffic flow into the congested nodes to the neighboring nodes. Using SIDA, load balancing at initial stage of routing can be obtained and SSLB helps to deal with sudden link congestion. SIDA is an optimization algorithm which changes the traversal mode in Dijkstra's algorithm, from positive order to reverse order. After a link congestion, the traffic of the congestion node is shunted to the neighbor nodes using SSLB. This method improves link utilization and reduces the average number of congested links.

A reinforcement learning-based LEO satellite network routing algorithm was presented by Xiaoting Wang et al. [10]. Reinforcement learning uses iterative learning to assist the satellite node in determining the best transmission path in the absence of any prior knowledge about the network architecture. Here, the Q-Learning algorithm for reinforcement learning is applied. A Q-table is constructed for each of the satellite's periodic motions. During transmission, the Q-table is contained in the data packet. The satellite node selects the next hop transmission node based on the Q-table and neighbor information. The neighbor's details are provided via the hello packet, which exchanges messages with the nearby satellite node. The Q-table carried by the data packet contains the learning data that is recorded during the learning process. It is discovered that the enhanced algorithm has superior convergence time than the traditional algorithm.

Chaoying Dong et al. [11] came up with the idea of a load balancing routing algorithm based on extended link states in LEO constellation network. Here, the basic idea is to combine congestion avoidance along with expansion of the range of available paths. The load balancing routing algorithm based on extended link states (LRES) always select the optimal path, thus reducing the congestion probability. A dynamic congestion threshold setting mechanism is used, which can adapt based on traffic load. Finally, in case of link congestion, the proposed method uses a status notification and rerouting mechanism. These strategies help to avoid the problem of balancing the traffic load and network congestion.

Chenxi Li et al. [12] suggested knowledge graph aided network representation and routing algorithm for LEO satellite networks. This method optimizes path selection and reduces calculation cost with the aim of achieving lower packet loss ratio and average delay. The control plane, which consists of multiple LEO and GEO satellites, is equipped with a knowledge graph structure. With the use of a knowledge graph, the control plane computes routing policies and recognizes the dynamic topology based on NRL. The data plane's LEO satellites simply need to maintain the flow table, which is carried out in accordance with the controller's policy. They are not required to calculate routes. The control plane, which may abstract and model the network nodes, connections, and data packets, is then used to execute and compute the routing algorithms. A master controller of the GEO satellite and numerous slave controllers of LEO satellites is used to update routing paths more effectively and operate the network more flexibly.

3. COMPARATIVE ANALYSIS

A comparison of different routing techniques for LEO satellite networks is done on the basis of the algorithms used and their advantages.

Table -1: Comparative Study of Routing Techniques

S.No.	Authors	Proposed Method	Advantages
1.	Dongni Li et. al [1]	Link Reversal Algorithm using Destination Oriented Directed Acyclic Graph	Less packet overheads, faster convergence, guarantees loop-free routing
2.	Jiang Wenjuan et. al [2]	Improved Connection Oriented Routing Algorithm	Continuous communication is possible during inter-satellite handoffs or inter-orbit handoffs
3.	Zhian Yang et.al [3]	Dynamic Clustering Routing Algorithm (DCRA)	Adaptive, computational effective and needs less storage, robust to topology changes
4.	Wang Houtian et al. [4]	Ant-Colony Optimization Based Routing Algorithm	Better traffic load balancing, increased delivery rate
5.	Yilun Liu et. al [5]	Approximate Optimal Routing Algorithm(AORA)	Reduction in the computational complexity of routing
6.	Yonghu Zhu et. al [6]	Software Defined Routing Algorithm(SDRA)	Reduced end-to-end delay, packet dropping probability and increased network throughput
7.	Wei Liu et. al [7]	Load-Balancing Routing Algorithm	Improved average rejection ratio, average relative throughput

8.	Lu Zhang et. al [8]	Link State Information Based Routing Algorithm	Lower end-to-end delay, higher delivery ratio and better adaptability in link failure scenario
9.	Jiang Liu et. al [9]	Selective Iterative Dijkstra's Algorithm(SIDA), Selective Shunt Load Balancing(SSLB)	Low computational complexity and low signaling complexity
10.	Xiaoting Wang et. al [10]	Routing Algorithm based on Reinforcement Learning	Better convergence time
11.	Chaoying Dong et. al [11]	Routing Algorithm based on Extended Link States(LRES)	Balanced traffic load distribution, Reduced link congestion, Reduced packet loss rate, Improved throughput
12.	Chenxi Li et. al [12]	Knowledge Graph Aided Network Representation and Routing Algorithm	Lower packet loss rate and average delay

4. CONCLUSIONS

The routing problem in LEO (Low Earth Orbit) satellite networks is a complex challenge that must be addressed to ensure efficient and reliable communication. LEO satellite networks face several unique challenges that make the routing problem particularly challenging, including Dynamic Network Topology, Limited Bandwidth and Processing Power, High Latency, Interference and Signal Loss, Energy Constraints etc. To address the routing problem in LEO satellite networks, routing algorithms must take into account these unique challenges and ensure efficient and reliable communication. Various routing algorithms for LEO satellite networks were analyzed to find out the merits and demerits of each methods, which will be helpful for future research works.

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