Research and Application of Consultative Committee for Space Data Systems Wireless Communications Standards for Spacecraft

Cuitao Zhang, Xiongwen He

Abstract**—**According to the new requirements of the future spacecraft, such as networking, modularization and non-cable, this paper studies the CCSDS wireless communications standards, and focuses on the low data-rate wireless communications for spacecraft monitoring and control. The application fields and advantages of wireless communications are analyzed. Wireless communications technology has significant advantages in reducing the weight of the spacecraft, saving time in spacecraft integration, etc. Based on this technology, a scheme for spacecraft data system is put forward. The corresponding block diagram and key wireless interface design of the spacecraft data system are given. The design proposal of the wireless node and information flow of the spacecraft are also analyzed. The results show that the wireless communications scheme is reasonable and feasible. The wireless communications technology can meet the future spacecraft demands in networking, modularization and non-cable.

Keywords**—**CCSDS standards, information flow, non-cable, spacecraft, wireless communications.

I. Introduction

WITH the development of space technology, wireless communications technology in the spacecraft plays an increasingly important and even irreplaceable role to meet the networking, modular and cableless requirements and other new demands. Wireless communications technology gets more and more attention.

The CCSDS (The Consultative Committee for Space Data Systems) has accelerated the research on wireless communications technology in recent years on the basis of years of wireless communications study and tracking. At present, several wireless communications standards such as [1] and [2] have been developed for aerospace application. The recommendation [2] mentions Bluetooth (IEEE 802.15.1), Wi-Fi (IEEE 802.11) and WiMAX (IEEE 802.16) standards for high-speed data communications. These standards are most likely to be used in the inner of spacecraft for audio and video applications. In the cargo inventory monitoring field, standards of ISO 18000-6C and EPCglobal are proposed. For the application of spacecraft structure monitoring and astronaut location tracking, WiMedia (WPAN, IEEE 802.15.3) standard is proposed. For spacecraft environmental monitoring and control, CCSDS recommends the use of the wireless sensor networks standard IEEE 802.15.4. The IEEE 802.15.4 standard is intended to be used in low-speed wireless personal area networks (PAN). The key objectives are to achieve low power consumption and low cost. The CCSDS has defined the MAC (Medium Access Control) layer and PHY (Physical) layer protocols, but the network layer and higher layer are not defined. Based on the CCSDS standard, this paper studies the application of low-speed wireless communications technology based on IEEE 802.15.4 standard in spacecraft environment monitoring and control [3]-[5].

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II. Introduction of CCSDS Low-Speed Wireless Communications Recommendations

The CCSDS recommends that the low-speed wireless communications technology IEEE 802.15.4 standard be used in the field of spacecraft environmental monitoring and control, especially in low-rate, low-power applications [1]. For low rates, CCSDS gives a definition that the data communication rate does not exceed 250 kbps. For low power, CCSDS gives a definition that the power consumption does not exceed 10 mW. The CCSDS standard proposal defines only the PHY layer and MAC layer protocols of Open Systems Interconnection (OSI) to support the most basic wireless communications functions in the area of spacecraft environment monitoring and control. Higher layer protocols are to be implemented in subsequent releases to develop [1].

The CCSDS adopts the IEEE 802.15.4 standard as the PHY layer and MAC layer protocol. Based on this standard, equipments from different manufacturers can communication through the PHY layer and MAC layer network protocols. The packets of the new network device can be transmitted through other devices in the network without caring about the specific sensors or applications that produce the packets. At present, the network functions supported by CCSDS standards are limited to the function of PHY layer and MAC layer protocol stacks, that is, single-hop competition access mode and single-hop scheduling access mode in star topology network [1]. Each network node can communicate with a network coordinator or gateway, but can not communicate with each other. The CCSDS recommends that the network coordinator or gateway be able to communicate with the spacecraft backbone network in some way. Future standards will increase the supports for peer-to-peer communications and multi-hop relay communications between any two nodes in the network. In this way, the newly added nodes can not only communicate with the gateway, but also with other nodes in the same network, and even with other network equipments. The current CCSDS standard proposal for low-speed wireless communication technology temporarily does not support the point-to-point response mechanism and the packet retransmission mechanism, as they are implemented at the transport layer or application layer protocol stacks. The current PHY layer and the MAC layer protocol stacks do not support these functions [1]. The future protocol stacks will increase the network layer functions, such as IP (Internet Protocol) packets routing functions, etc.

In the area of wireless sensor networks, the single-hop competition access and single-hop scheduling access are two main types of access methods [1]. Both of them have their own characteristics. The single-hop competition access does not require network center control, and is especially suited for mobile ad-hoc network architectures, or other situations where it is desirable to minimize network management overhead and operational complexity [1]. In such a network, nodes in the network allow random access to the wireless channel and obtain wireless channel control in a competitive manner with other nodes. The most common access technique is Carrier-Sense Multiple Access with Collision Avoidance (CSMA-CA). The single-hop scheduling access technique requires a central control mechanism to coordinate all network nodes to access the wireless channel, and it is a synchronous access technique[1]. This technique is based on the pre-scheduled data flow for the node to allocate the wireless channel bandwidth, thus effectively avoiding the competitions between nodes. This approach increases network administrative overhead and operational complexity, but effectively ensures the quality of service (QoS), which increases the certainty of the network [1]. The most common method of scheduling access is Time Division Multiple Access (TDMA).

In terms of application support, CSMA-CA mode is most suitable for situations where node packet delay and jitter requirements are not high, but sometimes random short-term occupies larger channel bandwidth. CSMA-CA is not conducive to the determinism of the network, but is conducive to sudden and non-cyclical data transmission [1]. In contrast, the TDMA approach is well suited for applications that are relatively sensitive to packet delay and jitter and transfer more cyclical and predictable data streams. In addition, anti-jamming techniques such as frequency hopping are more easily applied to the MAC layer of the TDMA, rather than the MAC layer of the CSMA-CA. In the multi-hop relay communication network, TDMA access has an obvious advantage over CSMA-CA in anti-interference [1]. These two types of access methods both support the service quality assurance mechanism. Based on IEEE 802.15.4 standard, complete wireless communication protocols such as ZigBee, ISA100, etc. support QoS mechanism in the network layer.

CCSDS recommends that the PHY layer and MAC layer protocol should be compatible with the IEEE 802.15.4-2011 standard and should adopt the 2.4 GHz frequency band if the single-hop competitive access method is used in the field of spacecraft environmental monitoring and control [1]. If the single-hop scheduling access method is used, CCSDS recommends that the PHY layer and MAC layer protocol should be compatible with ISA100.11a-2011 PHY layer and MAC layer standard [1]. ISA100.11a MAC layer protocol based on IEEE 802.15.4 implements a series of mechanisms to enhance the overall service quality of the wireless communications network.

III. Advantages of Wireless Communications Technology

In the field of spacecraft environmental monitoring and control, a large number of spacecraft test data and health data need to be collected. These data are generally required to be collected through a dedicated cable for capture and transmission. The demands for this type of transmission cables on spacecraft are generally very high, and the connections between the cables are often very complex. Thus the spacecraft assembly is usually very cumbersome, time-consuming, inefficient and error-prone. These inconveniences prompt spacecraft engineers to concern about the use of wireless communications technology to replace the traditional cables. The use of wireless communications technology can not only achieve cableless data transmission and reduce the weight of the satellites, but also facilitate the modular design of spacecraft equipments, realize information network transmission, and improve the flexibility of spacecraft design, test and assembly.

The advantages of wireless communications technology relative to traditional cable transmission technology are mainly as follows:

1) Reducing the weight of spacecraft. Each part of the spacecraft requires the carrier to consume fuel. The cable usually takes up about 7% to 10% of the total weight of the spacecraft. The wireless communications technology can greatly reduce the weight of the cable. Thus the weight of the payload can increase to complete more scientific experiments. At the same time, the carrier can carry less fuel than before.
2) Increasing the flexibility of spacecraft design. The use of wireless communications technology can connect various devices on spacecraft. The design of spacecraft no longer needs to consider low-frequency cables between equipments in the satellite, reducing the difficulty of structure design. Wireless communications technology is also very conducive to spacecraft modular design. Upgrade of equipments and devices is more adaptable. For example, the addition of a wireless receiver can monitor the health of the payload without physical connection.
3) Improving the efficiency of spacecraft assembly. The elimination of a large number of cables and connectors significantly reduces the spacecraft assembly time, especially at the AIT stage when the spacecraft needs frequent disassembly, replacement of equipments. Wireless communications technology makes it easy to connect with the test equipments to avoid the original limited conditions, and can greatly improve test efficiency.
4) Reducing the cost of life cycle. Equipments using wireless communications technology are easy to upgrade and reconfigure. Wireless communications technology can

reduce the spacecraft life cycle costs.

5) Improving coverage. Due to structural reasons, the coverage of the traditional wired connection is limited, whereas the coverage of the wireless connection is broad. At the same time, the convenience of the wireless connection is conducive to the realization of spacecraft structure functional innovation.

IV. Applications of Low-Speed Wireless Communications Technology on Spacecraft

A. Application Situations

The CCSDS standard points out that the low-speed wireless communications technology based on IEEE 802.15.4 is used to build low-speed wireless PAN [1]. The network coverage is generally about 10 m, within the spacecraft size. The data transfer rate is about 250 kbps, almost equal to the data amount of spacecraft telemetry and telecontrol. It is very suitable for the spacecraft environmental monitoring and control identified by the CCSDS recommendation. This paper focuses on the application of IEEE 802.15.4 standard in spacecraft telemetry and remote control.

B. Design of Spacecraft Data System

In the wireless PAN based on IEEE 802.15.4, the network topology is a star topology. The gateway node can communicate with the spacecraft backbone network. The wireless node can communicate with the gateway node. A block diagram of the spacecraft data system based on PAN network is shown in Fig. 1.

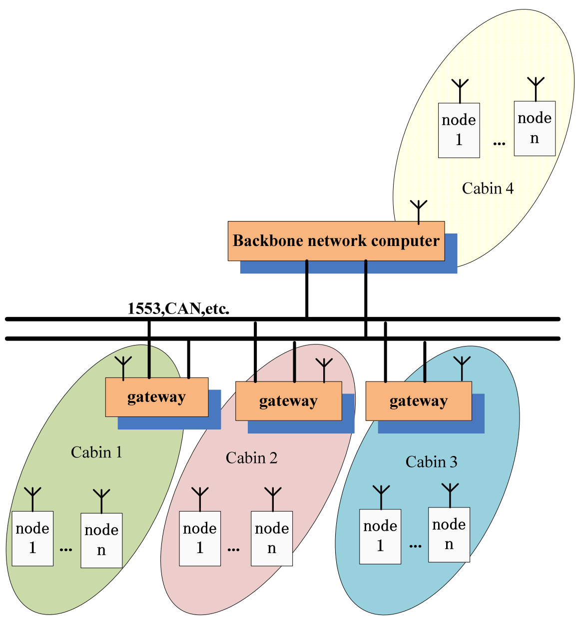

Fig. 1 Block diagram of spacecraft data system based on PAN network

In Fig. 1, each compartment of the spacecraft establishes a separate PAN network. Each PAN network can cover a communication distance of 10 meters, supporting the number of wireless nodes in 10-100. Each PAN network has a separate gateway connected to the cable backbone network, and can communicate with the backbone network. The spacecraft backbone network can be a conventional 1553B bus, a CAN bus or other bus. In each cabin, the wireless nodes can only communicate with the gateway nodes, and cannot communicate directly with each other. If they need to communicate with each other, they should first communicate with the gateway node, their messages should be exchanged though the gateway node. Wireless nodes have the basic telemetry acquisition, instruction output and other similar functions. The wireless transmitter transmission power is in the range of -15 dBm ~ 10 dBm [1]. Considering the electromagnetic compatibility, radio radiation, interference and other issues, the specific distribution of the RF nodes on the spacecraft should be paid special attention to.

C. Wireless Node Design

Wireless node design needs to consider the reliability of the node [6]. The use of wireless technologies on spacecraft introduces extra flexibilities when implementing wireless fault-tolerance and redundant design. The redundant design of the wireless interface compared to the traditional cable connection is much easier to achieve well effect. The design is simple, as shown in Fig. 2 [2]. Fig. 2 (a) shows the traditional cable connection implementing the cross redundant backup design. Each device's main and backup is connected to another device's main and backup through two sets of cables. Cable connections are relatively complex outside the devices. Fig. 2 (b) shows the wireless way of cross redundant backup design. The main and backup of each device are connected to two wireless communication modules respectively inside the equipment. No connections are required outside the equipments to realize the cross redundant backup design. Wireless communications technology effectively reduces the weight of spacecraft, and makes it easy to achieve networking, modular, cableless design of spacecraft.

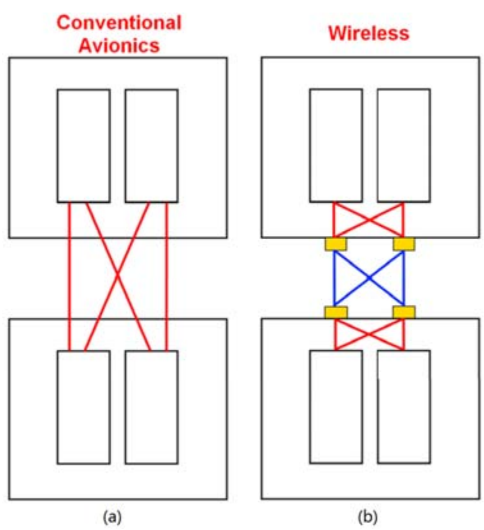

Fig. 2 Redundancy wireless interface design

Although the wireless communications technology has the above advantages, in practical applications there are many problems to be solved, such as EMC, EMI, RF radiation and other issues. The solutions of these problems have a great relationship with the specific structure of the spacecraft. Different structures often require for different solutions. In addition, the advantages of wireless communications lie in the design of wireless nodes. The principle of wireless node design is to simplify the spacecraft cable connection, shorten the spacecraft assembly time, reduce the spacecraft cable weight, and achieve spacecraft modular assembly.

At present, in the field of industrial control, a wide range of complete wireless communications protocols such as ZigBee, based on IEEE 802.15.4 PHY layer and MAC layer protocol, implement higher-level network layer protocol. These protocols realize not only the CCSDS defined single-hop competition access and single-hop scheduling access, but also multi-hop relay communications. The user can configure the required communication functions. Texas Instruments also offers a dedicated monolithic solution CC2530. The chip integrates the ZigBee complete protocol stacks and RF transceiver functions. The MAC layer and PHY layer protocol are compatible with IEEE 802.15.4 specification. It can work in the 2.4GHz frequency band, and is compatible with CCSDS standards. This chip also integrates an 8051 microprocessor and an ADC, SPI/UART ports, GPIO ports and other peripherals. Its power consumption is very low. It consumes only 0.4 μA current in the idle state. In the working state, it consumes about 24 ~ 29 mA current. Its supply voltage is 3.3 V. Assuming 10% duty cycle operating conditions, the average power consumption is only 8.3 mW. It meets the CCSDS proposal of less than 10 mW. The wireless node (or gateway node) design based on this chip is shown in Fig. 3.

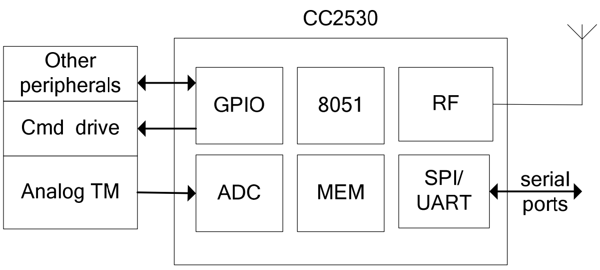

Fig. 3 Wireless node design

Based on the design of wireless node above, traditional devices of the spacecraft only need to add a few small components (such as command-drive chips, multi-channel analog multiplexers, etc. according to the specific requirements of the single device) so as to discard the heavy cables for telemetry and telecontrol. In this way, it is very easy to extend more than 10- channels of command-drive and telemetry acquisition channels for each device. The channel number is enough for each device. Gateway nodes need to use the serial ports to communicate with the spacecraft backbone network through the gateway computer. This scheme easily meets the spacecraft common equipment requirements for remote control and telemetry. And the cost is very low. For each device, the weight of the new added wireless node is much lighter than the weight of external cables. The advantages of wireless communications technology are fully reflected. Low-speed wireless communications technology not only reduces the weight of spacecraft, but also reduces the time cost in spacecraft assembly. Spacecraft testing is also simplified. Improving efficiency is the purpose and real reason to apply wireless communications technology on spacecraft.

D. TC and TM Information Flows

For the TC information flow, if the spacecraft receives direct commands from the ground, the TC information flow is the same as the original wired connection. This article will not describe the details. For indirect commands or data injection, the backbone network computer will first send the received data to the corresponding gateway computer, the gateway computer will then transfer the information to the gateway node through the serial ports interface, and finally the gateway node will send the data wirelessly to the target wireless node. If the wireless node receives the TC information, it will execute the commands directly.

For the TM information flow, each wireless node sends their telemetry data to the gateway node of the PAN network. The gateway node collects the data and then transfers the data to the gateway computer through the serial ports. The gateway computer then processes the data and then sends the data to the backbone network. The backbone network computer groups the data into packages and sends them down to the ground.

V. Conclusion

Based on the analysis of the CCSDS standard of low-speed wireless communications technology, this paper summarizes the advantages of wireless communications technology applying on spacecraft, and puts forward an application example of low-speed wireless communications technology for spacecraft environment monitoring and control. The paper gives the block diagram of the spacecraft data system and the key interface reliability design. It also gives the design suggestions of the wireless nodes, analyzes the feasibility of the design scheme, and points out the problems that need to be solved urgently. Low-speed wireless communications technology can meet the spacecraft demands in networking, modularization and non-cable, and is a very promising technology for future spacecraft.

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