Research and Implementation of Real-Time Monitoring Technology of Space Constellation Network Status

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Abstract. At present, the space network is booming. In the face of an increasingly large space network, how to monitor the network status with high real-time performance becomes increasingly important. This paper is directed to the space network, and proposes a highly real-time technology scheme for space constellation network status monitoring, which supports real-time acquisition of various types of space network status information. Based on the idea of the integration of the satellite and the ground, the design and implementation of both the satellite and the ground are carried out.

Keywords: Space network · Network management · SNMP · Satellite-ground integration

1 Introduction

Space network is a network constructed by satellites as nodes based on inter-satellite links. It is mainly for solving the information transmission problems of space platforms and serving for satellite communication systems. At present, the space network is booming, how to monitor and manage the network status with high real-time performance becomes increasingly important. The space network has the characteristics of continuous dynamic change and limited node resources. At present, the development of the space information network shows a trend of a sharp increase in the number of nodes, heterogeneous node types and diversified functional services. Therefore, real-time and rapid acquisition of space constellation network status information and the clear operating status of the space network are the foundation for the realization of the satellite space network communication function [1].

Currently, monitoring the status of the space constellation network by traditional telemetry has many disadvantages. For example, first, the huge amount of telemetry data on the entire network poses certain challenges for telemetry reception, storage, analysis, and observation; Second, telemetry information redundancy is a problem. It requires ground extraction before users can obtain information of interest; Third, for space network monitoring, after the initial acquisition of the space network status, the

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effective information required is the changed network status information, and it is not necessary to obtain all the space network status data; Fourth, telemetry resources are limited on the satellite, and a huge amount of network status information takes up too much telemetry resources. Therefore, it is of great significance to study the use of methods other than traditional telemetry to realize space network status monitoring.

2 Real-Time Monitoring Scheme of Space Constellation Network Status

Designing real-time monitoring scheme of space constellation network status needs to ensure compatibility and coordination of inter-satellite and satellite-ground communications, with good real-time performance. At present, the ground TCP/IP protocol stack is very mature, and has mature and complete supporting applications. Most of the satellites currently have embedded software environment, under which the lightweight TCP/IP protocol stack (LwIP) can run. LwIP is an implementation of the open source TCP/IP protocol stack. The main architecture and IPv4 kernel are mainly developed by C language and support IPv6. Its easy-to-clip and low memory characteristic makes it suitable for satellite applications [11, 12]. Simple Network Management Protocol (SNMP) is a network management protocol based on TCP/IP. It was proposed in 1988. With the rapid development of TCP/IP, SNMP network management technology has been rapidly promoted and applied [2]. In the field of network management, the SNMP protocol has the advantages of easy implementation and easy expansion, which makes it the most widely used network management framework at present, and has become the industry standard in the field of network management [6]. Based on the consideration of the integrated design of the satellite and the ground, the TCP/IP protocol stack is applied. And improve the simple network management protocol, which can ensure that the satellite and the ground can have good communication and can obtain the space constellation network status information with high real-time.

Therefore, the real-time monitoring scheme of the space constellation network status is: integrated design of the satellite and the ground, the IP protocol stack compatible with the ground is operated on the satellite, and the simple network management protocol (SNMP) in the LwIP protocol stack operated on the satellite is supplemented and improved to make sure it can run normally. The space network status information is managed by the satellite, and the ground obtains the network status information of each satellite node of the space network by using simple network management protocol commands. As shown in Fig. 1.

Specifically:

First, build an inter-satellite and satellite-ground communication network. Based on TCP/IP protocol stack, the inter-satellite and satellite-ground communication is implemented by using UDP communication protocol. In addition, through the inbound space constellation satellite node, the ground can communicate with any satellite in the constellation, which lays a foundation for the ground to obtain real-time network status information of any satellite node in the space network.

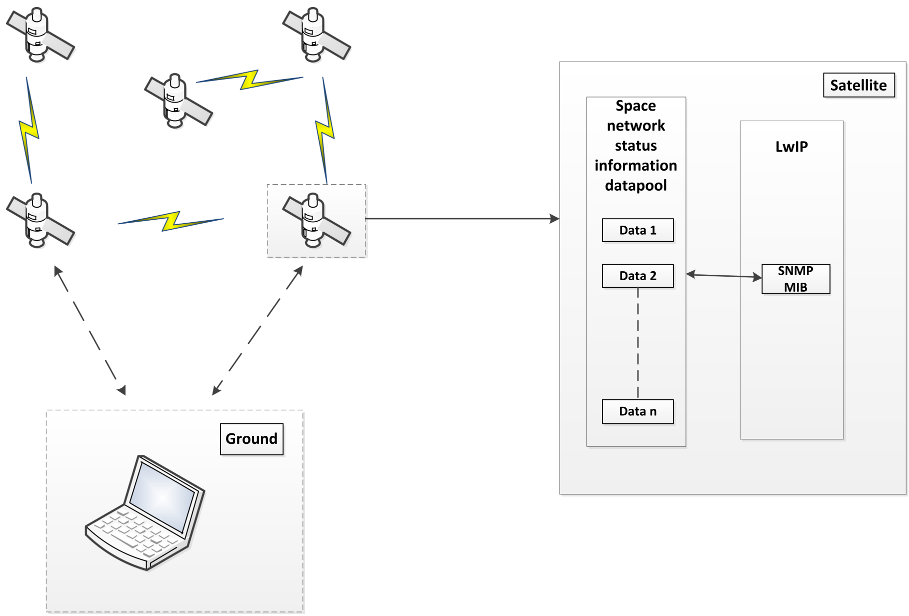

Fig. 1. Space network status real-time monitoring scheme

Second, complement and improve the Simple Network Management Protocol (SNMP), and ensure its normal operation under the LwIP protocol stack [10] to realize space network status monitoring. In the TCP/IP model, the SNMP protocol is located in the application layer, which relies on the transport layer UDP protocol for communication [4, 5]. In the process of space constellation network status monitoring, the management station and agent management model are adopted [7–9]. It is designed to realize the role of agent on the satellite and the role of management station on the ground in this paper. As shown in Fig. 2.

Management station: The management station is an entity that monitors the real-time network status. It is the issuer of commands related to the monitoring status of the entire space constellation network. It sends various management operation commands to the agent and provides space network monitoring personnel operation interface.

Agent: The agent is installed on the satellite node of the space network, monitors the working status of the satellite node where it is located, accepts management control commands from the management station, and reports the execution of the commands to the management station.

Based on the idea of integration of the satellite and the ground, the satellite part needs to be implemented: run the simple network management protocol (SNMP) under the LwIP protocol stack. The core components of SNMP are management information structure and identification (SMI) and management information base (MIB) [3]. All network devices that support SNMP maintain a MIB database that stores information about their operations. The management information base is a collection of management

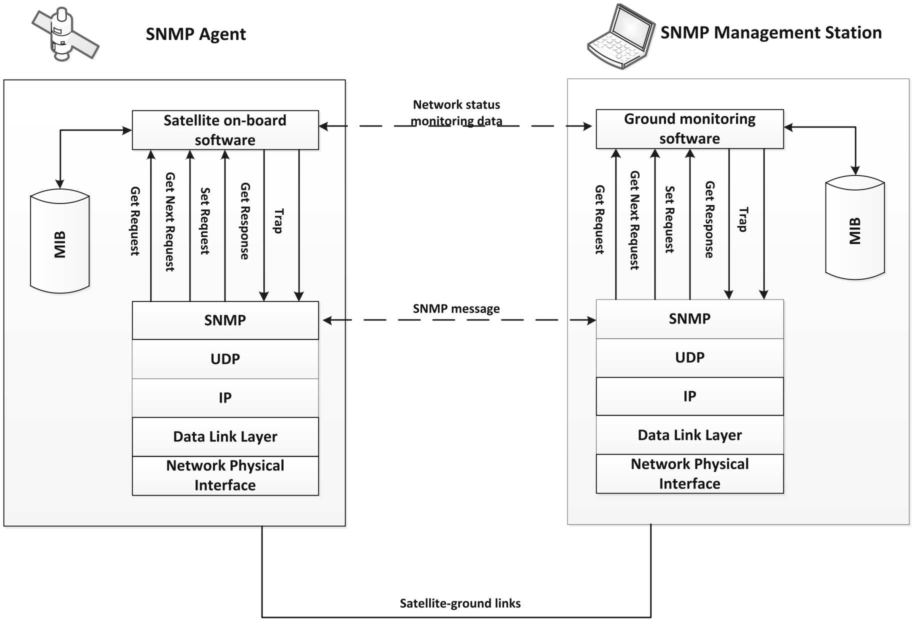

Fig. 2. Spatial network status real-time monitoring model

information. MIB uses SMI and ASN.1 to describe management information. The management information is established under the information tree defined by SMI (1.3.6.1). Each management information is a node of the management information tree and has a unique object identifier. By completing and improving the simple network management protocol, it can gather and manage all space network information on the satellite. Based on this scheme, the management information base corresponding to the satellite on-board network status information is defined and realized, and the network status information is obtained through the simple network management protocol and management information base. The ground part needs to be implemented: run the simple network management protocol under the IP protocol stack, and get the network status information of each satellite node in the space constellation network from the ground by the SNMP command. By interpreting the network status information, get the current space constellation network connection status.

3 Space Constellation Network Status Information Acquisition

3.1 Space Constellation Status Information Acquisition Design

Satellite part (each satellite node in the constellation):

1) Design and implement a space network status information data set, which contains device name, UDP send count, UDP receive count, routing information and other information data that can represent the current space constellation network status, including space constellation network connection status.

2) Bind the space network status information data set with the LwIP protocol stack and routing table running on the satellite. Based on the satellite multi-task operating environment, each task cycle runs to continuously update and maintain the space network state information data set.
3) Supplement and improve the Simple Network Management Protocol (SNMP) for the spatial network status information data set. In addition, the simple network management protocol is combined with the satellite remote control function to provide the ground with access to obtain space network status information. The spatial network status information data set is transmitted to the ground in the form of aperiodic telemetry by relying on the SNMP command.

Ground part:

Run the simple network management protocol under the IP protocol stack, realize the SNMP GetRequest command and GetNextRequest command by remote control commands, and use the ground as a management station to obtain the space network status information of each satellite node in the space network in the form of acyclic telemetry. In addition, by obtaining the next hop address, the next hop IP address of each network segment can be clearly known. For the ground, the IP of each interface of each satellite is known and determined. Using the fixed network segment address as a clue, query each satellite in the transmission path of this network segment, the connection relationship between the satellites can be clarified, and the spatial network connection can be obtained.

3.2 Realization of Space Constellation Status Information Acquisition

Satellite part:

First, the design of space network communication capabilities. Design the protocol stack and external interface to make the protocol stack run normally to achieve inter-satellite and satellite-ground communication. Use Netconn-API to realize the communication mechanism between LwIP protocol stack and the outside, and define the external interface through NETIF. Through the above two parts, the normal operation of the LwIP protocol stack and the communication with the outside are realized to ensure the normal communication in the space network, including inter-satellite and satellite-ground communication. The flow chart for defining the use of Netconn is shown in Fig. 3.

Second, the design of space network UDP communication. Follow the steps below to implement UDP communication under the LwIP protocol stack:

1) Create UDP communication thread (udptx_thread);
2) Initialize source IP, destination IP and transmission content;
3) Create Netconn;
4) Complete the binding of netconn and destination IP;
5) Call netconn_sendto to complete the message sending.

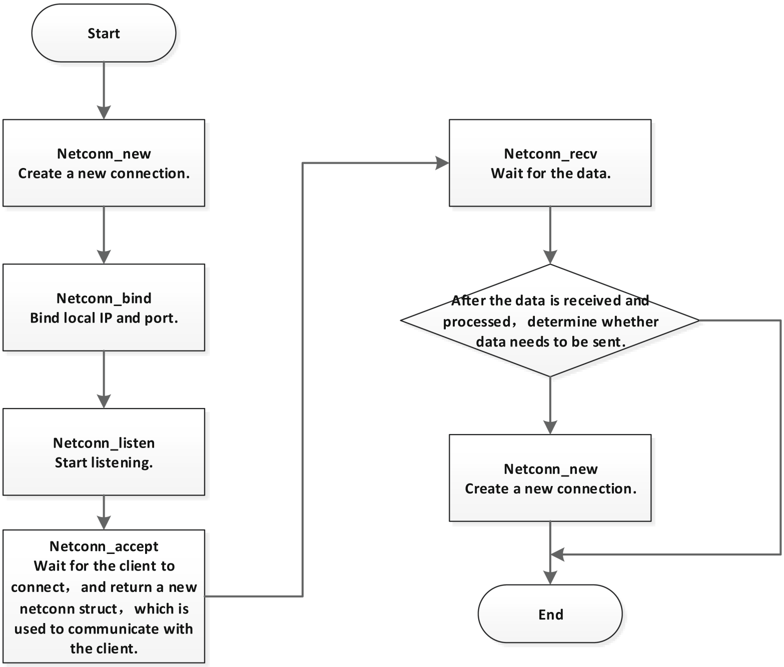

Fig. 3. Netconn implementation flow chart

Third, space constellation network status information acquisition:

1) Determine the required space network status information. as follows: DeviceName-the name of the device; UDPSendNum-the count of sending UDP messages; UDPReceiveNum- the count of receiving UDP messages; NextHopIP-the next hop IP in the routing table. The above information can be expanded as needed.
2) Bind the determined space constellation network status information with the LwIP protocol stack and routing table running on the satellite. Bind network status information such as DeviceName, UDPSendNum, and UDPReceiveNum in the space network status information data set to the LwIP protocol stack. Bind NextHopIP to the routing table. In the multi-tasking environment of satellite-based software, keep updating and maintaining the space network status information data set.
3) Add the space network status information data set to the management information database, and design the corresponding object identifier as follows:
   DeviceName-1.3.6.1.2.1.1.5
   UDPSendNum-1.3.6.1.2.1.2.2.1.17.
   UDPReceiveNum-1.3.6.1.2.1.2.2.1.11.
   NextHopIP-1.3.6.1.2.1.4.21.1.7
4) Determine the SNMP initialization method. Since the Netconn-API is used, an initialization method conforming to the API needs to be selected. The initialization

process is shown in Fig. 4. In order to correctly respond to GetRequest and GetNextRequest commands, it is necessary to ensure that the MIB information is hooked into the correct initialization function during initialization.

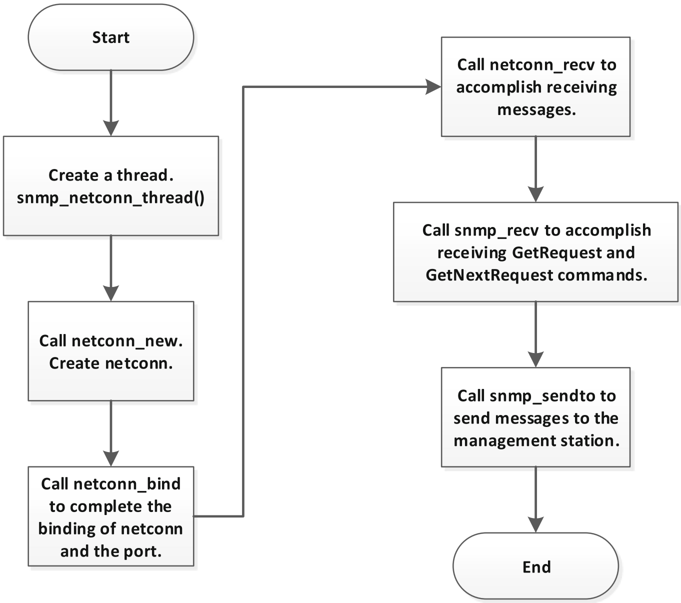

Fig. 4. SNMP initialization flow chart

5) Create a routing table. LwIP itself does not provide a routing mechanism, so the routing table needs to be implemented, including: establishment of the routing table, addition and deletion of routing table entries, access to the routing table, and hooking the completed routing table into the LwIP protocol stack. The specific design is as follows:

   1) Determine the structure content of the routing table entry.
   2) Implement the following functions to complete the routing table management function, including: add entry for routing table; remove a certain entry in the routing table; query an entry in the routing table according to the destination route and return its position in the routing table; query an entry in the routing table according to the destination route and return its Netif; query the next hop address of an entry in the routing table according to the destination route and return; get the current routing table.
   3) Hook the created static routing table into the LwIP protocol stack.
   4) The next hop address information class is implemented in the management information base, and the nexthop_static_route information is obtained by calling nexthop_static_route.

Ground part:

Use the ground IP protocol stack and C # for software implementation to ensure the normal operation of the SNMP protocol. The software flow chart of receiving UDP messages is shown in Fig. 5. Complete sending GetRequest command and GetNextRequest command, the specific implementation flow chart is shown Fig. 6 and Fig. 7.

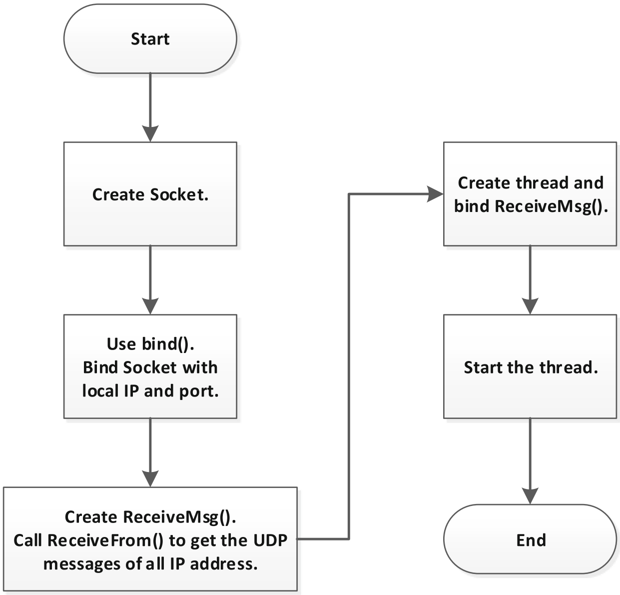

Fig. 5. UDP receiving software flow chart

4 Testing and Verification

4.1 Simulation Test Model and Environment

A simple network scenario is built using commercial shelf products to verify the research content of the paper. The constructed network scenario is shown in Fig. 8:

There are three satellites and a computer in the model. The three satellites communicating with each other simulate space network, a computer simulates ground monitoring equipment. In the above simulation test environment, three STM32 development boards are used to simulate three satellites, and a computer is used to simulate ground equipment. The three development boards are connected to each other through a serial port, and the development board 3 is connected to a computer through a network port. Table 1 shows the network interface configuration of each device:

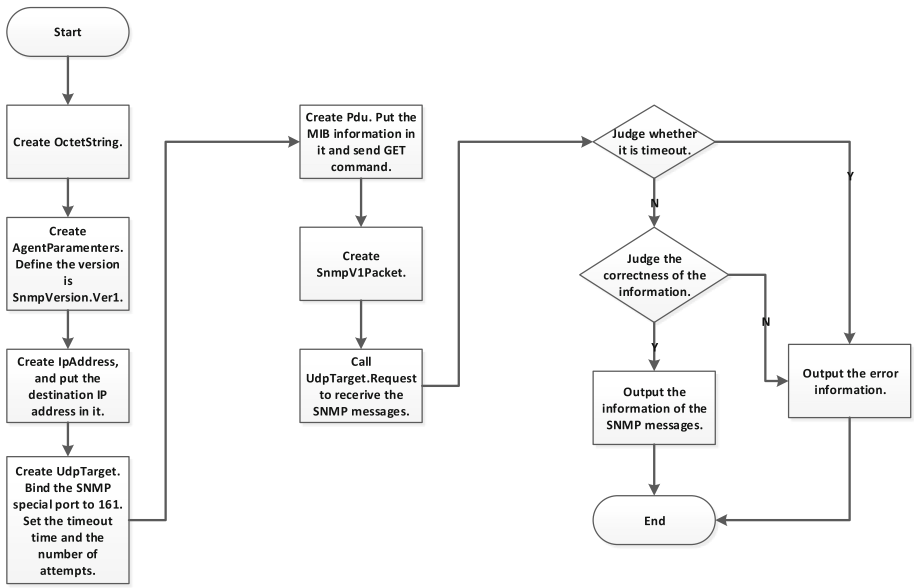

Fig. 6. GetRequest command flowchart

The routing design scheme is shown in Table 2:

4.2 Space Constellation Network Communication Test Results

According to the simulation test model established in Sect. 4.1, design satellite 2 (development board 2) to send UDP information, the destination address is the ground equipment (notebook computer), namely the source IP: 192.16.1.2, the destination IP: 192.168.0.4, the data content: Hello UDP.

The operation status of satellite 2 (development board 2) monitored by ground monitoring software is shown in Fig. 9. From the figure, we can see the operation status of the satellite on-board software, and the UDP transmission count is increasing.

4.3 Space Constellation Network Status to Obtain Test Results

According to the simulation test model established in Sect. 4.1, the ground equipment (notebook computer) and satellite 3 (development board 3) are directly connected via a network cable. To test the connectivity of the network, the GetRequest command and the GetNextRequest command are sent to satellite 1 (development board 1).

Destination IP: 192.168.3.1, device name (1.3.6.1.2.1.5) is obtained by the GetRequest command. The operation of ground monitoring software is shown in Fig. 10. UDP receive count (1.3.6.1.2.1.2.1.11) is obtained by the GetNextRequest command. The operation of ground monitoring software is shown in Fig. 11. UDP send count (1.3.6.1.2.1.2.1.17) is obtained by the GetNextRequest command. The operation of ground monitoring software is shown in Fig. 12.

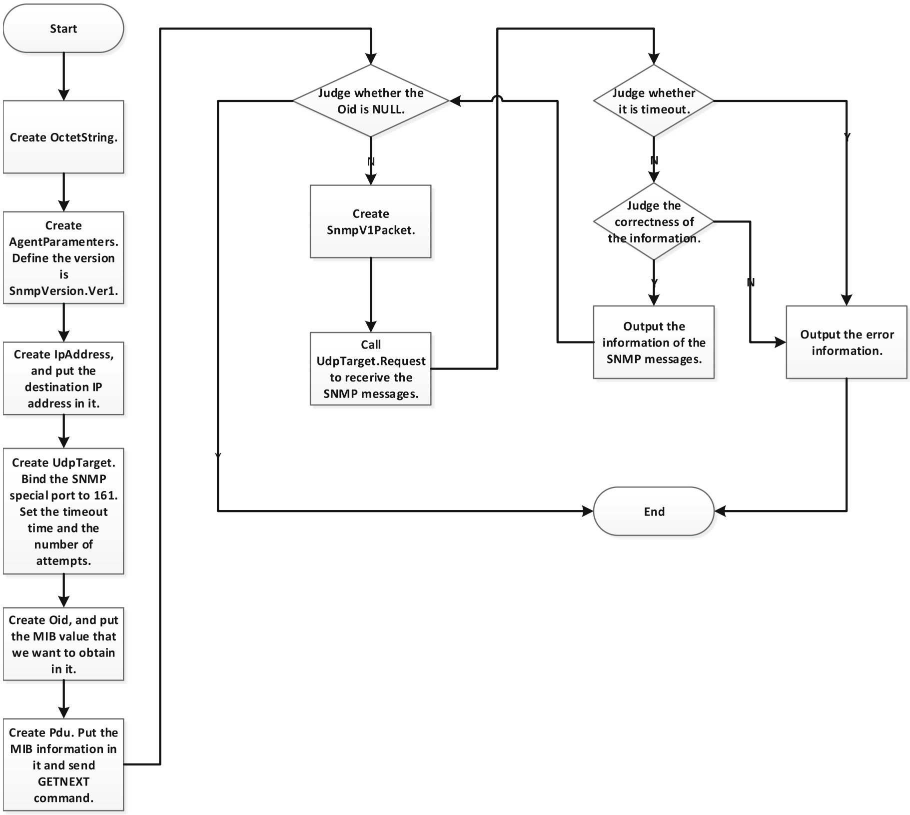

Fig. 7. GetNextRequest command flowchart

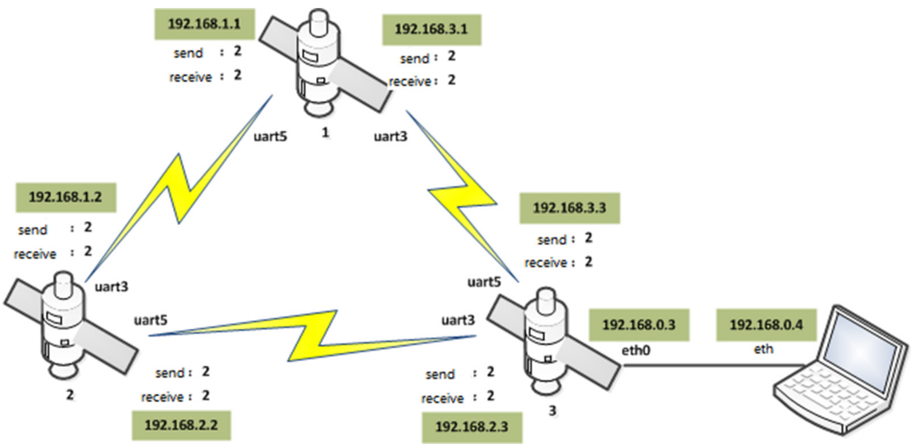

Fig. 8. Spatial network model

Table 1. Device network interface configuration table

Device	Port	IP
Development board1	uart3	192.168.3.1
	uart5	192.168.1.1
Development board2	uart3	192.168.1.2
	uart5	192.168.2.2
Development board3	uart3	192.168.2.3
	uart5	192.168.3.3
	eth0	192.168.0.3
Computer	eth	192.168.0.4

Table 2. Routing design scheme table

Device	Destination IP	Next hop IP	Subnet mask
Development board1	192.168.0.4	192.168.3.3	255.255.255.0
	192.168.3.3	192.168.3.3	255.255.255.0
	192.168.1.2	192.168.1.2	255.255.255.0
	192.168.2.3	192.168.3.3	255.255.255.0
Development board2	192.168.0.4	192.168.1.1	255.255.255.0
	192.168.3.3	192.168.1.1	255.255.255.0
	192.168.1.1	192.168.1.1	255.255.255.0
	192.168.2.3	192.168.2.3	255.255.255.0
Development board3	192.168.0.4	192.168.0.4	255.255.255.0
	192.168.3.1	192.168.3.1	255.255.255.0
	192.168.1.2	192.168.2.2	255.255.255.0
	192.168.2.2	192.168.2.2	255.255.255.0

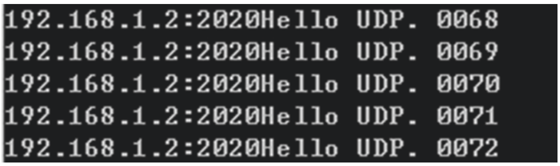

Fig. 9. Ground monitoring software operation

Space network connection status test:

According to the simulation test model established in Sect. 4.1, read the satellite on-board routing table, obtain the next hop address of the corresponding route and output it,

Fig. 10. Ground monitoring software to obtain the name of the device

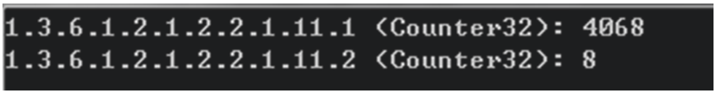

Fig. 11. Ground monitoring software to obtain UDP receive count

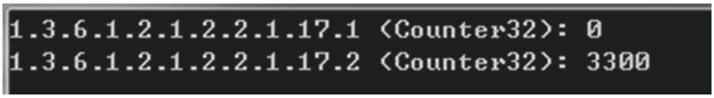

Fig. 12. Ground monitoring software to obtain UDP send count

and get space network connection status. NextHopIP (1.3.6.1.2.1.4.21.1.7) is obtained by using the GetNextRequest command. The result of obtaining the information about NextHopIP of all satellites is shown as follows Table 3:

Table 3. The result of obtaining the information about NextHopIP.

Device	Result
Development board1	1.3.6.1.2.1.4.21.1.7.0.0.0.0 < IPAddress >: 192.168.3.3
	1.3.6.1.2.1.4.21.1.7.192.168.2.0 < IPAddress >: 192.168.1.2
	1.3.6.1.2.1.4.21.1.7.192.168.3.0 < IPAddress >: 192.168.3.3
Development board2	1.3.6.1.2.1.4.21.1.7.0.0.0.0 < IPAddress >: 192.168.1.1
	1.3.6.1.2.1.4.21.1.7.192.168.1.0 < IPAddress >: 192.168.1.1
	1.3.6.1.2.1.4.21.1.7.192.168.2.0 < IPAddress >: 192.168.2.3
Development board3	1.3.6.1.2.1.4.21.1.7.0.0.0.0 < IPAddress >: 192.168.0.4
	1.3.6.1.2.1.4.21.1.7.192.168.0.0 < IPAddress >: 192.168.0.4
	1.3.6.1.2.1.4.21.1.7.192.168.2.0 < IPAddress >: 192.168.2.2
	1.3.6.1.2.1.4.21.1.7.192.168.3.0 < IPAddress >: 192.168.3.1

From the table, satellite 1 (development board 1): the next hop address of the default route is 192.168.3.3, the next hop address of the 192.168.2.0 network segment is 192.168.1.2, and the next hop address of the 192.168.3.0 network segment is 192.168.3.3. Satellite 2 (development board 2): the next hop address of the default route is 192.168.1.1, the next hop address of the 192.168.1.0 network segment is 192.168.1.1, and the next hop address of 192.168.2.0 network segment is 192.168.2.3. Satellite 3 (development board 3): the next hop address of the default route is 192.168.0.4, the next hop address of the 192.168.0.0 network segment is 192.168.0.4, the next hop address of the 192.168.2.0 network segment is 192.168.2.2, and the next hop address of the 192.168.3.0 network segment is 192.168.3.1.

According to the information we have, the spatial network connection status of the entire space constellation shown in Fig. 8 can be obtained.

4.4 Test Results of the Ground Monitoring Software Platform

In order to monitor the network status and clarify the spatial network connection status, the following ground monitoring software platform is made to integrate the above functions, as shown in Fig. 13. Figure 13 show the state after the stand-alone "acquire" button.

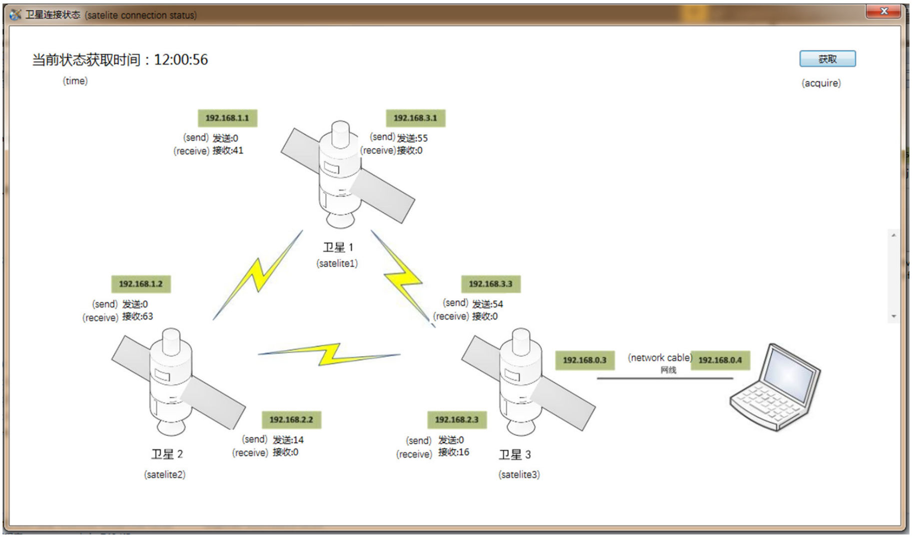

Fig. 13. State diagram of ground monitoring software after acquisition

5 Summary

Facing the booming development of space constellation networks, real-time monitoring of space constellation network status is increasingly important. Traditional reliance on telemetry for downlink space network status information has the shortcomings of poor real-time and poor autonomy. This paper proposes the idea of integrating the satellite and the ground, and runs the simple network management protocol under the satellite LwIP protocol stack. Under the premise of maintaining good compatibility with the ground, the realization of monitoring space network status information has high real-time and autonomously obtainable capabilities.

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