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Data Management of Space Station Bus Network

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Abstract. Compared with other spacecrafts, there are many bus networks and many interactive data. Moreover, it has the bus network connection and data management functions among the three space station capsules, and the manned spaceships and cargo spaceships. Aiming at the problem of data management of space station bus network which can be combined and separated dynamically, through the design of multi-level bus networks and docking bus networks in the capsule, the data management solution is given from the system level. The process of telemetry management, telecommand management and interactive data management between subsystems are described in detail. Through the unified protocol design and routing management, the integrated networking and data communication between the spacecrafts are realized, which reduces the complexity and test difficulty of the system. This method has been tested and verified in the space station task, which not only ensures the reliability of docking and separation between the space station capsules, but also takes into account the flexibility and expansibility of data management.

Keywords: Space station · Data management · Rendezvous and docking · Bus network

1 Introduction

China's manned space projects are implemented in accordance with the "three-step" development strategy. The first step is to "start with a manned spaceship, launch several unmanned test spaceship and a manned spaceship" to solve the transportation problem between space and earth; the second step is to launch a space lab and realize rendezvous and docking. The third step is to "build a large space station" [1–3].

After more than 20 years of development, China has made remarkable achievements in manned space flight, manned rendezvous and docking, and has completed the first two steps, and is now in the third step of building a manned space station with Chinese characteristics [4]. The strategic goal of China's space station project is to build and operate the near earth space station, so that China will become a country that independently masters the long-term manned flight technology in near earth space, has the ability to carry out long-term scientific and technological experiments in near earth space and comprehensively develop and utilize space resources [5].

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Bus network data management belongs to the on-board data handle system, which is the key component of the space station. It is responsible for the bus communication management in each capsule and the bus communication management function between capsules of the space station. It plays an important role in the information communication and control of the space station. In the process of rendezvous and docking between each capsule of the space station and the transport spaceships (manned spaceships and cargo spaceships), the bus network data management is responsible for establishing the docking bus network among multiple spacecrafts, realizing the functions of telecommand, command transmission, telemetry data collection and control data transmission [6]. The complexity of the space station task brings challenge to the design of bus network data management between multiple spacecrafts.

2 Mission Characteristics

China's space station consists of kernel capsule, experimental capsule I and experimental capsule II. The three capsules form the basic configuration of the space station through rendezvous and docking and capsule transposition [5]. During the space station is in orbit, it performs rendezvous and docking with manned spaceship and cargo spaceship to form a combination, which realizes the transportation of people, goods and propellant fuel.

There are independent and combined flight modes between multiple capsules of the space station, and the mode of rendezvous and docking with multiple manned spaceships and cargo spaceships is complex. These tasks put forward the following requirements for the design of bus network data management of the space station:

1) Ensure the reliable transmission of information under the independent and combined flight mode of three capsules. It is required to continue to use 1553B bus network with high reliability as the main network to realize data flow control. Through the combination and separation of special docking bus, the other capsules' subnets and transport spacecraft subnets are integrated into the kernel capsule's subnets to realize the real-time synchronous exchange and collaborative control of Multiple Spacecrafts' information. Fast switching between independent flight mode and combined flight mode among the spacecrafts is achieved.

2) Requirements for integrated networking and data communication between the spacecrafts and within one spacecraft. During the space station is in orbit, there are at least five spacecrafts, including three capsules, a manned spaceship and a cargo spaceship, which need data communication at the same time. If the communication protocols and data formats are not unified, it will greatly increase the cost of protocol conversion and the difficulty of equipment realization. Therefore, it is necessary to design a unified communication protocol and data format to realize the integrated networking and communication among the spacecrafts.

3) Hierarchical management of multiple bus networks. According to the experience of the international space station, there are hundreds of electronic devices in a single capsule of the space station, and the maximum number of terminals in a single 1553B bus is 32. Therefore, it is necessary to manage multiple 1553B buses. The category of 1553B bus network includes the main bus network, combination bus between the three

capsules, docking bus with transport spaceships, and secondary bus networks within the subsystems.

3 Bus Network Design

The bus network is designed in a hierarchical way. The first level bus is used for the main control of the whole capsule, including the system bus in the capsule and the docking bus between the spacecrafts. The system bus in the capsule manages the main computer equipment of each subsystem. The docking bus manages the communications between the capsules and spaceships in combination mode. The second level bus is used to control and manage the equipment in each subsystem.

The design of the single capsule bus network of the space station is shown in Fig. 1. The onboard computer is the bus control terminal (BC) of the first level bus, which manages multiple docking buses and system buses. It is the control center of the whole network, responsible for the telecommand data, downlink data transmission and control of the whole capsule. In addition to connecting the equipment in the capsule, the docking bus is also connected with the docking bus of other capsules. The kernel capsule is connected with the experimental capsule I and experimental capsule II through the docking bus to form a combination, which form the whole space station. Each subsystem controller is connected to the first level bus as the remote terminal (RT) of the first level bus and the BC of the second level bus. It is responsible for receiving the telecommand data and instruction data from the central computer, forwarding them to the equipment in the subsystem through the second level bus, collecting the telemetry data, display data or control data in the subsystem, and transmitting them to the onboard computer. Onboard computer transmits the control data to other subsystem controllers, packages and frames all received telemetry data and then descend them to the ground.

The information combiner receives the whole capsule's telemetry data from the onboard computer, multiplexes the real-time telemetry, delay telemetry, bus monitoring data, etc., generates several virtual channel data units (VCDU [7]) and sends them to the ground through the physical channel.

After the space station is out of the TT & C area, the real-time telemetry is converted to delay telemetry. At this time, the onboard storage device stores the delay telemetry data of the capsule, and transmits the data after entering the TT & C area. According to the application of space lab [6], the capacity of onboard storage device needs to be designed above 1000 GB to meet the requirements of long-term use in orbit.

The docking bus network is divided into two levels. The first level is the docking bus in the capsule, which is used to establish the bus communication link after the kernel capsule forms a combination with the experimental capsule I and experimental capsule II. The second level is the special docking bus with the transport spaceship, which forms a combination with the manned spaceship and the cargo spaceship respectively, and then establishes the bus communication link. The docking bus network design of the space station is shown in the Fig. 2.

The kernel capsule is connected with the experimental capsule I and experimental capsule II through the docking bus. Before the docking, each capsule is in independent flight mode. The onboard computer, as the BC end of the docking bus, controls

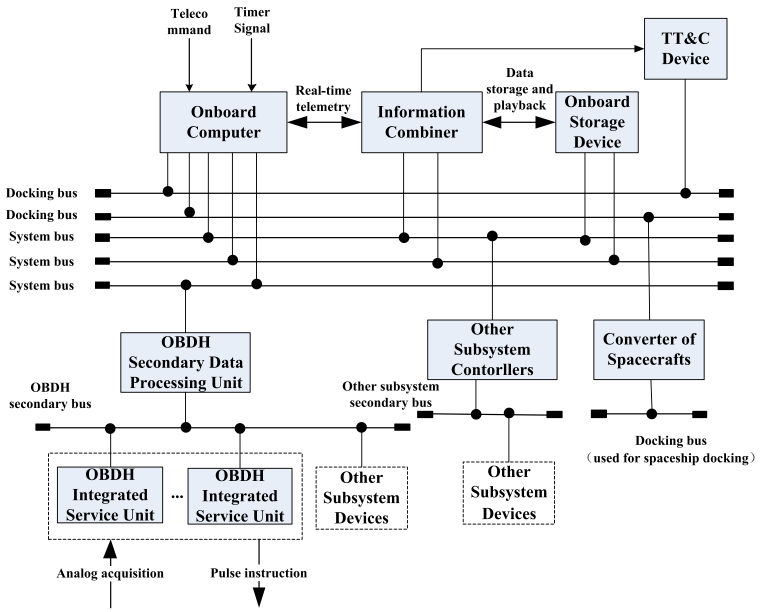

Fig. 1. Bus network topology diagram in single capsule

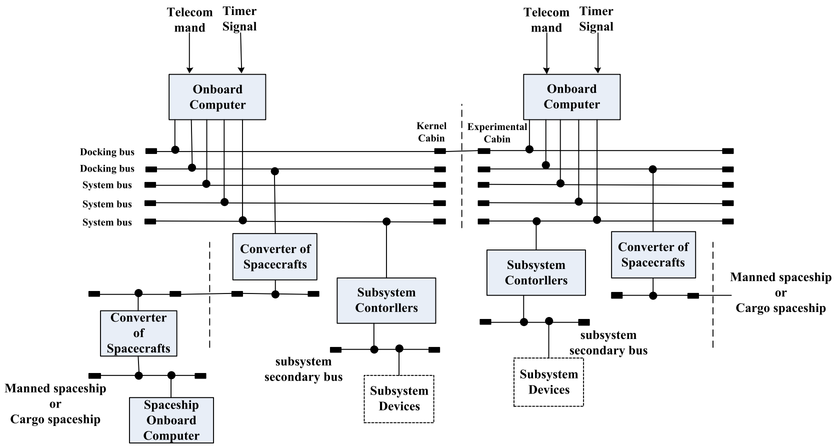

Fig. 2. Bus topology diagram of docking bus network

the data communication on the bus. After the docking, the independent flight mode is transformed into docking mode, and the onboard computers of experimental capsule I and experimental capsule II are transformed into RT terminals. The onboard computer of kernel capsule is still used as BC terminal to manage the data communication on the docking bus. The data management on the system bus is still in the charge of the onboard computer in each capsule. In this way, bus channels are established to ensure the interconnection of information between the three capsules, providing a reliable network channel and data management mode for the long-term operation of the three capsules in the space station.

In the special docking bus, the converter is designed to connect the space station network and the transport spaceship network. In the state of combination, the two subnets cooperate to complete the information management of the combination. After separation, the docking bus is disconnected, and the space station network and the transport spaceship network independently complete their own data management tasks. The converter plays the role of gateway and realizes the data communication and protocol conversion between multiple spacecrafts.

The devices of space station and transport spaceships are not directly connected to the docking bus, but are used as information transfer through the converter. In the process of docking and separation, the system bus and docking bus are completely physically isolated, even if there is a fault, they will not affect each other. The onboard computers of both sides can always be used as the control terminals of their respective system buses. In case of rapid docking or evacuation, the working mode can be switched quickly without switching the bus control terminals, which ensures the real-time and reliability of network access and separation between two spacecrafts. In accordance with the docking bus design of the space lab, the bus switch is used on the docking bus for bus connection and disconnection.

4 Data Management Design

4.1 Telemetry Management

Telemetry management realizes the process of telemetry acquisition, telemetry package, telemetry framing and telemetry frame downlink. There are three levels in total. The first level is that each terminal device obtains telemetry data (including analog quantity, temperature quantity, dual-level quantity and software state quantity) through sensors. The second level is that each subsystem controller collects telemetry data of the first level through the secondary bus and packages them. The third level is that the onboard computer collects telemetry packages of each subsystem controller, which are multiplexed to virtual channel frames to transmit and downlink.

The telemetry management protocol uses CCSDS [8] Advanced Orbit System (AOS) [7] protocol to realize the data communication from space station to ground. It uses four kinds of services [9] provided by AOS: virtual channel packet (VCP) service, bit stream service, virtual channel access (VCA) service and virtual channel frame (VCF) service.

As shown in Fig. 3, through the virtual channel packet (VCP) service, each subsystem controller encapsulates the telemetry data as EPDU [10] on the secondary bus, organizes them into EPDU packet sequences and sends them to onboard computer, which encapsulates all packets as MPDU and sends them to the information combiner for transmission in transfer frame data field. Through bit stream service, the continuous bit sequence, including image and voice data, is encapsulated as BPDU by information combiner and transmitted in transfer frame data field.

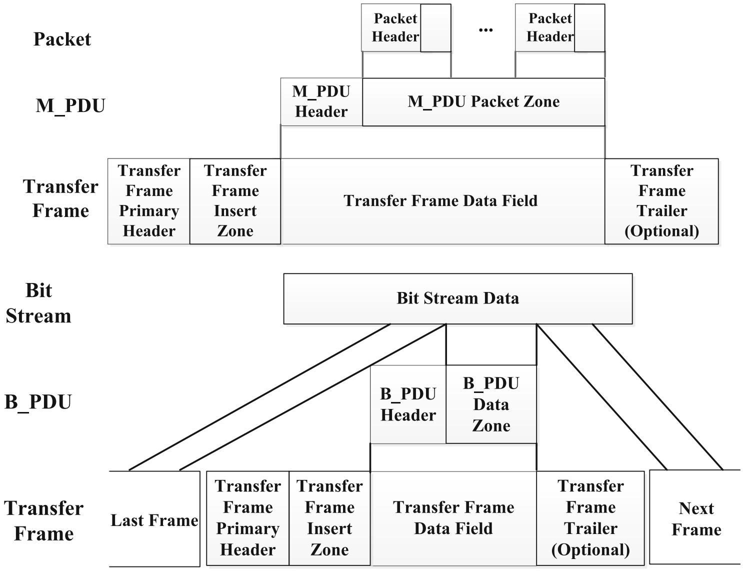

Fig. 3. Data processing process of VCP service and bitstream service

4.2 Telecommand Management

The telecommand management function uses CCSDS telecommand data link protocol [11] to realize the telecommand data receiving and forwarding function. The data format uses the standard data format of telecommand transmission frame, and the standard EPDU packet is used in the data field. After receiving the telecommand frame from the ground, the onboard computer processes the frame routing and packet routing respectively.

If the telecommand frame comes from the other spacecraft (other capsules or spaceships), the frame routing is performed and sent to the target spacecraft for processing. If it is the telecommand frame of other terminals in the capsule, it will be routed to the corresponding bus device according to the VCID. If it is a telecommand frame that needs to be processed by the capsule onboard computer, telecommand packet analysis shall be carried out, packet routing shall be carried out according to the APID of telecommand packet and distributed to the corresponding terminal equipment for processing.

4.3 Interactive Data Management Between Subsystems

The standard EPDU packet is used for data transmission among subsystems. APID is used to identify the spacecraft, the subsystem and the data type. The onboard computer routes the package according to the package routing table, and sends the EPDU packet to the destination device to support the data communication between the capsule and the spaceship. The main elements of the packet routing table are designed as follows Table 1:

The onboard computer searches the routing table according to the APID of the EPDU packet, and routes the packet to the onboard computer of the destination spacecraft

Table 1. Packet routing table

APID	Source Device ID	Destination Device ID	Packet Length	Period
2 bytes (valid for lower 11 bits)	1 byte	1 byte	2 bytes	1 byte (integer multiple of 50 ms)

according to the spacecraft identification in the APID. If it belongs to this spacecraft, finds the next hop address, and routes the packet to the destination terminal device.

5 Experiment and Verification

The bus network design and data management method of space station has been applied to the space station mission, and the subsystem test and system level test have been completed. During the test, the data management test of docking bus network is carried out by simulating the docking and separation between the three capsules, manned spaceship and cargo spaceship. Some of the tests are described as follows Table 2:

Through the system level test, it is found that the single capsule of the space station can realize at least six sets of bus network data communication and management functions, and the single bus data communication rate can reach about 300 kbps. Through

Table 2. Test results of data management of space station

Test Item	Test Content	Test Situation
Single capsule's data management test	Telemetry management	The telemetry acquisition, organization and downlink of all terminal devices on the bus in the capsule are tested
	Telecommand management	The telecommand, frame and packet forwarding and processing are tested
	Interactive data management between subsystems	Receiving, forwarding and processing of packets between subsystems are tested
Three capsules' data management test	Telemetry management	After the docking of the three capsules, the acquisition, organization and downlink of the telemetry in a capsule are tested, and the function of telemetry package framing between capsules are tested

(*continued*)

Table 2. (*continued*)

Test Item	Test Content	Test Situation
	Telecommand management	Telecommand frame forwarding, telecommand packet receiving and processing are tested
	Interactive data management between subsystems	Receiving, forwarding and processing of packets between capsules are tested
Data management test of docking combination of space station and spaceships	Telemetry management, Telecommand management, Interactive data management between subsystems	After the docking combination of the space station and the transport spaceships, the telemetry data of the spaceships collected by the space station through the converter, the telecommand data sent to the spaceships and the interactive data processing are Tested
Docking and separation data management test	Docking and separation data management of three capsules and spaceships	Through the repeated docking and separation process, the data communication and processing are correct, and the switching between independent flight mode and combined flight mode is realized

the frame and packet routing mechanism, the integrated networking and data communication between devices are realized, the data format is unified, the protocol conversion overhead is avoided, and the difficulty of system implementation and test is reduced. It supports the rendezvous, docking and separation functions among three capsules, manned spaceships and cargo spaceships. It realizes the safe, reliable and fast switching between independent flight and combined flight modes among the spacecrafts.

6 Conclusion

Space station bus network data management is an important part of the space station mission, which involves the information management between the three capsules of the space station, manned spaceships and cargo spaceships. It is also an important direction of the future development of the space field. The bus network data management method designed in this paper can support single capsule independent flight mode, three capsules docking flight mode, docking and separation flight mode with manned spaceships and cargo spaceships, which is safe and reliable. Through the unified protocol design and routing management, the function of integrated networking and data communication between spacecrafts and within spacecrafts is realized. This method has been tested and verified in the space station mission.

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