Research on Space Information Network Protocol

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Abstract. This paper introduces four space information network protocol researched and applied internationally: space IP protocol, CCSDS protocol, protocol combining CCSDS and TCP/IP, and delay/interrupt tolerant network (DTN) protocol. The protocol architecture, protocol components and functions are introduced and analyzed. At the same time, the method of performance improvement of space satellite communication TCP protocol is briefly introduced.

Keywords: Space information network · CCSDS · DTN · TCP/IP

1 Introduction

The space information network is a network system that acquires, transmits and processes space information in real time on the basis of a space platform (such as synchronous satellite or medium or low orbit satellite, stratospheric balloon and manned or unmanned aerial vehicle). The space information network can serve major applications such as ocean sailing, emergency rescue, navigation and positioning, air transportation, and Aerospace measurement and control. It supports high dynamic, broadband real time transmission of ground observations downwards, and supports ultra long range, large delay reliable transmission of deep space detection upwards. Because the space communication environment has the characteristics of large link delay, high bit error rate, asymmetric forward reverse link and easy interruption, the existing Internet TCP/IP protocol cannot adapt well to this environment, CCSDS (Consultative Committee for Space Data Systems) has extended and improved the TCP/IP protocol, composed the SCPS protocol suite adapted to the space network. In order to adapt to the restricted network environment such as long delay and intermittent connection of space communication, a Delay/Disruption Tolerant Network (DTN) protocol is proposed.

2 Characteristics of Space Information Networks

Space information networks have many different characteristics compared to terrestrial networks and face the following challenges [1]:

(1) The space information network is sparse and the network topology changes frequently. The high speed operation of the satellite in orbit makes the network topology unstable.

Q. Yu (Ed.): SINC 2019, CCIS 1169, pp. 163–171, 2020.
https://doi.org/10.1007/978-981-15-3442-3_13

(2) The orbits of satellites or spacecraft are pre-set, predictable, and very different from the two-dimensional motion models commonly used in mobile ad hoc networks.
(3) The link is asymmetric and the propagation delay is large. In order to reduce the overhead of terrestrial mobile terminals, many satellite systems employ a downlink/uplink asymmetric communication scheme. Due to the long distance of space data transmission, the transmission delay is much larger than that of the terrestrial network, and the asymmetry of the link makes it easy to reduce the efficiency of data transmission.
(4) The high error rate of data transmission link. The distance between the interstellar, inter-satellite, and star-to-earth links is large, and the data signal strength is proportionally attenuated as the transmission distance increases. At the same time, the transmission is easily distorted by various random factors such as sputum phenomenon, eclipse phenomenon, weather state (rain decay, etc.), shadow effect, multipath effect, ionization effect, etc., resulting in high data transmission error rate.
(5) Intermittent network connection. In a space network, due to the different orbits and speeds of the communication nodes, the stability of the communication link connection is poor, and the space environment is affected, and the link is interrupted frequently.
(6) The complexity of the network protocol. Spacecraft has a wide variety of functions. The application system is self-contained and the communication protocol standards are different. The terrestrial network protocol adapts to low latency data transmission. The long delay space network protocol does not match the terrestrial network protocol.
(7) The finiteness of node resources. The high cost and environmental constraints of spacecraft require spacecraft communication equipment to be small in size, light in weight, low in power consumption, and high in performance. The resource allocation of equipment is strictly limited, and the aerospace-grade anti-irradiation device is usually used on the star. To ensure high reliability, the performance of the device itself is much lower than that of terrestrial commercial devices, so the node resources are limited, and the calculation, storage, processing and transmission capabilities of the on-board load are relatively weak.
(8) The particularity of the space environment. The ionosphere, troposphere, and space electromagnetic activities easily destroy the communication function of the space network nodes. This requires strengthening the research on the node protection capability. The redundancy, reliability, and security of the system should be fully considered in the design.

3 Space Information Network Protocol System

At present, the space information network protocol system mainly includes: a space IP protocol system, a CCSDS protocol system, a protocol system combining CCSDS and TCP/IP, and a delay/interrupt tolerant network (DTN) protocol system. These protocol systems are interdependent. The mature technology of terrestrial Internet TCP/IP and the application verification of space IP provide a clear direction for the improvement of CCSDS recommendations. The protocol system combining CCSDS and IP can take advantage of TCP/IP. And can meet the requirements of space communication, DTN protocol architecture can solve the problem of reliable transmission under heterogeneous conditions in deep space environment.

3.1 Space IP Protocol System

The NASA Goddard Space Center established the OMNI project in 2002 to provide addressing capabilities, standard Internet protocols, and network application capabilities for future space missions, enabling users to establish end-to-end connectivity with their spacecraft anytime, anywhere. To this end, OMNI uses terrestrial commercial Internet technology for spacecraft, integrates space networks with terrestrial networks, and ensures that all network nodes operate as Internet nodes, enabling all-IP interconnection of terrestrial end users to spacecraft, reflecting different technological development ideas from CCSDS. The TCP/IP based protocol used by OMNI is shown in Fig. 1.

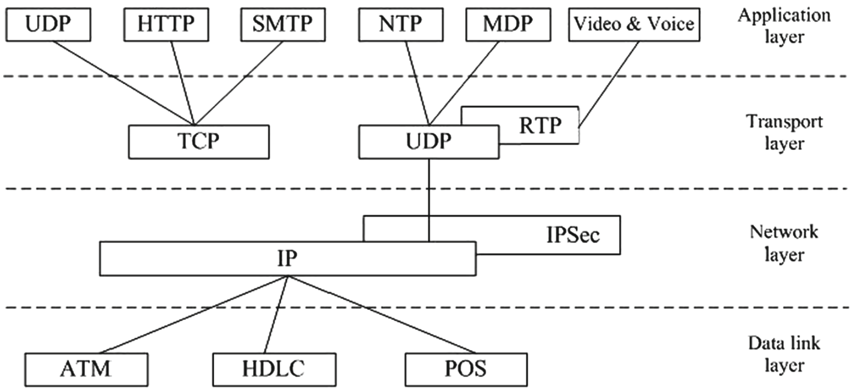

Fig. 1. Space TCP/IP protocol system

(1) Data link layer. Use data link layer protocols that are commercially available on the ground system, such as HDLC (Advanced Data Link Control), POS (Packet over SONET), and ATM (Asynchronous Transfer Mode). It is convenient for the air ground link and the commercial router to directly interface at the data link layer.
(2) Network layer. Use the IP protocol. Use IETF standard routing protocols, such as RIP, OSPF, BGP, etc. Use mobile IP protocol to solve the problem of single spacecraft flying over multiple ground stations. Use mobile network protocols (RFC3963) to solve the problem of multi access spacecraft moving through multiple ground stations.
(3) Transport layer. Use TCP and UDP protocols (and RTP protocol). The spacecraft real time telemetry data and payload data are transmitted using the UDP protocol. In the abnormal situation, the spacecraft is blindly controlled. Under normal circumstances, the spacecraft is controlled by the TCP protocol, and signaling information

related to the mobile IP protocol is transmitted. Real time multimedia communication is supported by the Real-time Transport Protocol (RTP). The RTP family consists of two protocols: Data Transfer Protocol (RTP) and Control Protocol (RTCP). RTP is responsible for transmitting data packets with real time information. It generally works on the base of UDP, it adds information such as time scale and serial number. The receiving end uses RTP to synchronize video and audio data. RTCP is responsible for monitoring network service quality, communication bandwidth, etc., and notifying it to the sender.

3.2 CCSDS Protocol System

The protocol architecture defined by CCSDS includes: application layer, transport layer, network layer, data link layer, and physical layer, each layer contains several combinable protocols. Figure 2 shows the CCSDS space communication protocol reference model.

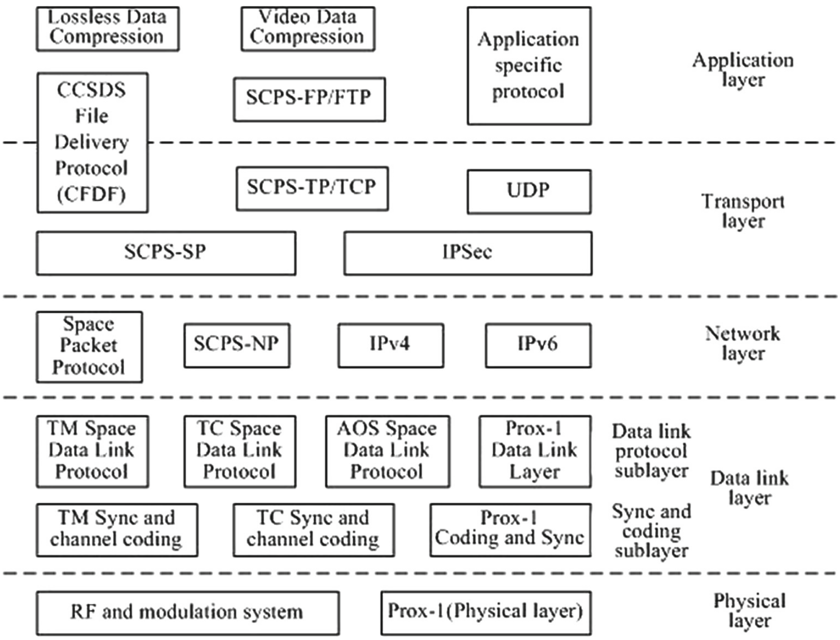

Fig. 2. CCSDS protocol system

(1) Physical layer. CCSDS defines a radio frequency and modulation system that specifies the physical layer protocol between the spacecraft and the ground monitoring station. The Prox-1 link protocol defines the physical layer characteristics of adjacent space links.
(2) Data link layer. The CCSDS Data Link sublayer defines the method of transmitting data over a space link using packets. The Synchronization and Channel Coding

sublayer defines a method of frame synchronizing and channel coding over the space link. The CCSDS Data Link Protocol sublayer consists of four protocols: TC Space Data Link Protocol, TM Space Data Link Protocol, AOS Space Data Link Protocol, and Data Link Layer of the Prox-1 Space Link Protocol. The above protocol specifies the ability to transmit data in a space link, collectively referred to as SDLP (space data link protocol). Correspondingly, CCSDS also specifies three specifications for the synchronization and channel coding sublayer of the data link layer: TM synchronization and channel coding, TC synchronization and channel coding, coding and synchronization layer protocol of the Prox-1 space link protocol.

(3) Network layer. CCSDS specifies two network layer protocols: Space Packet Protocol SPP, SCPS-NP (Space Communication Protocol Specification-Network Protocol), which implements the routing function of the space network. SPP is based on no connection and does not guarantee the sequential transmission and integrity of data. The core of the SPP is to configure the LDP (Logical Data Path) in advance, and use the Path ID instead of the complete end address to identify the LDP. This improves the efficiency of space information transmission, but is only suitable for static routing communication. Compared with the standard IP protocol, the SCPS-NP protocol has three improvements: NP provides four types of packet headers for users to choose between efficiency and function; both connection-oriented routing and connectionless routing are supported; compared with ICMP, SCPS Control Information Protocol (SCMP) provides a link break message. IPv4 and IPv6 packets of the Internet can also be transmitted over the space data link protocol, and can be reused with SPP, SCPS-NP or a space data link alone [3,4].

(4) Transport layer. The CCSDS transport protocol SCPS-TP provides end-to-end transport services to space communication users. The TP can identify and distinguish data due to data loss caused by network congestion, bit error or link interruption, and implement functions such as header compression, selective negative acknowledgment, time stamp, and rate control. The transport layer data is generally transmitted by the network layer protocol. In some cases, the transport layer data can also be directly transmitted by the link layer protocol. The TCP and UDP of the Internet can run on the IPv4, IPv6, and SCPS-NP. The SCPS Security Protocol (SCPS-SP) and Internet Security Protocol (IPSec) can be used with transport layer protocols to provide end-to-end data protection [2].

3.3 Protocol System Combining CCSDS and TCP/IP

In October 2000, the Jet Power Lab launched the Next Generation Space Internet (NGSI) project to study the use of the CCSDS protocol and the IP protocol to interconnect the space network with the terrestrial network to achieve a "space Internet" that supports future space missions. NGSI uses a combination of CCSDS and TCP/IP, which continues to use CCSDS recommendations at the data link layer, to use IP and its extension technologies at the network layer. The TCP/IP protocol and the CCSDS protocol, or other protocols suitable for space tasks, are used at the transport and application layers. The protocol system combining CCSDS and TCP/IP is shown in Fig. 3.

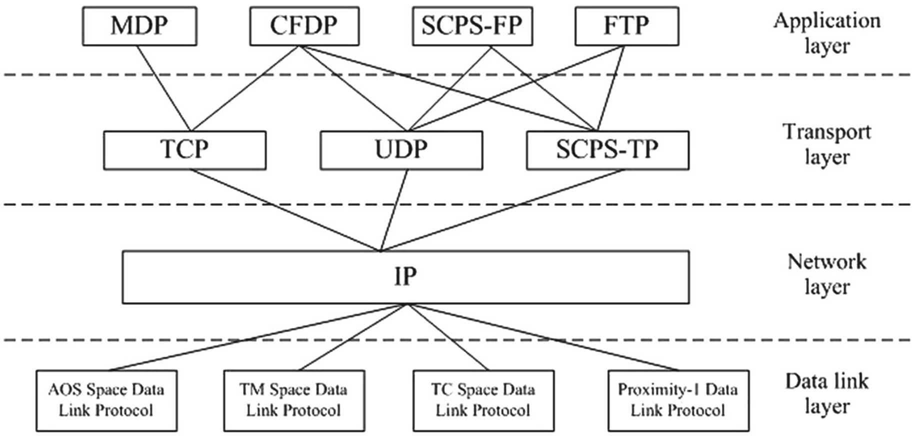

Fig. 3. Protocol system combining CCSDS and TCP/IP

3.4 Protocol System Based on Delay/Interruption Tolerant Network

Delay/Disruption Tolerant Network (DTN) is a new type of network system that can communicate in a restricted network environment such as long delay and intermittent connection. The concept of DTN was first proposed by the US Propulsion Laboratory in 2003. The Internet Research Task Force (IRTF) then formed the Delay/Interrupt Tolerant Network Research Group (DTNRG) on the DTN based on the Interstellar Network Research Group (INRG). In 2007, the DTN network architecture and the Bundle Protocol (BP) were proposed. In 2008, the convergence layer protocol was defined, including the TCPCLP (TCP Convergence Layer Protocol) protocol, the Saratoga protocol, and the

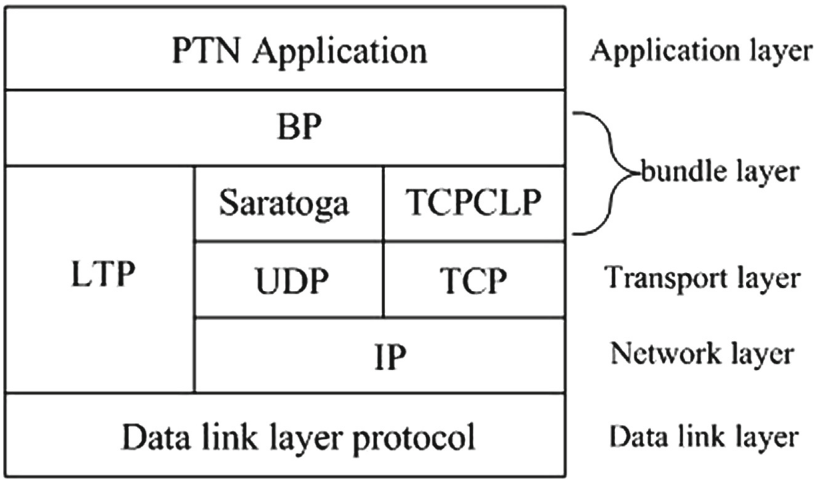

Fig. 4. Architecture of Delay/interrupt Tolerant Network protocol

Licklider Transmission Protocol (LTP). At the same time, in order to improve the shortcomings of the BP protocol, a supplementary plan was formulated. Currently, researchers have conducted extensive research in the relevant fields of DTN and have carried out specific deployments and experiments. The core method of the delay/interrupt tolerant network architecture is to add an intermediate layer, the bundle layer, between the application layer and the lower layer (data link layer or transport layer). Figure 4 shows the architecture of the delay/interrupt tolerant network protocol [5].

4 TCP Protocol Performance Improvement Method of Space Communication

In a series of RFC documents developed by the Satellite Working Group and the Network Working Group in the Internet Engineering Task Force (IETF), there are many strategies for improving the performance of TCP protocols applied to satellite links. The solution considered from the TCP protocol itself is an end-to-end solution and a link layer solution. TCP enhancements in end-to-end solutions include: TCP enhancements (increase initial window, byte count, use larger window sizes, select acknowledgments, forward acknowledgments, etc.), TCP-Peach, and STCP (shared TCP). Link layer solutions include: ARQ protocol and adaptive forward error correction (FEC) [6]. These methods are all adapted to the space network environment by improving the TCP protocol itself, but they all have certain limitations. At the same time, there are special protocol clusters in the space communication environment to achieve better performance, such as the SCPS series protocol.

In order to make the space link part have higher transmission performance and ensure good data transmission capability under long delay and high bit error conditions, we can use the idea of "segmentation" from the perspective of the link itself. The link is "segmented" into segments, each segment using the relevant protocol applicable to that segment. There are two main technologies now, one is the Spoofing technology, and the other is the Splitting technology. Spoofing, as its name implies, is the meaning of protocol spoofing and is based on the network environment. Spoofing technology cuts long delay satellite links into segments and uses spoofing techniques to speed up link initiation. Since the Spoofing technology divides the entire TCP connection into segments, the protocol gateway is used to split the long-latency link in the entire link, and the TCP link is still used for data transmission in the satellite link part, and the gateway responds as a virtual destination node. The information is sent to the host at both ends, which speeds up the startup speed, and can also be applied to the retransmission of lost data, which greatly shortens the delay of the information at both ends of the transceiver, and improves the performance to some extent, because the transmission performance of the TCP protocol itself is limited by In the space communication environment, the improvement in overall performance is limited.

Another way to improve from the perspective of satellite links is TCP Splitting, which is to cut a complete link into segments and use the transmission protocol for the link itself in each link segment. The part of the link with high delay and high bit error in the entire link is separated from the whole. Splitting can fully adapt to network characteristics without modifying the client host and server protocols. As shown in Fig. 5, Splitting cuts it into three segments. The first segment is the client host to the protocol gateway. This part uses the original TCP protocol. The second segment is the protocol gateway to the satellite node. Use a proprietary protocol for the space link. The third segment is the satellite node to the satellite server side, which also uses the original TCP protocol. The most important feature of the Splitting technology is the end-to-end transmission. Compared to Spoofing, which increases the startup speed of link transmission and the speed of recovery from congestion, Splitting can greatly improve the transmission performance of complex space link segments.

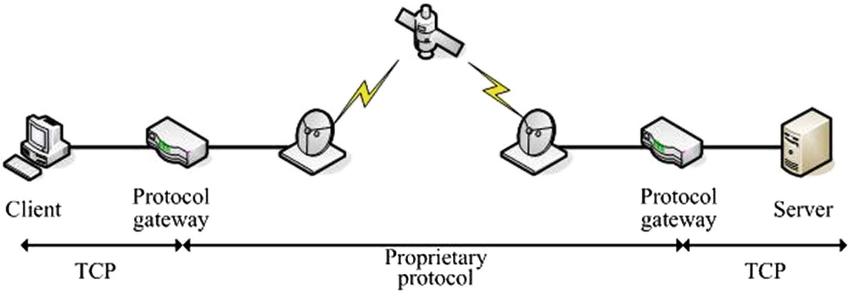

Fig. 5. Splitting technology link segment diagram

5 Conclusion

The four space information network protocol systems have their own characteristics. The advantage of the IP protocol system based on the terrestrial commercial standard is that the available software and hardware resources can be used to reduce the cost of the space mission. The interoperability between the space information network and the terrestrial network is better, but the processing capability of the spacecraft is also proposed. The CCSDS protocol system draws on the idea of terrestrial computer networks, and its design takes into account the new needs of future space missions. The CCSDS protocol performs better in terms of throughput and protocol overhead than the terrestrial network, but at the cost of certain CCSDS recommendations that do not fully conform to the layered principle of the ISO reference model and uses a different data format with the ground. The interoperability of the network is poor. Moreover, the CCSDS protocol does not solve the problem of dynamic routing. The protocol system combining CCSDS and TCP/IP not only utilizes the resources of commercial standards and good interoperability, but also has certain inheritance to existing CCSDS resources. The DTN-based protocol system addresses the deep space environment, and the deep space environment challenges the specific protocol performance of the data link layer to the transport layer. It needs to conduct in-depth research on layered protocols and cross-layer mechanisms, which will certainly promote the development of the DTN-based space IP protocol and the CCSDS protocol.

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