Research for Data Communications Based on IPv6 in Integrated Space-Ground Network

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Abstract. The integrated space-ground network and its architecture are the focus and difficulty in research. Aiming at the problems of the incompatibility between satellite networks, satellite networks and ground networks, and the insufficiency of space network address resources, we propose an integrated space-ground network architecture based on the next generation Internet protocol IPv6. It combines the space communication protocols defined by CCSDS. The network layer protocol based on IPv6 is the foundation of the architecture. It ensures the interconnection and interoperability among inter-satellite networks and intra-satellite networks. The protocol of each layer in the architecture is designed. The IPv6 protocol, inter-satellite and intra-satellite transmission format, inter-satellite routing and intra-satellite communications are analyzed and designed. The experimental results show that the designed satellite router realizes the network communication and routing of IPv6 packets in intra-satellite and inter-satellite networks. It shields the differences between the satellite and ground network systems at the protocol level. It makes the satellite networks have good scalability and adaptability as with as the ground networks.

Keywords: Satellite network · Inter-satellite routing · Intra-satellite communication

1 Introduction

With the rapid development of aerospace industry and the advantages of space network in Civil Communications and military fields, integrated space-ground network has become a hot research topic and key project in China. In recent years, the construction of information network has made rapid progress and achieved remarkable results. However, the development of China's space information network and ground Internet is very imbalanced, showing the characteristics of "the space information network is weak and ground Internet is strong". In the space information network, China has initially built communication relay systems, navigation and positioning systems, earth observation systems and other systems. However, each satellite system is built independently, the number of satellites is seriously insufficient, and the type of satellite is relatively simple. What is more prominent is that satellites do not have a space network and cannot have a comprehensive efficiency. The planning and designs are not efficient

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in integrated space-ground network, the advantages of the integration of space and earth has not been realized, and the information service capability of the integrated space-ground network has not been formed [1–4].

The International Maritime Satellite (INMARSAT) has 11 GEO communication satellites in orbit, which can provide global mobile communication and IP access services. The United States and other countries have established satellite communication systems with space networking such as Iridium and AEHF. The idea of integrated space-ground network such as Interplanetary Network (IPN) and transitional communication satellite system (TSAT) is proposed. A series of space technology experiments, including space router (IRIS) are carried out [5–9].

The construction of space network and the engineering realization are still needed to be strengthened. Although there are nearly 100 satellites such as remote sensing satellites, navigation satellites and communication satellites on orbit, the satellites have the following problems:

(1) Most of these satellites are working independently and are unable to communicate and connect with one another.
(2) Communication protocols between satellites are not uniform and inconsistent with international standards. As a result, they can't communicate with each other. Even if there are individual satellites that can communicate with each other, they are still isolated from most satellites. The other satellites are difficult to access and communicate with them.
(3) The number of ground stations is insufficient. One single satellite operation mode is difficult to interact with the ground, and can't be integrated into a unified network with the ground network.

Similar to the initial stage of the development of ground network, the development of space technology has put forward higher requirements for the framework of space communication [10]. It is necessary to guarantee the integration of space information system and ground information network through network technology. The ground Internet technology based on IP network provides an effective means for the integration of space network and ground network. At present, the global IPv4 address resources have been basically exhausted, and the address resources allocated to our country are very few, which can not meet the needs of the space network for address resources. However, the next generation Internet protocol IPv6 has a huge amount of address resources, which can solve that problem. At present, IPv6 is the only core protocol that can replace IPv4 in the next generation of Internet. It has been widely recognized and applied in the field of Internet [11].

Therefore, based on the next generation Internet protocol (IPv6), this paper designs the data Communications in Integrated Space-ground Network. It shields the differences between different systems at the protocol level, and provides users with cross-system services and applications that do not need to distinguish between space and ground. It provides design schemes and technical reference for the implementation of integrated space-ground Network.

2 Communication Protocol Architecture Design

The integrated space-ground network consists of the ground network and space network. It uses a unified technical framework, unified technical system and unified standards. Space network consists of space-based backbone network, space-based access network and ground node network. Ground network is more mature, so this paper focuses on the space network, including inter-satellite communication (including satellite-to-ground communication) and intra-satellite communication.

In order to realize the communications in integrated space-ground network, the design of space network communication protocol architecture follows the following principles:

(1) Integration and standardization principles. The space network and ground network are considered as a whole networks, the network can be interconnected and interoperable, and the network protocols meet uniformed standards.
(2) Efficient adaptability and scalability principles. The space network is required to be as scalable and adaptable as the ground network, with flexible network expansion and access modes.
(3) Minimum Cost Principle. It is designed to avoid the problem of extra overhead caused by multiple protocol transformations to adapt to different communication protocols, so that the network communication performance is optimal.

Based on the above principles, the satellite network adopts IP packet forwarding mode in the network layer which is the same with the ground network, and puts the IP network above the physical layer and the data link layer of the satellite network. When interconnecting with the ground network, the satellite network can be regarded as an independent subnet, which assigns IP addresses to each satellite node, and carries out network access and routing through the satellite router to shield the changes of network topology. The space network topology based on IP is shown in Fig. 1.

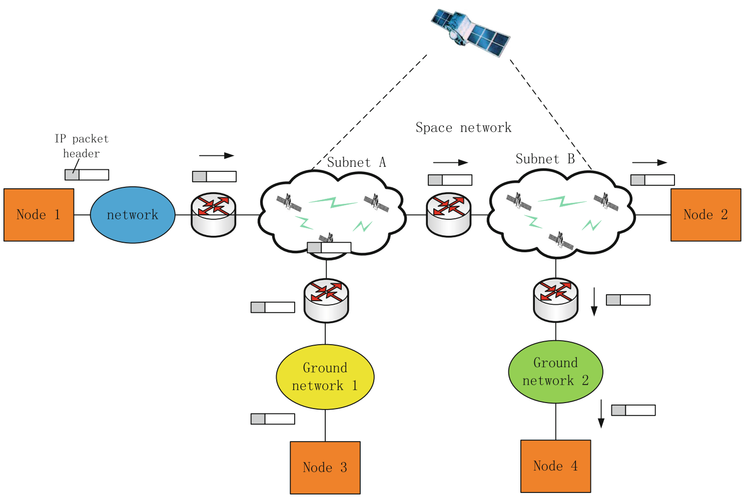

Fig. 1. Space network topology based on IP

The lower layer of IP network layer mainly completes the data transfer function between nodes of a certain data link. When it needs to transmit across multiple data links and networks, IP network layer can realize the data transmission from node to node in different satellite networks or ground networks. In Fig. 1, the network packet switching and routing control are implemented by satellite routers between the satellite sub-networks and between the satellite sub-networks and ground networks. By satellite router, when node 1 communicates with node 2 in satellite subnet B, it sends IP packets to subnet A and routes to node 2 via two hops. When node 1 communicates with node 4 on the ground, it transmits to ground network 2 after several routes. It completes point-to-point communication with node 4 across inter-satellite network and ground network.

The adoption of IP network in satellite networks has the following advantages:

(1) The interconnection of multiple heterogeneous subnets is realized. IP network layer can shield the differences between different networks, including satellite networks and ground networks, realize data transmission across multiple networks, and enable communication between space networks and any nodes in the ground network, so as to achieve the purpose of space-ground integration and interconnection.
(2) It is compatible with ground network. As one or more sub-networks, satellite networks can directly use IP packets to communicate with ground networks, which reduces the cost of protocol conversion.
(3) The network has good reliability and flexibility. Due to the packets forwarding, when a satellite communication link is disconnected, the satellite network can reflect the change of the satellite network topology in real time. The routing table can be modified to forward packets to the destination satellite node through other links. It is suitable for the satellite network environment with changing network topology.

The design of inter-satellite network and intra-satellite network communication protocol is the key problem in integrated space-ground network. Although the CCSDS protocol is relatively perfect in space application, it can not be directly used to communicate with the ground network and has the problem of protocol conversion. In order to realize the interconnection between satellite network and ground network, the ground network protocols are applied to satellite network. Combined with the IPv6 protocol of ground network, the space communication protocols defined by CCSDS, the integrated space-ground network communication protocol architecture as shown in Fig. 2 is established. The network layer protocol based on IPv6 is the foundation of the architecture. It ensures the interconnection and interoperability among the inter-satellite networks and the intra-satellite networks.

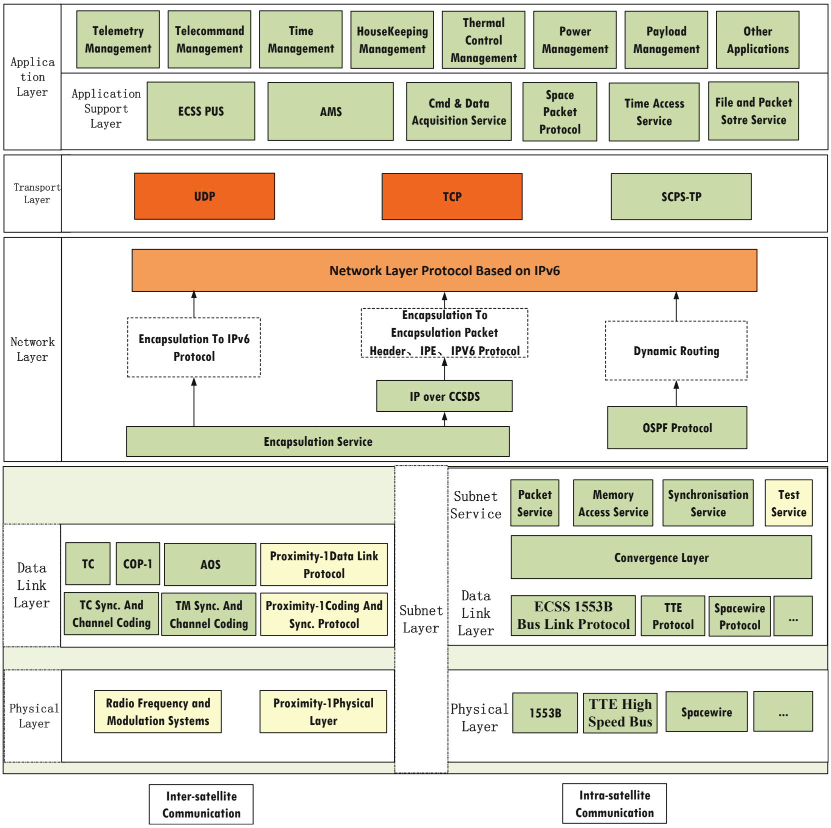

Fig. 2. Communication protocol architecture of integrated space-ground network

2.1 Physical Layer

According to the different communication links of satellite network, the physical layer is divided into the inter-satellite communication physical layer and the intra-satellite communication physical layer. The physical layer of inter-satellite communication includes radio frequency modulation system and Proximity-1 physical layer. The physical layer of inter-satellite communication includes 1553B bus, TTE high speed bus, spacewire bus and so on.

2.2 Data Link Layer

The data link layer is responsible for data transmission between nodes directly connected to physical links. In the data link layer, the inter-satellite communication protocol uses CCSDS defined Telecommand space data link protocol (TC), Advanced Orbiting System (AOS), COP-1, Proximity-1 spatial link protocol, remote control synchronization and channel coding, telemetry synchronization and channel coding, Proximity-1 coding and synchronization sub-layer protocol. According to the different communication media, the intra-satellite communication protocol can adopt five kinds of standard services: 1553B communication protocol, TTE communication protocol, spacewire communication protocol, convergence layer protocol and subnet services.

2.3 Network Layer

Based on IPV6, the network layer provides the upper layer users with a unified addressing and routing service in inter-satellite network and intra-satellite network, which is the core of the whole architecture. The network layer includes IPV6 protocol, packaging service, IP Over CCSDS protocol and OSPF protocol. The IP packets are encapsulated by IP Over CCSDS, and the IPE header is added. Then the IP packet is encapsulated by the encapsulation of the encapsulated services, which can be transmitted through the inter-satellite link.

2.4 Transport Layer

The transport layer provides end to end data transmission services for the upper users and plays a reliable role in transmission. The layer is processed only on communication nodes without processing on the router. The specification of space communication protocol – Transport Protocol (SCPS-TP) defined by CCSDS, can be used as a transport layer protocol. Because IPV6 protocol is applied in the network layer, TCP and UDP can be used directly in the transport layer. The packets generated by them can be transmitted directly to IPV6 protocol in the network layer for processing. The communication protocol and process are not different from those of the ground network, which facilitates the efficient integration of space network and ground network.

2.5 Application Layer

The application layer is mainly related to the spacecraft platform and load application, which can be divided into application support layer. In the application support layer, this protocol architecture provides standard services for satellite-ground operations, remote operations between spacecrafts and intra-satellite data transmission through PUS protocols and application support layer services of SOIS. The PUS standards are part of the European space standards organization ECSS's standard series, which defines 16 types of operations to meet the needs of ground operations. The standards describe in detail how these businesses are used by the ground for standardized operations, and define in detail the data formats for business requests (remote packages) and business reports (telemetry packages).

3 Integrated Design of Inter-satellite and Intra-satellite Communications

3.1 IPv6 Protocol

Although both are in IP network layers, IPv6 and IPv4 are very different in protocol format. IPv4 has a fixed header length and a larger number of fields. These fields need to be filled in regardless of whether they are used in the communication process, which wastes and consumes network bandwidth and routing performance greatly. In order to reduce the burden of the router, IPv6 protocol omits the checksum field of the packet header, so the router no longer calculates the checksum, thus improving the efficiency of data routing, and part of the identification code becomes an option to re-optimize the packet format.

One IPv6 address consists of 16 bytes and can effectively provide almost unlimited network address space, so the IPv6 address resources used by spatial networks are no longer restricted.

The second major improvement to IPv6 is simplification of the header, which consists of seven domains (13 domains in IPv4) with a fixed length (40 bytes). This improvement enables routers to process packets more quickly, thus improving router throughput and shortening latency.

The third major improvement is to support the optional functions. This is essential for the new header, because the previously required domains have now become optional domains, allowing routers to simply skip options that are not relevant to it. This improvement speeds up the packets processing [12].

3.2 Inter-satellite and Intra-satellite Transmission Format Design

According to the integrated communication protocol architecture, the conversion between satellite-to-ground and inter-satellite protocols is minimized. KA or laser high-speed physical links are used for satellite-to-ground and inter-satellite's communications in physical layer. AOS protocol is used in this layer. IPv6 protocol, encapsulation service and IP Over CCSDS protocol are used in network layer. UDP protocol is used in transport layer. Space packet protocol or other extended protocols are used in application layer. Inter package protocol or other extension protocol.

Between satellites, complete data with synchronous header and LDPC encoding is transmitted in physical layer. The data link layer uses CCSDS AOS protocol, encapsulates AOS header, insertion domain, MPDU header and other data domains. The network layer uses encapsulation header and IPv6 format to carry out routing processing based on IPv6. The transmission layer uses UDP packet, while the application layer uses space packet or user defined data.

The processing of each layer in the inter-satellite and intra-satellite integrated communication protocol architecture is shown in Fig. 3. When the data is transmitted, the protocol header and the data of the application itself are appended to the data. All packets received from the upper layer are passed to the underlying layer by encapsulating the protocol header of the layer. The encapsulation header and IPE header are removed by the satellite router, and then sent to the receiver. After each protocol layer, there will be information identifying the sender and receiver of the packet. The data link layer is identified by the spacecraft ID in AOS. The network layer has an IPv6 address. The transport layer uses the port number as the address to identify the two end nodes, and the application layer uses the APID of the space packet as the address of the application.

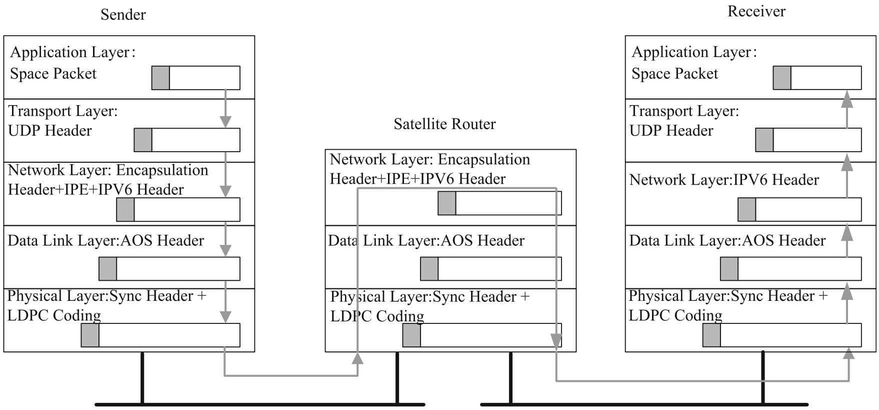

Fig. 3. Processing of each layer in integrated communication protocol architecture

3.3 Inter-satellite Routing

To make the satellite networks to be interconnected, the problem of inter-satellite routing must be solved first.

Although the routing problem has been well solved and applied in ground networks, there are still many difficulties in satellite network. In performing inter-satellite routing, the following main characteristics of satellite networks should be considered:

(1) Limited capacity for on-board processing and storage;
(2) Longer time delay and higher error rate;
(3) Highly dynamic network topology.

In view of the fact that many dynamic routing algorithms require high computing and storage resources, and the processing capacity of satellite router is still low, in order to solve the above problems, this paper uses static routing design, through hardware and software cooperation, in a less overhead way to achieve inter-satellite routing function. The operation of routing table is the key part of the whole routing protocol. It records the routing information of the whole network. It has a direct effect on the efficiency of routing. Therefore, a hardware routing table is designed, which contains IPv6 address, next hop address and inter-satellite port information. The inter-satellite routing table is designed in Fig. 4.

After receiving the inter-satellite data, FPGA parses the network layer and gets the next hop address and inter-satellite communication port by looking up the table according to the destination IPv6 address. If they are the other satellite's data, it sends

Destination IPv6 Address	IPv6 Address of Next Hop	Inter-satellite communication Port

Fig. 4. Structure of inter-satellite routing table

them to that satellite through the inter-satellite link port. If they are the local satellite's data, it sends them to the local satellite's device through the intra-satellite bus. The routing table is updated by injecting routing tables through software.

3.4 Intra-satellite Communication

The integrated communication protocol architecture takes intra-satellite communication as a part of the network architecture, which effectively solves the communication problem between intra-satellite equipment nodes and other satellite equipment nodes. It is not only suitable for traditional 1553B bus, but also for Time-Triggered Ethernet (TTE) high-speed bus. Because of the difference of the bus communication process, the protocol layers of the two buses are slightly different.

The onboard router designed in this paper not only serves as inter-satellite routing, but also has the function of intra-satellite data routing. As shown in Fig. 5, 1553B bus is used inside the satellite. After receiving data from other satellites, the satellite router parses the space packet and sends them to 1553B bus through the space packet protocol, packet service and data link aggregation protocol. And then the RT address of the device in 1553B bus is generated according to the APID (application layer address) in the space packet. The space packet is routed to the destination bus device in 1553B bus.

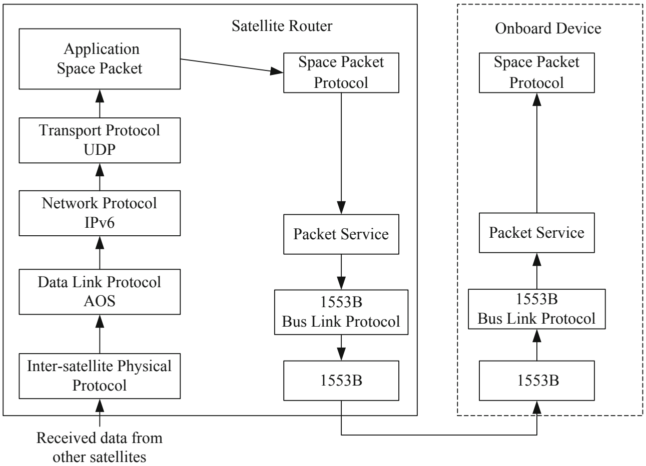

Fig. 5. Communication process of intra-satellite 1553B bus

As shown in Fig. 6, a TTE high-speed bus is used in the satellite. After receiving data from other satellites, the satellite router knows that the data needs to be processed by itself after judgement by software. The data in network layer is transmitted downward to the data link layer. Then the data is sent to TTE bus as the data link layer data by adding the MAC header of the TTE network. After receiving the data, the device on the TTE bus can get the application data and process it after parsing UDP/IPv6 packets. It can be seen that the process is interconnected with the ground network.

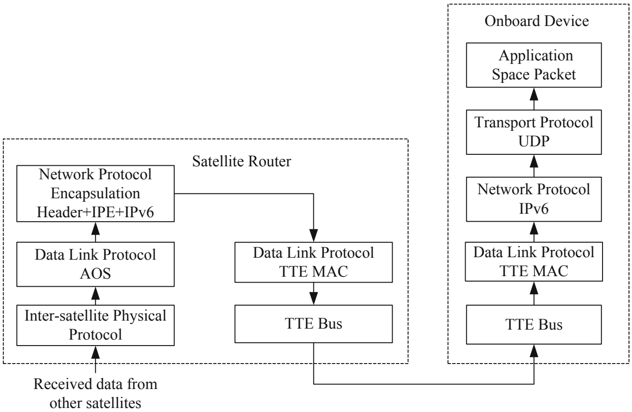

Fig. 6. Communication process of intra-satellite TTE bus

4 Implementation and Verification

This paper tests and verifies the satellite router based on IPv6, which realizes inter-satellite communication and intra-satellite data routing. In hardware configuration, a four-core anti-irradiation processor S698PM with main frequency up to 600 MHz is used, a FPGA chip XC5VFX130T is used, and a six-channel high-speed TLK2711 interface is used in inter-satellite data communication. The inter-satellite links are established with six satellites (or ground stations) through laser or KA antennas, and the peak rate of receiving and receiving can reach 1 Gbps per interface. A high-efficient time-triggered Ethernet TTE is used in intra-satellite bus communication to realize high-speed data communication of various devices in the satellite, and the data transmission rate can reach up to 1 Gbps.

The data from other satellites is sent to TLK2711 interface 1 by ground test equipment. After judging that the data will be sent to the other satellite by IP address, the satellite router queries the routing table and sends it to the destination satellite through TLK2711 interface 2. In this way, the inter-satellite communication function is verified.

The satellite data is sent to TLK2711 interface 1 of the satellite router through the ground test equipment. After judging that the data will be processed by the satellite's SMU (System Management Unit) device by IP address, the satellite router sends it to SMU via TTE bus. As shown in Fig. 7, The IPv6 packets communicated through TTE bus are monitored by the network monitoring tool WireShark. The satellite router is the transmitter, its IPv6 address is fd01:: A, and the receiving address is fd01:: 6. The satellite router receives the local satellite's IPv6 packet and routes it to the other device in the local satellite. In this way, the intra-satellite communication function based on IPv6 is verified, which indicates that the IPv6 packet can be transmitted directly in the intra-satellite network.

No.	Time	Source	Destination	Protocol	Length	Info
155	7.63475000	10.74.15.155	10.74.15.255	NBNS	92	Name query NB WWW.SOHU.COM<00>
156	7.65866300	10.74.14.2	10.74.15.255	NBNS	92	Name query NB WWW.SOHU.COM<00>
157	7.67374600	HonHaiPr_b2:bf:08	Broadcast	ARP	60	Who has 10.74.15.146? Tell 10.74.14.60
158	7.72662000	Dell_71:92:8d	Broadcast	ARP	74	Who has 10.64.1.106? Tell 10.74.14.40
159	7.73274700	HonHaiPr_b2:ad:7c	Broadcast	ARP	60	Who has 10.74.14.33? Tell 10.74.14.31
160	7.78487500	fd01::a	fd01::6	ICMPv6	94	Echo (ping) request id=0x0001, seq=18, hop limit=128 (no r
161	7.78573100	fd01::6	fd01::a	ICMPv6	94	Echo (ping) reply id=0x0001, seq=18, hop limit=128 (reques
162	7.78830700	D-LinkIn_e9:3e:4a	Broadcast	ARP	60	Who has 10.74.14.132? Tell 10.74.14.135
163	8.03334900	10.74.14.60	10.74.15.255	NBNS	92	Name query NB WWW.SOHU.COM<00>
164	8.04059900	10.74.14.29	10.74.15.255	NBNS	92	Name query NB WWW.SOHU.COM<00>
165	8.11160900	HonHaiPr_b2:bf:08	Broadcast	ARP	60	Who has 10.74.14.37? Tell 10.74.14.60
166	8.17052400	HonHaiPr_b2:ad:7c	Broadcast	ARP	60	Who has 10.74.15.146? Tell 10.74.14.31

Fig. 7. IPv6 packets from satellite router to SMU

The experimental results show that the designed satellite router realizes the whole network communication and routing of IPv6 packets in intra-satellite, inter-satellite and ground network. It ensures the whole network access with the minimum protocol overhead.

5 Conclusion

The integrated space-ground network is one of the important designs of the system engineering. The implementation of the integrated space-ground network will push the top-level design of information system and the integration of space and ground to a new height, and will realize the leap-forward improvement of the service ability of information system in China [13]. Aiming at the present situation and requirement of integrated space-ground network, this paper presents the design of integrated space-ground network communication protocol architecture based on IPv6, and analyzes and designs IPv6 protocol, inter-satellite communication format based on UDP/IPv6 and CCSDS protocol, inter-satellite routing, inter-satellite communication and so on. Finally, it gives the experimental verification. It provides technical support for the construction and engineering implementation of integrated space-ground network.

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