# A Networking Transmission Method in the Case of Limited Satellite Transceiver

Yaoxu He, Hongyan Li(✉), Peng Wang, Hang Liu, and Fan Qi

State Key Laboratory of Intergrated Service Networks, Xidian University, Xi'an 710071, China
hyli@xidian.edu.cn

**Abstract.** Due to the cost and hardware limitations of the satellite, it is difficult for a single satellite to establish multiple data communication links at the same time. When the satellite network carries a large amount of data transmission, efficient network transmission in this resource-constrained network has become a challenge. Considering the constraints of a single transceiver, we propose a topology planning method based on connectivity fairness, and formulate the rules for satellite transceiver rotation; on this basis, we design a low-delay routing method under resource constraints, which is characterized by time-varying graphs, and uses traffic to calculate single or multiple paths that meet transmision requirements, which not only ensures equal connectivity opportunities, but also reduces the delay of end-to-end paths. Finally, relying on the iridium constellation, under the connectivity fairness topology configuration method, we simulate and analyze the algorithm, and prove that the network transmission has a lower path delay than the satellite over-the-top transmission.

**Keywords:** Resource constraints · Connectivity fairness · Low-delay routing · Networking transmission

## 1 Introduction

With the development of science and technology, satellite communication has become the main force of information transmission and communication, integrated into people's life and become an inseparable part of human daily life. The importance of satellite communication is not only reflected in ordinary communication transmission, but also has a profound impact on military national defense, production safety and economic development [1]. Now there is another bright spot in satellite communication-small satellite network. Since the concept of satellite communication was put forward, it has made great progress. In recent years, with the endless emergence of affordable and innovative commercial spot technology solutions, and the continuous progress of microelectronics and microsystem technology, the size of satellite components has been continuously reduced. so that people can design small satellites. Because of its low development cost and low energy consumption, small satellite network is playing a more and more important role in today's satellite communication technology. Its emergence has greatly bridged the gap of data shortage in


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many vertical industries, and with the arrival of the era of the Internet of things, satellites also play an important role in M2M communications.

However, due to the limitations of the cost and hardware conditions of the small satellite network, for example, a small satellite can only carry one transceiver, so that a single satellite can only establish a single data communication link at the same time, and it is impossible to build a complete end-to-end transmission path. in this context, how to quickly return a large amount of information from the satellite to the ground station has become a thorny problem. At the same time, the satellite nodes in the satellite network will operate periodically according to the orbit, and the communication links between the nodes will be disconnected frequently, so the satellite network topology is time-varying. In view of the above problems, this paper proposes a "step-by-step" strategy to meet the communication requirements of conventional tasks, by considering the time evolution characteristics of network topology and link connections in each period of time, to coordinate multi-satellite nodes to achieve joint scheduling of multiple transceivers, in order to ensure a fair connectivity opportunity for each satellite node, and then to ensure the fairness of task transmission among different satellite nodes. Enable all nodes in the satellite network to access the available links between them as well as possible. The goal of the strategy is to provide equal opportunities for all network nodes to exchange data traffic by establishing appropriate plans, and on this basis, an efficient resource scheduling method with low delay is established.

Reference [2] discusses an efficient broadcast and multicast tree construction algorithm for all-wireless multi-hop networks under the joint constraints of a limited number of transceivers and a limited number of available frequencies on network nodes. By using the method of formula derivation and simulation, this paper deduces the performance of energy-saving multicast of session traffic in wireless network under the condition of limited number of transceivers. The resource-constrained satellite network of intermittent Unicom is analyzed in reference [2], and a connection plan design (Contact Plan Design, CPD) is proposed to efficiently schedule the link according to the optimization objective in this environment. An analysis framework for resource-constrained small satellite networks is proposed in reference [3–6]. The extended traditional time spread graph is used as a tool to optimize the delay and throughput. These literatures have analyzed the resource-constrained satellite networks, but the common disadvantage is that the analysis process is based on mathematical formulas, which leads to the complexity and obscurity of the analysis process. And the resource scheduling problem of satellite networks with limited transceivers is still being studied, so we propose a new strategy to solve this problem.

In view of the limited satellite transceiver, this paper first proposes a "step-by-step" strategy based on connectivity fairness to ensure that each satellite node has the same connectivity opportunity; on this basis, a low-delay routing method based on "step-by-step" strategy is proposed, and one or more end-to-end low-delay paths satisfying service transmission are constructed according to the relationship between service resources and link available resources. Finally, we simulate and analyze the proposed strategy and method based on the iridium constellation, and the results show that compared with the satellite over-top transmission mode, single-path transmission has lower path delay. Multi-path transmission is suitable for link resource constraints to obtain lower delay.

## 2 Topology Planning Based on Fairness

In order to meet the fairness of inter-satellite transmission, a method of rotation of transceiver angle between satellites in constellation is designed, so that all satellites can get fair communication opportunities in a long time range. As shown in Fig. 1 below, a simplified satellite constellation is constructed, consisting of 16 satellite nodes, numbered 1 × 16. In the satellite constellation, the relative position between satellites does not change, in a given topology, each satellite can only have the opportunity to communicate with neighboring nodes. Because each satellite carries only a single transceiver. Therefore, if two satellites need to communicate between satellites, they need to point each other's transceivers to each other's location. As shown in Fig. 1, if satellite 1 needs to communicate with satellite 4, satellite 1 needs to point its transceiver to satellite 4, while satellite 4 points its transceiver to satellite 1.

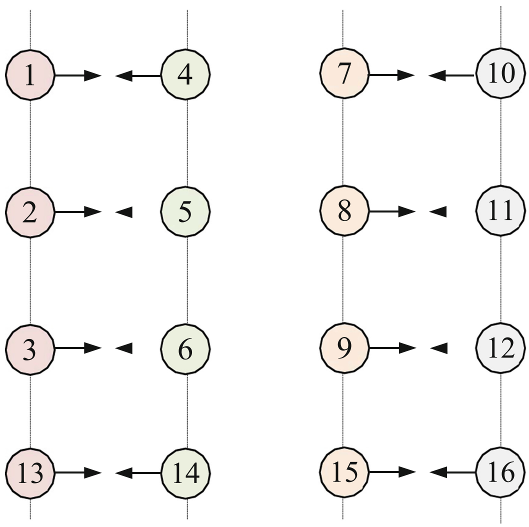


**Fig. 1.** Satellite constellation A possible transceiver orientation.

Based on the above description, we specify the orientation of the transceivers of all satellites in the satellite constellation at the initial time, and design the periodic rotation method of the satellite in a certain time range T, so that each satellite has a fair communication opportunity with all its neighboring nodes.

For a given constellation, we propose a satellite transceiver rotation method for fair communication. First of all, it is stipulated that during the initial period of time, all satellites communicate with satellites in adjacent orbits. This is shown in the topology of the first period of time in Fig. 2. Then when any satellite in the topology determines the rotation direction of its transceiver at a uniform speed, its neighbor node satellite transceiver rotates in the opposite direction. Therefore, when the rotation direction of any one satellite is determined, the rotation direction of other satellites in the

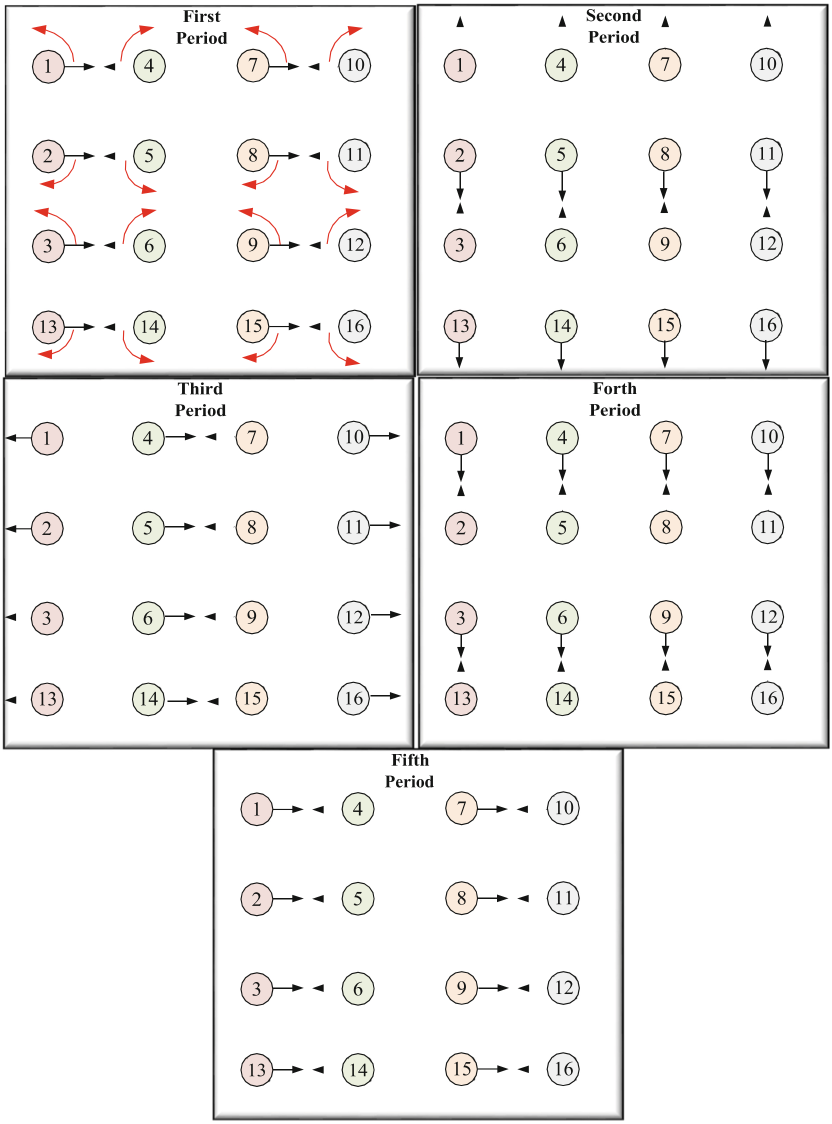


**Fig. 2.** Rotation method of each satellite transceiver in satellite constellation.

constellation can be determined. Based on this rotation method, the communication opportunity between the satellite and its neighbor nodes is the same in a rotation period. As shown in Fig. 2, satellite 5 rotates counterclockwise at a uniform speed, and its neighbor nodes 2, 4, 6 and 8 all rotate at a uniform speed clockwise, and in the next four periods, they can communicate with 6, 8, 4 and 2 respectively.

Therefore, based on the satellite transceiver rotation method, the satellite transceiver can communicate with each neighbor node in a rotation cycle, thus ensuring the fairness of the communication.

## 3 Low Delay Routing Method Based on Step-by-Step Strategy

In this paper, the topology planning method based on connectivity fairness is summarized, and the steering rules of satellite nodes with a single transceiver are given. based on this research, a low-delay routing algorithm is proposed to transfer data as quickly as possible. According to the amount of traffic that needs to be transmitted in different scenarios, we jointly consider the available satellite node resources and link resources, and obtain single-path and multi-path routing algorithms suitable for different scenarios.

The satellite with a single transceiver rotates periodically according to the configured rules, resulting in topological connections and link resources changing with time, with the characteristics of a time-varying network. Considering the accuracy and efficiency of the time-varying graph model, this paper uses the time expansion graph to model a single transceiver satellite network, as shown in Fig. 3.

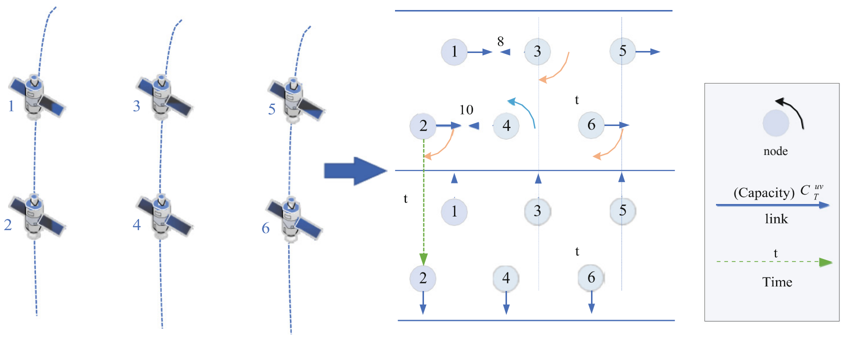


**Fig. 3.** The satellite network model of a single transceiver satisfies the steering rules of the satellite transceiver, and the green link represents the switching time of the satellite transceiver. (Color figure online)

The rotation direction of each satellite node is opposite to that of the neighboring satellite nodes, and the rotation time is t, so the period is Tunable 4t. Because the rotation handoff time between satellite nodes is much longer than the propagation delay of satellite links, link resources only consider the amount of data that can be transmitted by the link in a period of time. The links between different periods represent the longest time it takes for satellite nodes to switch neighbors, that is, rotation time t.

The core idea of low-delay routing algorithm based on connectivity fairness is to find one or more paths that satisfy low-delay transmission at one time. First of all, an end-to-end path with the lowest cost is calculated according to the transmission time of the data request, and the routing rule is similar to the CGR algorithm (reference). Then it is compared with the amount of data to be transmitted, and the above steps are repeated until enough end-to-end paths are found that all the data can be transmitted. The algorithm flow of solving single path and multi-path is given in Algorithm 1 and 2 respectively (Table 1).

**Table 1.** The description of single path algorithm

| Algorithm1 single path algorithm | |
|---|---|
| 1. | Input： Topology G, Source node s, Destination node d, Amount of data M, Start time $t_{start}$. |
| 2. | Output: The shortest delay of the $s - d$ is min_delay. |
| 3. | Initialize the distance of each node is the graph G, $A[v] = \infty, \forall v \neq s$; $A[s] = t_{start}$, add s to the priority queue Q. |
| 4. | While Q is not empty do { |
| 5. | u = min(Q); |
| 6. | If u is d, then |
| 7. | break; |
| 8. | For each node v adjacent to u do $A[v] = A[u] + uv_{delay}$; parent[v] = u;} |
| 9. | $C_{min}^{uv} = \text{min\_}capacity(path)$ |
| 10. | If $C_{min}^{uv} \geq M$ then |
| 11. | $\text{min\_}delay = A[u]$; |
| 12. | Output min_delay with the shortest delay of $s - d$. |

In the single path algorithm, the links in different periods are associated together by using the switching time of the satellite transceiver to form a shortest delay path to ensure the reliability of data transmission. It is worth noting that when the volume of traffic is graeter than the data that can be carried by the path the formula for calculat-ing the delay is as follws:

$$\text{min\_delay} = \text{ceil}\left(\frac{M}{C_{min}^{uv}}\right) * A[u] \quad (1)$$

Due to the constraints of satellite node resources in a single cycle, the number of end-to-end paths is limited, so the delay is composed of the sum of path delays in multiple periods. Unlike a single path, the flow of the multipath algorithm is as follows. The algorithm calculates multiple paths at one time according to the traffic, but needs to update the topology resources before calculating the next path to prevent the use of duplicate edges in multiple paths and does not meet the constraints of a single satellite transceiver. It is precisely because of the constraints of satellite resources that it is impossible for a satellite node to have more than 1 neighbors in a period of time, that is, there are no duplicate edges in multiple paths. The satellite rotates according to a certain period, and the data to be transmitted can be transmitted along the calculated different paths, making full use of the link resources of the network. The delay calculation formula of multi-path is as follows (Table 2):

$$\mathrm{min\_delay} = \mathrm{ceil}\left(\frac{\mathrm{M}}{C_{min}^{uv}}\right) * A[u] \tag{2}$$

**Table 2.** The description of multipath algorithm

| Algorithm 2 multipath algorithm |
|---|
| 1. Input: Topology G, Source node s, Destination node d, Amount of data M, Start time $t_{start}$. |
| 2. Output: The shortest delay of the s − d is min_delay . |
| 3. Initialize $capacity_{record} = 0$, $\mathrm{temp_{delay}} = 0$. |
| 4. While $capacity_{record} < M$ { |
| 5. Run Algorithm 1; |
| 6. $capacity_{record} = C_{min}^{uv} + capacity_{record}$, $\mathrm{temp_{delay}} = \max(\mathrm{temp_{delay}}, A[u])$; |
| 7. update(G);} |
| 8. Output min_delay with shortest delay of s − d. |

In order to clearly explain the two routing algorithms, a simplified satellite constellation with six nodes is constructed, and the nodes are marked with the number 1/6 respectively. The nodes represent the satellite nodes at different times, and the link indicates that there is a communication opportunity between the two satellites. The transceiver can be directed to each other to build a communication link. As shown in Fig. 4 below, each satellite has only one set of transceivers, and each satellite has communication opportunities only with neighboring nodes. For example, satellite 1 may communicate with satellite 2 or satellite 3. Satellite 3 may communicate with satellite 1 or satellite 4 or satellite 5. Assuming that the amount of data to be transmitted is 10 m, the link capacity on each link is known, and the rotation period of the satellite is 4, now the satellite node 1 needs to communicate with the satellite node 6 and transmit the data.

Figure 4 shows the schematic diagram of single-path and multi-path solution. First of all, a time spread graph model is constructed, which correlates the topologies of different periods and characterizes the distributable relationship of transceiver resources of constellations in different periods. The model is shown in Fig. 5 below.

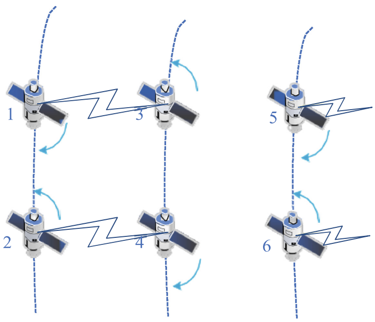


**Fig. 4.** A simplified 6-star network constellation in which each satellite node turns to the opposite of its neighbor satellite node.

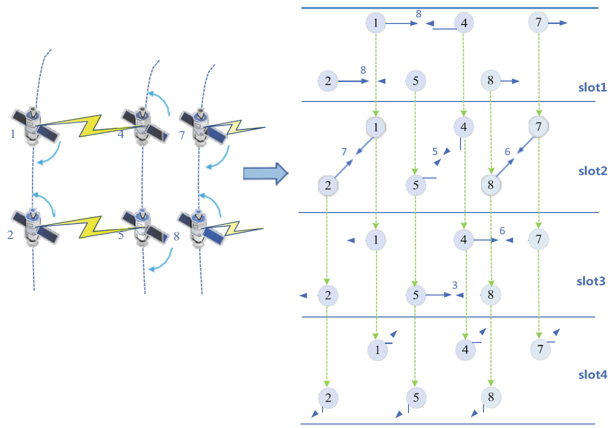


**Fig. 5.** The time expansion chart of the satellite network shows the topological connection of a cycle.

As shown in Fig. 6, a constellation consisting of six satellites uses a step-by-step strategy to run an one-cycle topology. Node 1 is selected as the source node and satellite 8 is selected as the destination node. If the traffic to be transmitted is 3 m, then follow the purple path 1-3-4-6 in the figure on the left, and it will take 2 periods of time to transmit. However, at this time, the transmission traffic is 10 m, and because the link capacity is only 3 m, if the single-path algorithm is used, the path will follow the purple path for 3 times, and it will take 14 periods of time; if the multi-path algorithm is used, a total of 3 paths will be calculated, and marked red in the figure on the right, the maximum delay of the three paths is 6 periods. Compared with the singlepath algorithm, it is 8 times faster (Fig. 6).

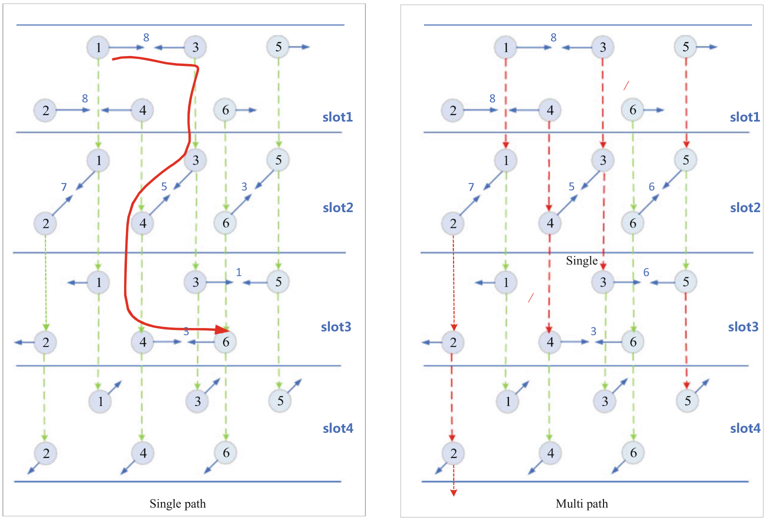


**Fig. 6.** The schematic diagram of the algorithm shows that the red path on the left is the result of the single-path algorithm, and the red link on the right is the three paths obtained by the multi-path algorithm (except for handoff delay).

Under the condition that the resources of satellite transceivers are limited, the low-delay routing method based on synchronous walking strategy aims at low delay, and the algorithm can be adjusted according to the amount of data to be transmitted, so as to meet the needs of different scenarios and improve the resource utilization of the network. it provides a reliable end-to-end transmission path for services.

## 4 Performance Evaluation and Simulations

In this paper, the communication connection between satellite networks is established by networking, and the information is sent from the originating node to the node that establishes a communication connection with the ground station, which greatly shortens the information transmission waiting time for sending information from the originating node to the ground station.

In order to evaluate the proposed algorithm, we select the iridium constellation for simulation. We configure each node in the constellation as the synchronous walking strategy proposed above, each satellite has four neighbors, rotates according to certain rules, 100 s switches, 400 s is a cycle. The Iridium constellation has six orbits, and the number of satellites in each orbit is 12. Here, the first satellite in each orbit and the sixth satellite are selected to transmit data to the ground station.

In the case of sufficient network link resources, the constructed single path can meet the data transmission. We simulate the 2G transmission service on each selected satellite node and compare the delay required by single path and over-top transmission. The simulation results are shown in Fig. 7.

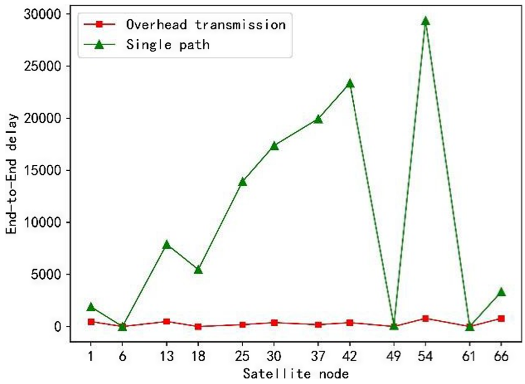


**Fig. 7.** The schematic diagram of the algorithm shows that the red path on the left is the result of the single-path algorithm, and the red link on the right is the three paths obtained by the multi-path algorithm (except for handoff delay). (Color figure online)

The simulation results show that under the condition of a single transceiver, the delay required for satellite over-the-top transmission is much larger than that for single-path transmission. By correlating and utilizing the link resources of different periods, the delay of the selected path can be greatly reduced. If the network link resources are tight, it can not guarantee that it can be transmitted all at once, so it is necessary to build multiple paths for transmission at the same time. By reducing the link capacity resources, we simulate the multipath algorithm and compare it with the single path. The simulation results are shown in Fig. 8.

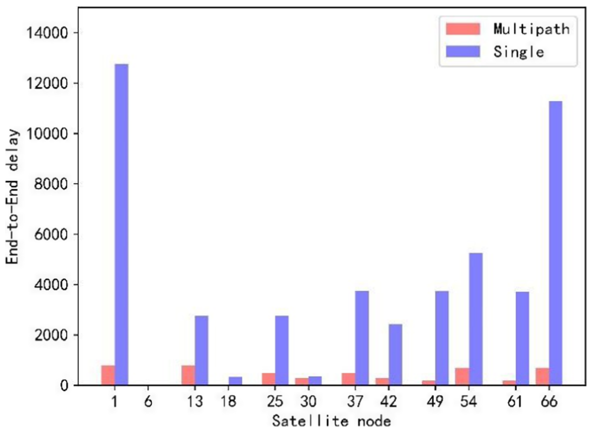


**Fig. 8.** Comparison of single-path and multi-path (ordinate is end-to-end delay, unit is second, Abscissa is the label of satellite node).

We can see intuitively that the delay required for multi-path transmission is much lower than that for single-path transmission of the same traffic. The reason is that the previously proposed topology planning method is periodic. The algorithm looks for multiple end-to-end reliable paths at one time, makes full use of link resources in different periods, and reduces the delay of the path.

Under the condition of ensuring the connectivity fairness of a single transceiver satellite, the low-delay routing algorithm constructs a low-delay end-to-end path to ensure the transmission of traffic. Under the condition of resource first, multi-path transmission can often achieve better performance.

## 5 Conclusion

This paper studies the problem of network transmission in satellite network under the condition of limited transceiver. Considering the problem of fair transmission in satellite networks, a "step-by-step" strategy is proposed to establish a fair satellite network transmission mechanism, and on this basis, the relative size of service bandwidth and link bandwidth is considered. two routing algorithms, single-path and multi-path, are proposed, which correlate and utilize the topology resources in different periods to ensure the end-to-end delay and improve the utilization of network resources. The algorithm has analysis and consideration for different situations and has good practicability. Finally, based on the specific satellite network scenario, the performance of single-path and multi-path routing algorithms is simulated and compared with that of traditional non-networking satellite network topology. verify the advantages of satellite network transmission under the constraint of a single transceiver, and reveal that the "step-by-step" strategy and network transmission have important practical significance for the communication between satellite and ground station.

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