Adaptability Analysis of IP Routing Protocol in Broadband LEO Constellation Systems

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Abstract: With the inclusion of satellite Internet as the information infrastructure in China's "new infrastructure" category, relevant domestic industries and scientific research institutes have successively carried out the design of broadband low earth orbit (LEO) constellation systems and key technical research. As the core technology for the satellite-to-ground network communications of a broadband LEO constellation system, routing technology is extremely important for the efficient and reliable transmission of various service data. Focusing on the two important broadband LEO constellation systems in China, in-depth analysis and simulation of the high dynamics of the satellite-to-ground satellites are conducted in this paper to obtain more accurate network topology changes and characteristics; then the adaptability of the ground standard IP routing protocol to the broadband LEO constellation system is analyzed, and an LEO constellation simulation scenario is built with the Opnet software. The simulation results of the convergence performance of the standard IP routing protocol are produced. The results show that the IP protocol does not perform well for LEO satellite constellation networks. Based on the studies, some solutions are proposed to take full advantages of the characteristics of LEO satellite systems. These can also provide a reference for the choice of inter-satellite routing architecture and protocol technology for broadband LEO constellation in the future development.

Keywords: satellite Internet; IP routing protocol; high dynamic networking

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1 Introduction

Modern communication networks can be divided into three categories, that is, fiber-based terrestrial networks, line of sight (LOS) microwave cellular based mobile communication networks, and low earth orbit (LEO) and geostationary (GEO) based satellite communication networks. With the global popularity of Internet applications and the rapid growth of the "Internet + service" industry, the terrestrial mobile communication business has gradually changed from initially supporting only basic voice and data communications to "mobile Internet + service". Moreover, a new service model is also proposed for satellite communication demands. Thus, the LEO broadband constellation system emerges with high speed, large capacity and low latency[1]. Constructing a constellation network with inter-satellite links to support broadband mobile user access applications worldwide has become a research hotspot[2–3]. It is easy to think of using the mature IP routing technology of the ground fixed network to solve the routing problem of inter-satellite network[4]. However, this inter-satellite network of LEO broadband constellation has the characteristics of node dynamics and topology dynamics that terrestrial fiber networks do not have[5]. In order to come up with a suitable inter-satellite network routing solution, the adaptation of the IP routing protocol in such a high-dynamic scenario needs to be studied and analyzed. Starting from the working mechanism of the IP routing protocol, this paper analyzes the impact of the high dynamics of the broadband LEO constellation on the routing protocol's convergence performance. Some routing solutions for the LEO constellation inter-satellite networking are proposed with simulation and verification.

2 Broadband LEO Constellation Systems at Home and Aboard

Iridium, ORBCOMM and Globalstar systems are currently the only three LEO constellation systems in orbit and these systems are narrow-band satellite mobile communication systems. Among them, the Iridium system is the only system in the world with inter-satellite links[6]. Its routing problem can be solved based on the combination of ephemeris calculations, time slices and circuit switching. It is not necessarily based on the idea of IP (no public reports on the specification implementation method are found). So far, there is no fully-built inter-satellite broadband system in the world. **Table 1** shows several typical examples of broadband constellations worldwide.

As illustrated in Table 1, OneWeb adopts the scheme of bent pipe transponder, which does not have the technical problem of inter-satellite routing, and 74 satellites have already been launched; Starlink realizes the coexistence of transparent bent pipe satellites and on-board processing satellites. The on-board processing satellites of Starlink have inter-satellite links and the capacity of on-board processing is more than 10 Gbit/s. Of the hundreds of satellites that have been launched, there is no public report on the resolution of on-board processing and routing. Moreover, there are currently two important satellite systems (System 1 and System 2) in China. System 1 considers 60 to 240 on-board processing satellites, all of which have inter-satellite links and the capacity of each satellite is more than 10 Gbit/s. The system can support both broadband and mobile services. System 2 considers 100 to 2 000 transparent and on-board processing satellites. The on-board processing satellites have inter-satellite links and the capacity of each satellite is more than 10 Gbit/s. This system mainly supports broadband services. Both the systems are still in the experiment stage and they have launched several test satellites. It will take a certain period of time to build these systems. But before the construction is complete, the technical problems such as high-dynamic routing must be solved. In order to solve these problems, we must deeply analyze the dynamics of the constellation and study its pattern and characteristics.

▼Table 1. Overview of typical broadband low earth orbit (LEO) satellite constellation systems

Typical Satellite System	OneWeb	Starlink	Domestic Satellite System 1	Domestic Satellite System 2
Number of satellites	720	Tens of thousands (4 000 at early stage)	60 – 240	100 – 2 000
Frequency	Ku, Ka	Ku, Ka	L, Ka	Ka
Inter-satellite link	No	Plan to have	Yes	Plan to have
Inter-satellite routing	No	No (plan to have)	Yes	No (plan to have for some of the satellites)
Satellite capacity	–	More than 10 Gbit/s	More than 10 Gbit/s	More than 10 Gbit/s
Progress	The test satellites are in orbit.	The test satellites are in orbit (without inter-satellite links).	The test satellites are in orbit (with inter-satellite links).	The test satellites are in orbit (without inter-satellite links).

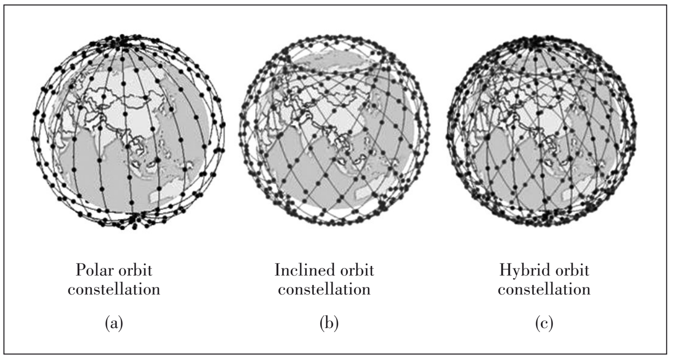
3 Dynamics of Broadband LEO Satellite Constellation

3.1 Satellite Constellation Coverage Characteristics

Two types of satellite constellations are considered: the polar orbit constellation and the inclined orbit constellation[7–8]. The polar orbit constellation solves the problem of polar coverage and the inclined orbit constellation solves the problems of multiple coverage and capacity increase in areas with dense traffic.

These two constellation types can be used independently or superimposed (**Fig. 1**). Fig. 1a illustrates a scenario of polar orbit constellation with 220 satellites, Fig. 1b illustrates a scenario of inclined orbit constellation with 360 satellites, and Fig. 1c illustrates a scenario of hybrid orbit constellation.

The choice of constellation type depends on the coverage re-



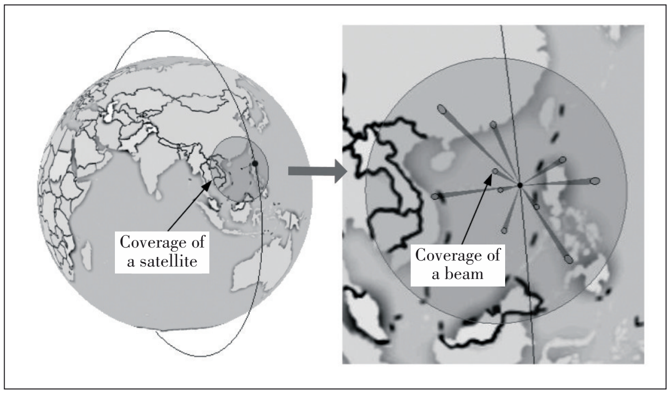
▲Figure 1. Satellite constellation deployment scenarios.

quirements, and is related to the payload configuration, especially the antenna configuration. According to OneWeb's early conception, seamless global coverage can be achieved through about 600 satellites, with fixed-beam antennas on the satellites and without inter-satellite networking[9]. However, due to the density of satellites and the fixed beams, it will be a waste of resources in high latitude areas, especially the Polar Regions if the power is not adjustable. For this reason, current inter-satellite networking constellations mostly use adjustable beams generated by phased array antennas.

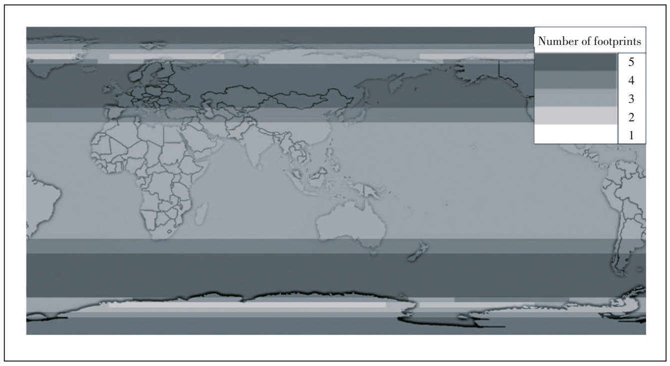
As mentioned above, a system of 220 polar orbit satellites with inter-satellite networking, where each satellite has 10 Ka adjustable beams, can achieve 100% reachable global coverage. In this case, the beam scan range need to be −47.2° to 47.2°, and the seamless coverage rate of the spot beam to the ground is 0.863%.

A system of 400 inclined orbit satellites with inter-satellite networking, where each satellite also has 10 Ka adjustable beams, can achieve 100% reachable coverage in the area between ±65° latitudes, and the seamless coverage rate of the spot beam to the ground is 1.558%.

A hybrid orbit constellation combined with the above two types of constellation can achieve triple reachable global coverage in the area between ±72° latitudes. **Fig. 2** shows the coverage footprint of a single satellite. **Fig. 3** shows the coverage footprint of hybrid orbit constellation.



▲**Figure 2. Reachable coverage of a single satellite (10 spot beams).**



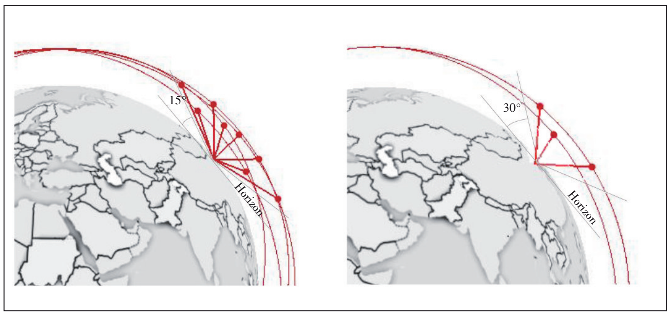
▲**Figure 3. Multiple footprints of hybrid orbit constellation (consist of 220 polar orbit satellites and 360 inclined orbit satellites).**

3.2 The Number of Visible Satellites from Earth and Its Influencing Factors

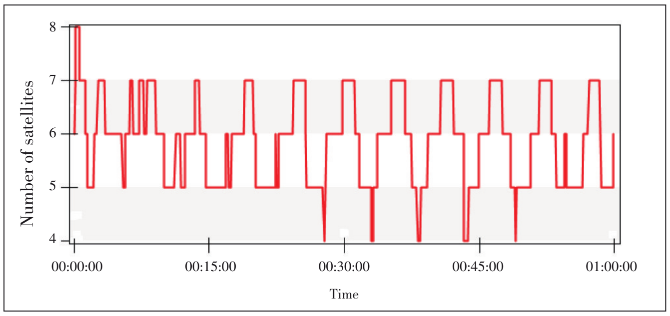
The number of visible satellites from earth (from gateway stations and from terminals) will affect the frequency of satellite-to-earth link switching, the number of gateway antennas, and channel configurations, which is the basis of analyzing the satellite-to-ground link changing frequency. Changes in the number of satellites over the same period of time indicate the stability of the satellite-to-earth link. **Fig. 4** shows the maximum number of visible polar orbit satellites from the earth at different ground elevation angles. In Fig. 4a, there are up to 8 satellites that can be seen from the ground at an elevation angle of 15° and in Fig. 4b, there are up to 3 satellites that can be seen from the ground at an elevation angle of 30°.

As for the number of visible satellites from gateway stations, in order to align a gateway station with the satellites as long as possible and aim at seeing as many satellites as possible, the gateway station usually sets a lower elevation angle. It is assumed that the elevation angle is 15°, the altitude of satellite is 1 000 km, and the valid connection time between the satellite and gateway station is longer than 2 min. According to the satellite orbit parameters, the number of satellites that can be seen at each gateway can be obtained through theoretical calculations and simulations by moving speed and gateway station parameters. According to the distribution characteristics of satellites in the constellation, the satellites in high latitude regions are more densely distributed than those in lower latitude regions. Therefore, different ground positions affect the number of visible satellites. In this paper, we assume that the gateway station is located in Beijing deployed near 116.4° east longitude and 39.9° north latitude. **Fig. 5** shows the variation of the number of visible satellites at the gateway station in the scenario of polar orbit constellation with 220 satellites. **Fig. 6** shows the variation of the number of visible satellites at the gateway station in the scenario of inclined orbit constellation with 360 satellites. And **Fig. 7** shows the variation of the number of visible satellites at the gateway station in the scenario of hybrid orbit constellation with 580 satellites.

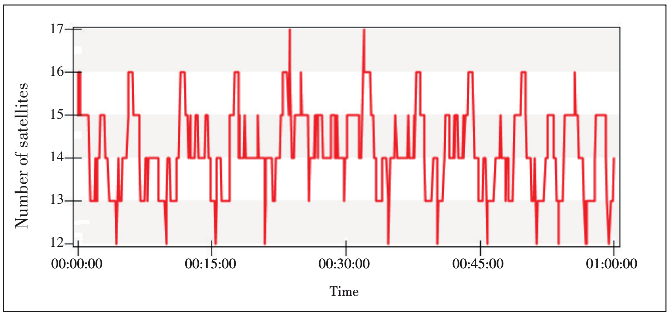
Since a terminal needs to consider low cost, the scan angle achieved by the phased array antenna is limited and only a minimum communication angle of 30° can be achieved. There-



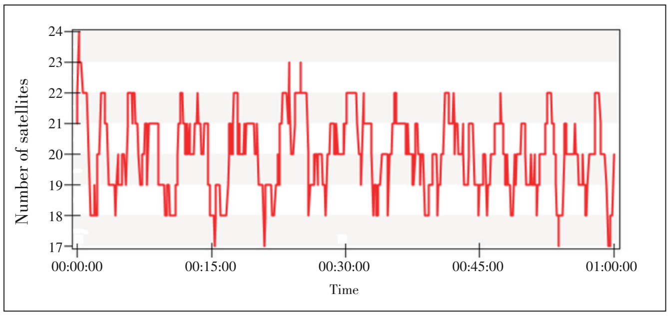
▲**Figure 4. The number of visible polar orbit satellites under different ground elevation angles.**



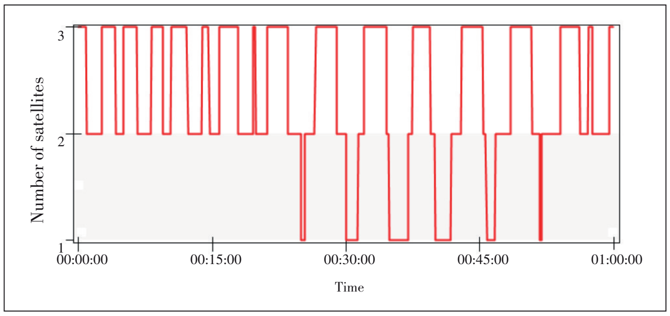
▲ **Figure 5. The number of visible satellites from the gateway station within 1 hour (polar orbit constellation).**



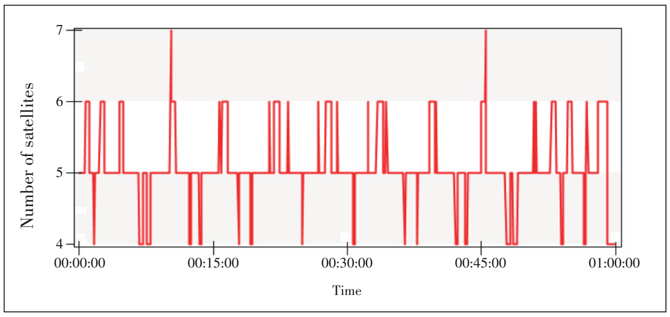
▲ **Figure 6. The number of visible satellites from the gateway station within 1 hour (inclined orbit constellation).**



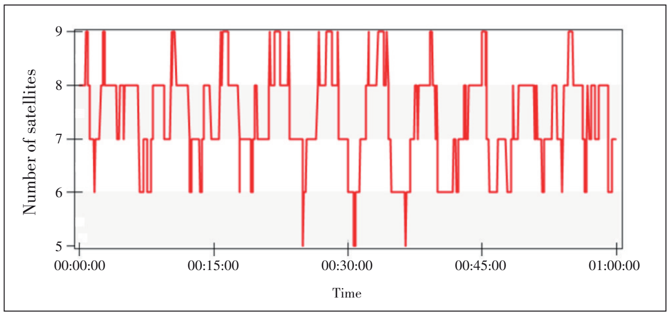
▲ **Figure 7. The number of visible satellites from the gateway station within 1 hour (hybrid orbit constellation).**



▲ **Figure 8. The number of visible satellites from the terminal within 1 hour (polar orbit constellation).**



▲ **Figure 9. The number of visible satellites from the terminal within 1 hour (inclined orbit constellation).**



▲ **Figure 10. The number of visible satellites from the terminal within 1 hour (hybrid orbit constellation).**

fore, compared with the gateway station, the number of visible satellites from the terminal will be different. **Figs. 8**, **9** and **10** show the variation of the number of visible satellites from the terminal, with an assumption that the terminal location is the same as that of the gateway station and the ground elevation angle is 30°.

The number of visible satellites from the gateway station and terminal is shown in **Table 2**. In the same constellation, more satellites can be seen if the ground communication angle is lower.

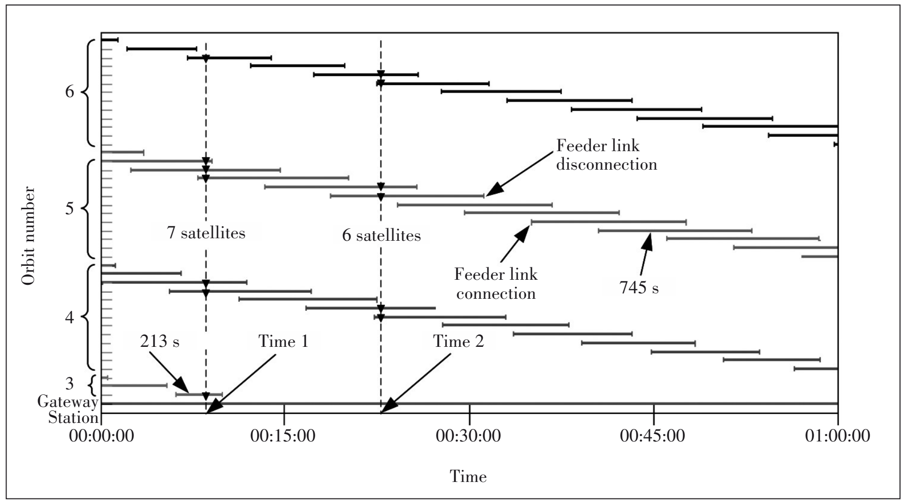
3.3 Variation of Visible Duration of Gateway Station or Terminal to Satellite

In order to ensure that the data from each visible satellite can be transmitted to the gateway station, multiple antennas should be deployed on the gateway station. The maximum number of antennas should be determined by the number of visible satellites. The number of visible satellites will cause the variability of the feeder link when the number changes over time. Therefore, it is necessary to analyze the variation law of visibility of satellites from the gateway station.

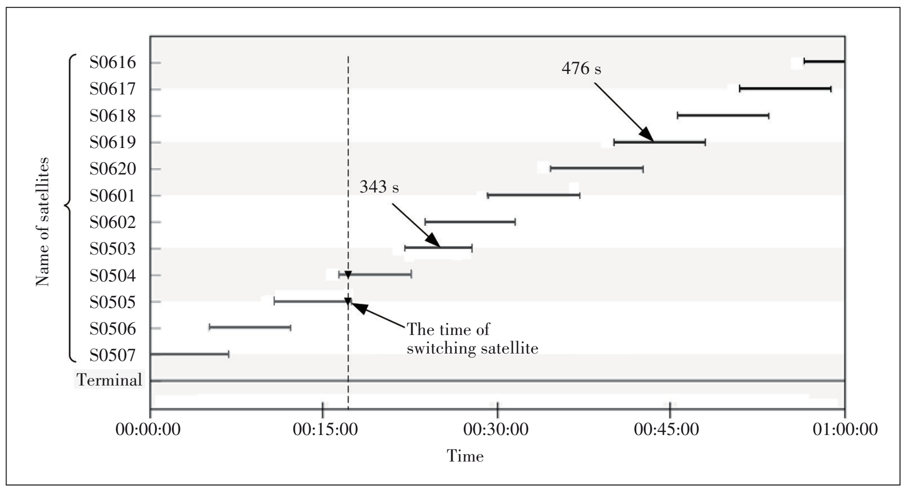
▼**Table 2. The number of visible satellites from ground nodes**

Constellation	Number of visible satellites			
	Gateway station		Terminal	
	Max.	Min.	Max.	Min.
Polar orbit	8	4	3	1
Inclined orbit	17	12	7	4
Hybrid orbit	24	17	9	5

According to the simulation results in Section 2.1, for the situation where up to 8 polar orbit satellites can be seen, 8 pairs of antennas are deployed at the gateway. The gateway station can see up to 4 orbital planes at the same time, and a single orbital plane can see up to 3 satellites at the same time (without the case where there are 3 satellites in the 4 orbital planes at the same time). **Fig. 11** shows the relationship between the visible durations of satellites from the gateway station within one hour. In Fig. 11, 7 satellites can be seen at the gateway station at Time 1, and 6 satellites can be seen at Time 2. As time advances, when the current satellite leaves the switch station's field of view to the sky, the antenna waits or selects a satellite to establish a feeder link. Among them, the longest satellite visible duration is 745 s, and the shortest visible duration is 213 s.



▲Figure 11. Visible durations of satellites from the gateway station (polar orbit constellation).



▲Figure 12. Visible durations of satellites from the terminal (polar orbit constellation).

For the terminal, it can only select a satellite in the visible area to establish a satellite-to-earth link at a certain moment. Therefore, it is assumed that the satellite with the longest visible time in the visible area is selected to establish the satellite-to-earth link, and when the currently connected satellite is about to leave the visible area, the terminal will switch to the next satellite. The satellite switching is determined by the relative position between the terminal and the visible satellite. When the terminal is located in the middle of two orbital planes, it will switch to the other orbital plane, otherwise the terminal will always switch to the satellite in the same orbital plane. For the polar orbit constellation, the changes of the satellite-to-earth link between the ground terminal and the satellite is shown in **Fig. 12**. The abscissa is the visible time and the ordinate is the satellite names (for example, S0507 represents the seventh satellite on the 5th orbital plane). The line segment in Fig. 12 is the visible duration of a single satellite and the segment length is the duration of the connection between the terminal and a single satellite. Within one hour of simulation time, the longest visible time between the terminal and the satellite is 476 s, and the shortest visible time is 343 s.

Since the gateway station deploys multiple antennas, the establishment or disconnection of the satellite feeder link on any visible satellite can be considered as a change in the state of the satellite-to-earth link and the terminal only selects the satellite with the longest visible duration to establish the link. Therefore, at a certain moment, the terminal can only access one satellite and maintain a stable connection. The simulation and analysis method for the inclined orbit constellation is the same as that for the polar orbit constellation. For the gateway station, the difference is only reflected in the number of visible orbits and satellites, while for the terminal, the results of inclined orbit simulation are basically the same as the polar orbit simulation.

3.4 High Dynamic Change of Network Topology Caused by Frequent Interruption of Hetero-Orbital Inter-Satellite Links

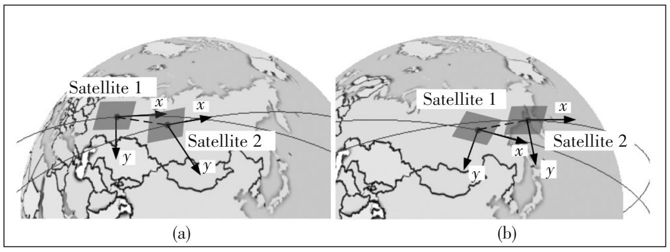
Each satellite in the constellation establishes inter-satellite links with four adjacent satellites in the same orbit and two neighbor orbits. The satellites in the same orbit can remain relatively stationary. Therefore, the inter-satellite links in the same orbit can remain stable connection. While there is a relative movement between satellites in different orbits, the inter-satellite links in different orbits are difficult to keep continuous connections due to the limitation of antenna tracking capability and installation location.

As shown in **Fig. 13a**, before the intersection of two adjacent orbits, the antenna of Satellite 1 points to Satellite 2 in the direction of y-axis and **Fig. 13b** shows that after the crossing point, the antenna of Satellite 1 points to Satellite 2 in the negative direction of y-axis. Therefore, in the area near the highest latitude that the satellite can reach, the hetero-orbital inter-satellite link needs to be disconnected, and the satellite re-establishes the link with the neighboring hetero-orbital satellite after leaving the corresponding area. These cause the frequent changes of hetero-orbital inter-satellite link topology.

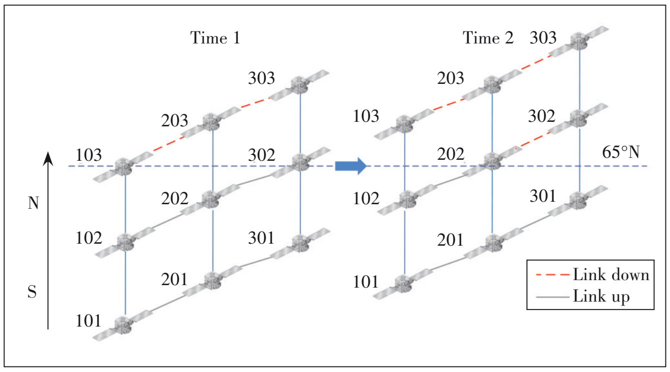
After the satellite enters the high latitude area, the up-down change of the inter-satellite link is shown in **Fig. 14**, where the solid line represents the connection state of inter-satellite link and the dashed line represents the disconnected state of the inter-satellite link. With reference to the inter-satellite link between the Iridium constellations[10] and the limit on the link between different orbits as shown in Fig. 13, it is assumed that the inter-satellite link is disconnected when the polar orbit satellite enters the area beyond ±65° latitudes and that the inclined orbit satellite enters the area beyond ±55° latitudes. When the satellite moves from south to north, the satellite 302 (the second satellite on the third orbital plane) enters the 65° latitude area and the inter-satellite link between the satellite 302 and satellite 202 is disconnected.

The polar orbit constellation and the inclined orbit constellation have different orbital inclination angles, so the up-down positions of the inter-satellite links between the two different orbits are different. For the polar orbit constellation, every time the satellite enters or leaves the area beyond ±65° latitudes, the topology of inter-satellite link will change, so the variation in the number of satellites in the area beyond 65° north latitude can reflect the up-down change of the inter-satellite links. Inclined orbit satellites are the same as polar orbit satellites.

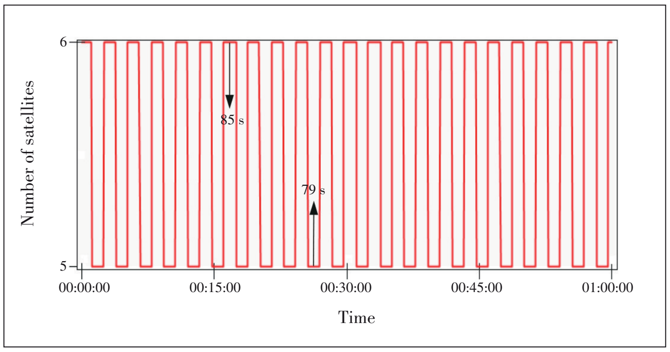
The variation of the number of satellites in the polar orbit constellation and the inclined orbit constellation in the high latitude area is simulated in one hour (**Figs. 15**, **16** and **17**). The inter-satellite link changes 44 times within 60 minutes of the polar orbit constellation and the longest topology stability time is 85 seconds while the shortest topology stability time is 79 seconds. The orbital period of the 220-satellite polar orbit constellation is about 109 minutes and the inter-satellite link topology changes 80 times during the orbital period. The inter-satellite link changes 44 times within 60 minutes of the inclined orbit constellation and the longest topological stability time is 44 seconds, while the shortest topology stability time is 8 seconds, the orbital period of 360-satellite constellation is about 108 minutes, and the inter-satellite link topology changes 240 times during the orbital period.



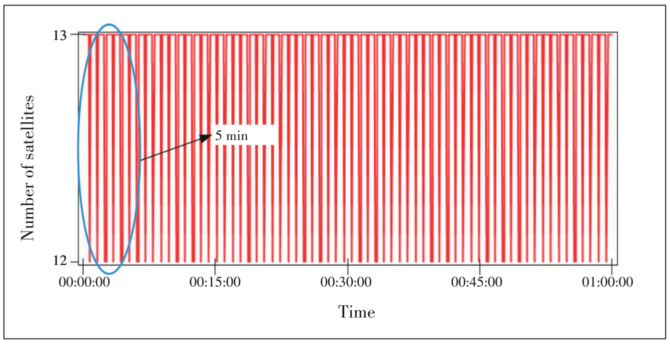
▲**Figure 13. Direction changes of hetero-orbital inter-satellite links.**



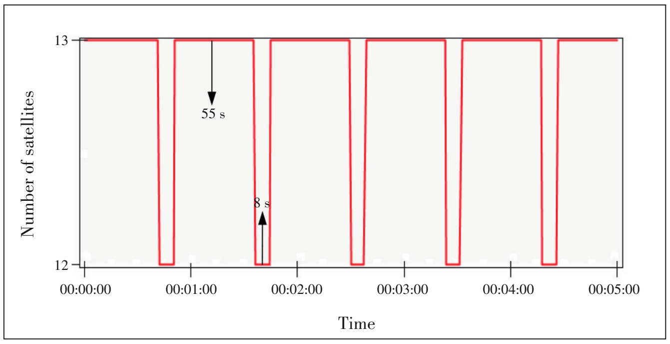
▲**Figure 14. Variation of hetero-orbital inter-satellite links.**



▲ **Figure 15. Variation of the number of visible polar orbit satellites from the area beyond ±65° (60 minutes).**



▲ **Figure 16. Variation of the number of visible inclined orbit satellites from the area beyond ±55° (60 minutes).**



▲ **Figure 17. Variation of the number of visible inclined orbit satellites from the area beyond ±55° (5 minutes).**

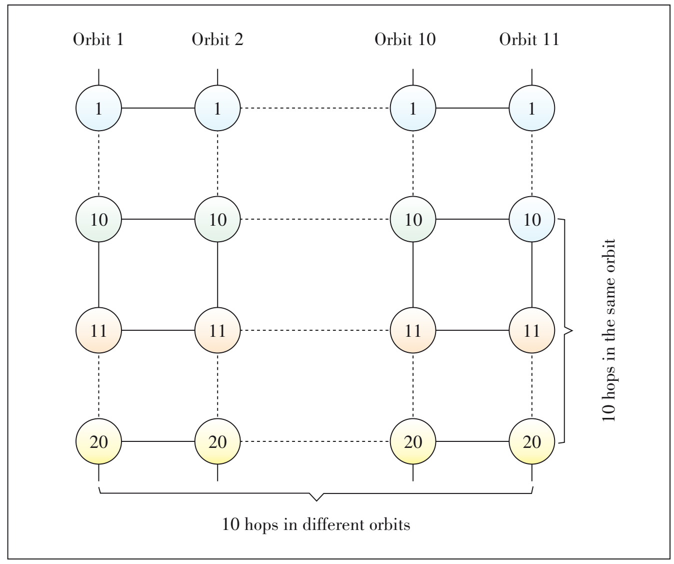
4 Adaptability Analysis of Ground IP Routing Protocol

4.1 Adaptability Analysis of RIP Protocol

The Routing Information Protocol (RIP) is a routing protocol based on distance vector. Each router running the RIP protocol in the network maintains a routing table to reach other destination networks. The routing table includes information such as the destination network segment, interface and hop count. The router periodically (30 s by default) sends routing tables to its directly connected neighbors. Each receiver adds 1 to the hop count in each routing table and forwards it directly to its neighbors until all routers in the network obtain routing information for the entire network[11]. The working principle of the RIP protocol is shown in **Fig. 18**.

The RIP protocol uses the hop count to measure the distance to the destination network segment and the hop count is used as a metric value. RIP specifies that the metric value is an integer between 0 and 15. The number of hops greater than or equal to 16 is defined as infinity, that is to say, the destination network or host is unreachable. Due to this limitation, RIP is not suitable for large-scale networks. Take a 220-satellite polar orbit LEO constellation for example. The maximum number of hops in the inter-satellite network is 20, with 10 hops in different orbit planes plus 10 hops in the same orbit plane (**Fig. 19**), which has exceeded the network scale supported by RIP ability.

The RIP protocol relies on periodically sending routing update messages as a link detection mechanism. When no routing update messages from the neighbor are received within a specified time, the link to the neighbor is considered to be faulty, then the routing table is updated and spread to the neighbors. When the satellite-ground link or the inter-satellite link is disconnected and the routing reconvergence starts, the routing table is updated immediately if the route metric value

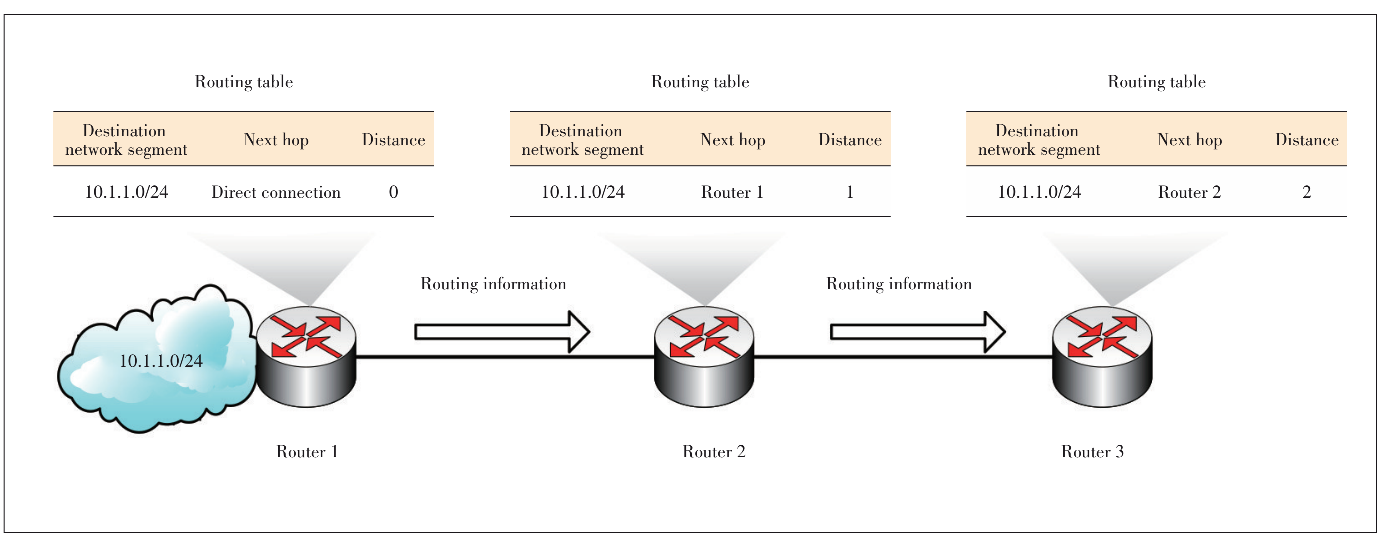


▲ **Figure 19. The number of hops between satellites in low earth orbit (LEO) constellation system.**

of the node becomes smaller and the update time is between 10 s and 40 s; but if the route metric value of the node becomes larger or remains unchanged, the routing table will wait till the timer expires and the update time is between 160 s and 190 s. When the case of inter-satellite switch for the user occurs, the RIP protocol routing update procedure is shown in **Fig. 20**.

4.2 Adaptability Analysis of OSPF Protocol

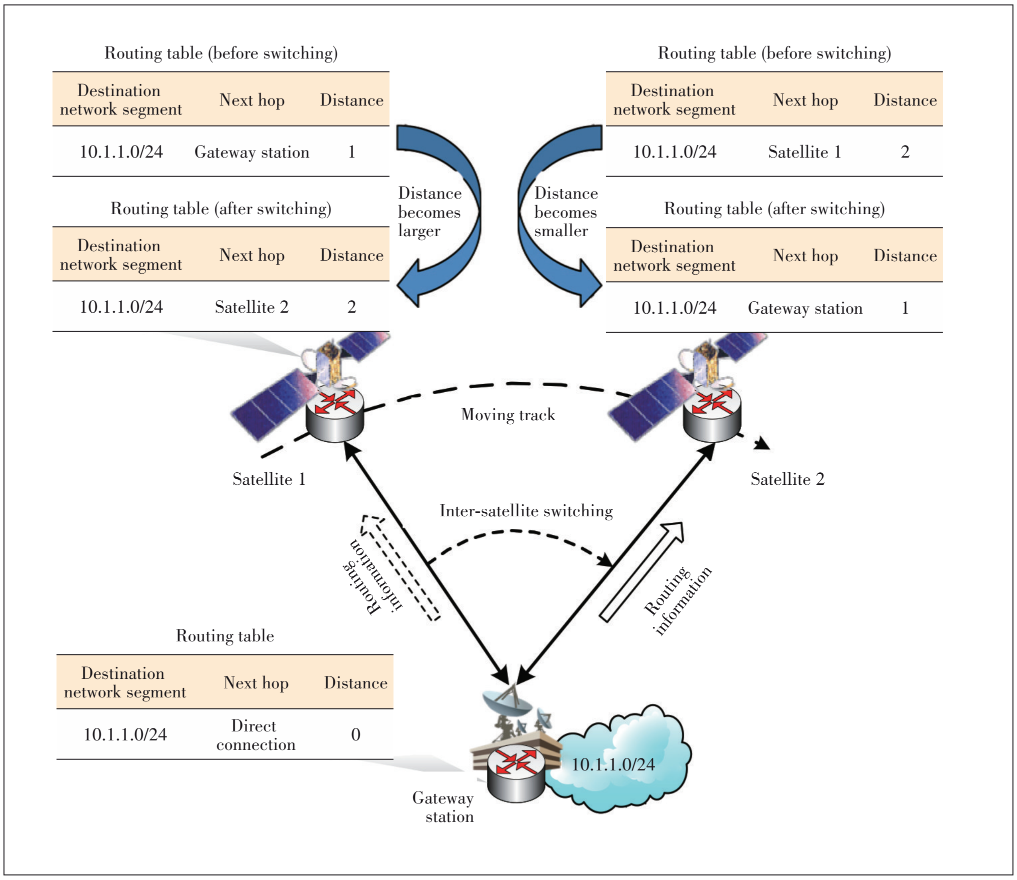
The Open Shortest Path First (OSPF) protocol selects routes based on the link state algorithm. The link state includes the information of which routers the router is adjacent to and the metric value of the connected link[12]. The working process of OSPF in a routing domain is mainly the discovery and maintenance of neighbor routers, the synchronization of the link state



▲ **Figure 18. Working principle of Routing Information Protocol (RIP).**

database, and the calculation of routing. The OSPF routing learning process in the broadband LEO constellation system is shown in **Fig. 21**.

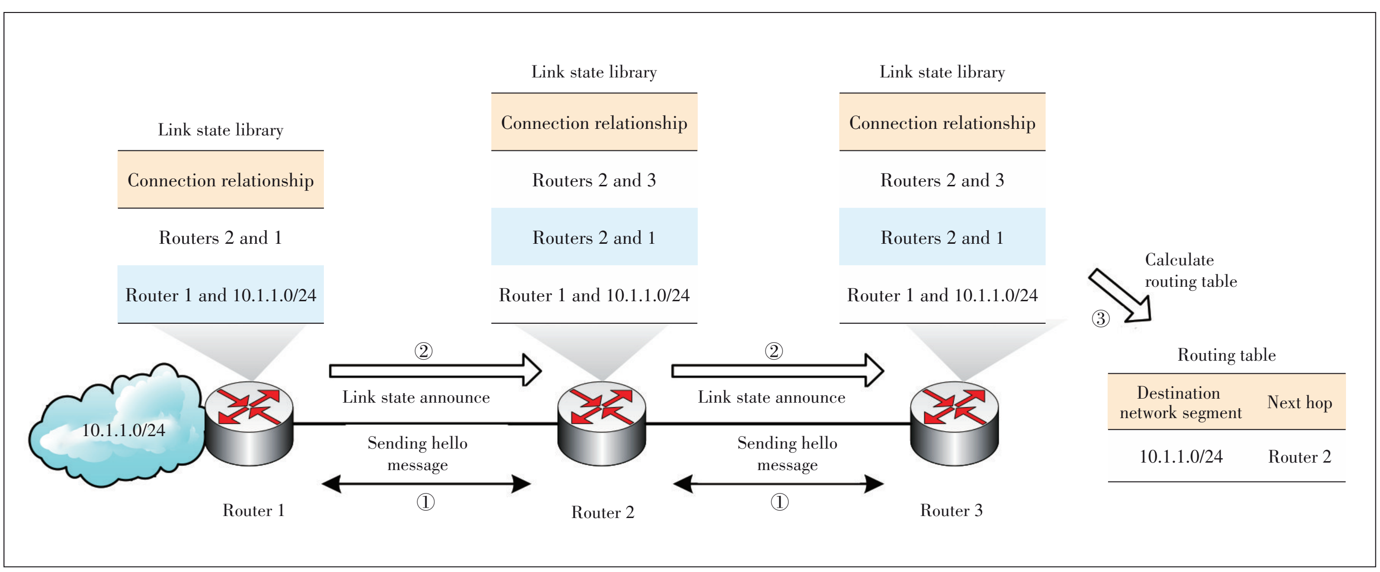
The OSPF protocol relies on periodically sending Hello messages as a link detection mechanism. When the neighbor's Hello message is not received within a specified time, it is considered that the link connected to the neighbor has failed, so the link status is updated and the other neighbors are informed. When a satellite-to-ground link or an inter-satellite link of different orbit plane satellites is connected or disconnected and the routing reconvergence happens, the link status is updated immediately if the link metric value of the node becomes smaller, and the update time is between 10 s and 20 s; If the link metric value of the node becomes larger or remains unchanged, the link status is updated after the timer expires, which takes 30 s to 40 s. When the case of inter-satellite switch for the user occurs, the OSPF protocol routing update procedure is shown in **Fig. 22**.



▲**Figure 20. Routing Information Protocol (RIP) routing update when inter-satellite switching occurs.**

5 Simulation and Verification

A routing test scenario of a polar orbit constellation with 220 (11×20) satellites is built with the Opnet simulation software, as illustrated in Fig. 19. The satellite identification can adopt the "Sxxyy" numbering rule, where "xx" is the orbit number and the



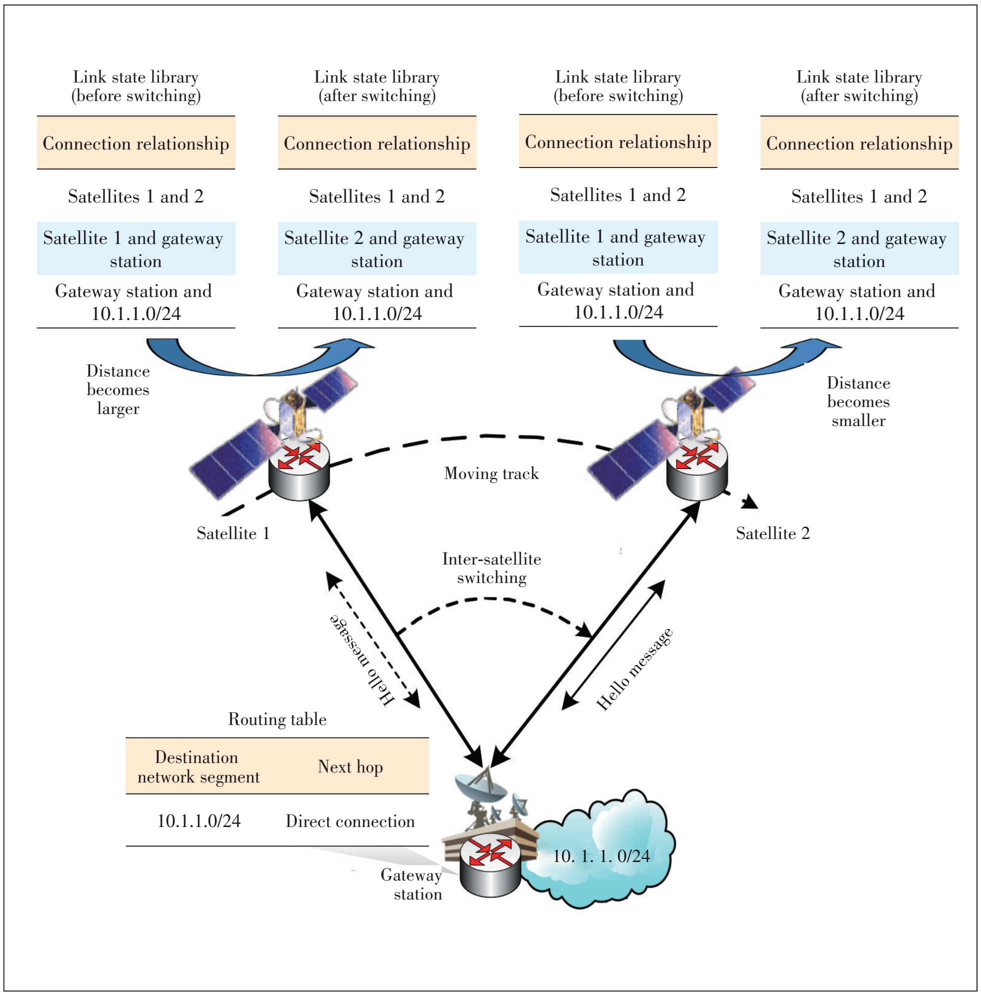
▲**Figure 21. Working principle of Open Shortest Path First (OSPF) protocol.**

range is 1 – 11, “yy” is the satellite number and the range is 1 – 20. By running standard routing protocols at each networking node (satellite and terminal) in the constellation networking scenario, the adaptability of the ground standard IP routing protocols (RIP and OSPF) in the cases of up-down states of the satellite-to-earth link and inter-satellite link is verified.

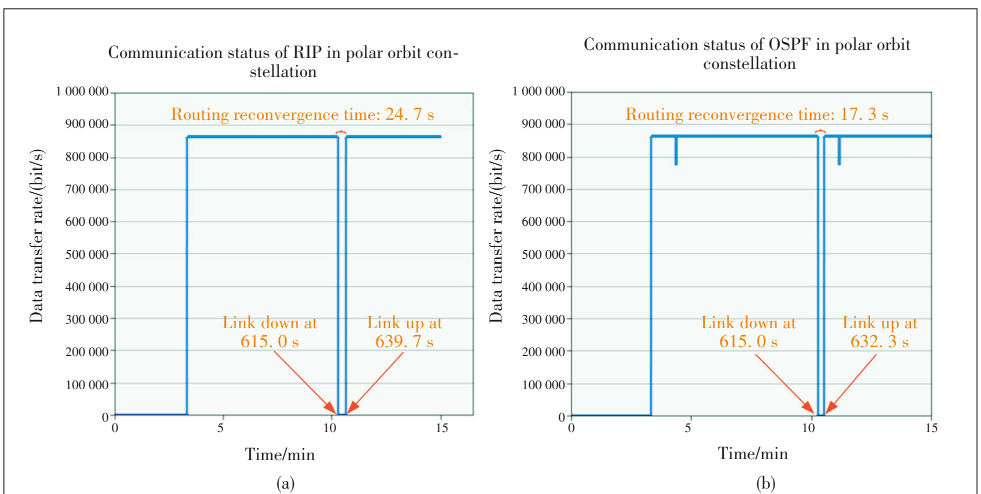
5.1 Routing Reconvergence on Satellite-to-Earth Link Change

In this scenario, all satellites and terminals run standard IP routing protocols. From the time of 200 s to the time of 900 s, Terminal 1 under the service of Satellite S0307 and Terminal 2 under the service of Satellite S0820 are interoperable with IP data services. Because of the high-speed operation of LEO satellite nodes, Terminal 1 switches from S0307 to S0305 at the time of 615 s, and the satellite-to-ground topology changes; the path between terminals becomes shorter, which triggers the reconvergence of the routing protocol.

The service transmission between Terminals 1 and 2 is shown in **Fig. 23**. The satellite-to-ground topology changes at the time of 615 s, which causes service interruption. When the RIP routing protocol is used, as shown in Fig. 23a, the route reconvergence is completed at the time of 639.7 s, the service resumes normal transmission, and it takes 24.7 s to achieve routing reconvergence; when the OSPF routing protocol is used, as shown in Fig. 23b, the route reconvergence is completed at the time of 632.3 s, the service resumes normal transmission, and it takes 17.3 s to achieve routing reconvergence.



▲**Figure 22. Open Shortest Path First (OSPF) routing update when inter-satellite switching occurs.**



OSPF: Open Shortest Path First RIP: Routing Information Protocol

▲**Figure 23. High dynamic routing reconvergence of satellite-to-earth link in polar orbit constellation.**

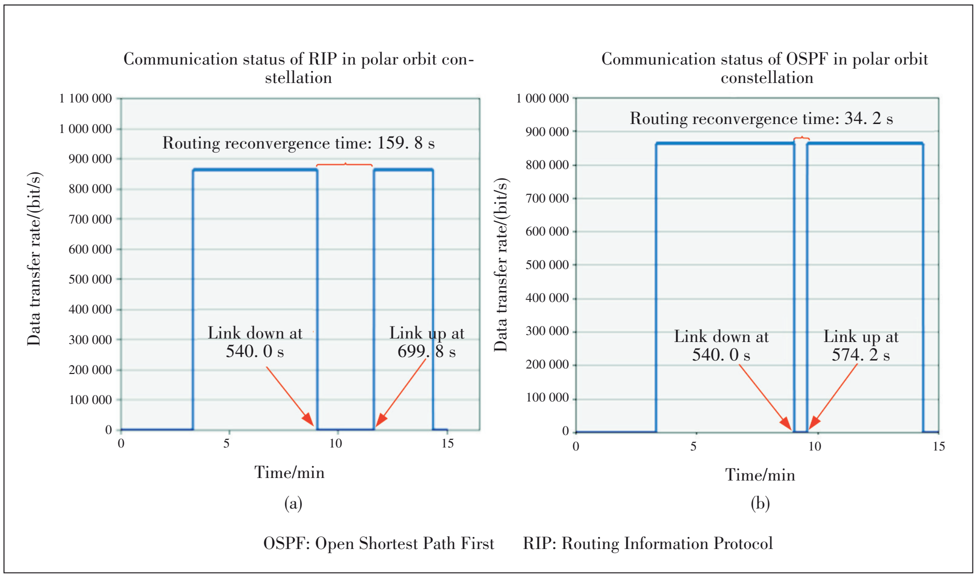
It can be seen from the simulation results that for the broadband LEO constellation system, the terminal needs to switch to the satellite every 343 – 476 s. If the standard IP routing protocol is adopted, the service transmission will be interrupted for tens of seconds, which will seriously affect the user experience. Therefore, the standard IP routing protocol cannot perform well for LEO broadband constellation systems. The solutions to this issue are proposed in Section 5.3.

5.2 Routing Reconvergence on Inter-Satellite Link of Satellites from Different Orbital Planes

All satellites and terminals in this scenario also run standard IP routing protocols. From the time of 200 s to the time of 900 s, Terminal 1 under the service of Satellite S0202 and Terminal 2 under the service of Satellite S0302 are interoperable with IP data services. At the beginning of the simulation, both S0202 and S0302 are located in areas with a latitude less than 65°. When it comes to the time of 540 s, if Satellite S0302 enters the 65° high latitude area, the hetero-orbital inter-satellite link between S0302 and S0202 is down and the path between the terminals becomes longer, which triggers the reconvergence of the routing protocol.

The service transmission between Terminal 1 and Terminal 2 is shown in **Fig. 24**. The change of the inter-satellite topology at the time of 540 s causes service interruption. When the RIP routing protocol is used, as shown in Fig. 24a, the routing reconvergence is completed at the time of 699.8 s, the service resumes normal transmission and it takes 159.8 s to achieve the routing reconvergence; when the OSPF routing protocol is used, as shown in Fig. 24b, the route reconvergence is completed at the time of 574.2 s, the service resumes normal transmission and it takes 34.2 s to achieve the routing reconvergence.

It can be seen from the simulation results that, for the broadband LEO constellation system, the inter-satellite network topology changes every 80 s or so and the convergence time of the RIP protocol is 160 s, which means that the RIP protocol cannot complete routing convergence within a time slice, which results in the satellites being always in the process of routing update. The convergence time of the OSPF protocol is 34 s, which means that the OSPF protocol cannot complete route convergence for nearly half of a time slice, resulting in a 50% reduction in service transmission efficiency. Therefore, the standard IP routing protocol cannot perform well for broadband LEO constellation systems. The solutions to this issue are also proposed in Section 5.3.



▲**Figure 24. High dynamic routing reconvergence of inter-satellite link in polar orbit constellation.**

5.3 Proposed Solutions

Based on the simulation results, it is possible to resolve the problems by making the following changes:

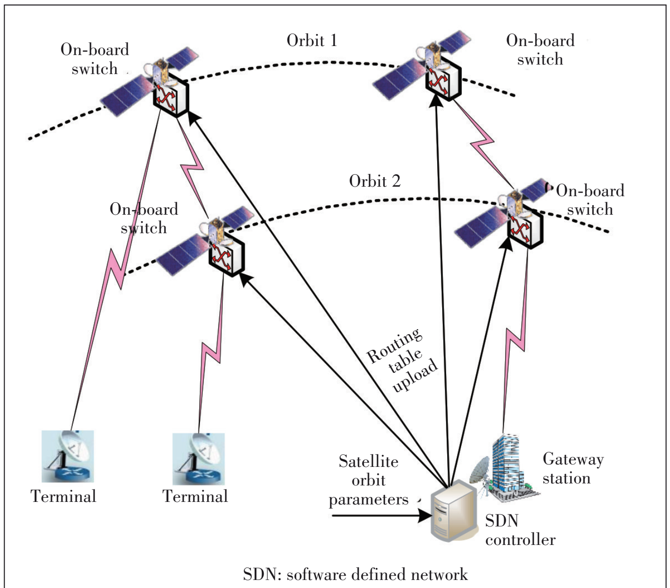
(1) Learning from the architecture of the software defined network (SDN) that separates the control plane and forward plane, the satellite can only retain the data forwarding function and the routing calculation is implemented by the SDN controller deployed at the ground gateway station, thereby reducing the pressure on the satellite routing calculation and supporting larger networks scale.

(2) The SDN controller can use the satellite's orbit parameters to perform topology prediction, calculates the routing table in each topology period in advance, and then uploads the routing tables to each satellite (**Fig. 25**). This can solve the problem of the long routing convergence time caused by the changes of network topology.

(3) The on-board switch switches to the corresponding routing table regularly to complete the data forwarding according to the corresponding routing table, so as to quickly realize the non-inductive switching of the user's service link and solve the problem of low service transmission efficiency caused by the slow convergence of the standard routing protocol.

6 Conclusions

Taking the inter-satellite Internet with low-orbit broadband constellation as the background, this paper starts from the high dynamics of satellite nodes and network topology, which is an important factor that affects the design of the LEO constellation routing protocol. Then, on the basis of the in-depth simulation and analysis of the characteristics of the LEO constellation, the routing convergence performance test and adaptability analysis of the ground standard IP routing



▲**Figure 25. SDN-based routing control architecture of broadband low earth orbit (LEO) constellation system.**

protocol are carried out. The results show that in the high dynamic inter-satellite interconnection LEO constellation system, the standard IP routing protocol cannot directly meet the networking application requirements of the LEO constellation network due to the long convergence time and frequent dynamic changes. The analysis of the characteristics of the LEO constellation in this paper is significant for the design of routing protocols under high dynamic characteristics. The advanced ground network design ideas need to be learnt and combined with the operating characteristics of the LEO constellation network to optimize the design of the satellite routing protocol. Specifically, the idea of SDN can be used for reference. The ground SDN controller can integrate satellite operation parameters, centrally perform routing calculation, and inject the routing table into the satellites. The satellites change to the corresponding routing table regularly to complete data forwarding according to the corresponding routing table. This conclusion can provide reference for routing architecture and protocol technical route selection for the broadband LEO constellation.

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