A Distributed Reservation and Contention Combined TDMA Protocol for Wireless Avionics Intra-communication Networks

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Abstract. To reduce the structural complexity of the cabin avionics communication system and meet the increasing demand for data exchange, Wireless Avionics Intra-Communication (WAIC) networks attract attentions from the academic and industrial researchers. Based on the analysis of the wired cabin avionics bus communication system and the analysis of the short-range wireless communication technologies, this paper firstly shows that Ultra Wideband (UWB) could be taken as the candidate technology of WAIC networks. To guarantee the maximum data transmission delay and improve the channel utilization, this paper proposes a Distributed Reservation and Contention Combined (DRCC) TDMA protocol for WAIC networks. Firstly, AP allocates the time slots to each node to ensure that each node can reserve the channel to transmit data. This can help guarantee the maximum data transmission delay. Secondly, if a node does not have data to transmit in its reserved slot, then the others nodes can contend to access into this time slot with p-probability. Simulation results show that compared to the fixed allocated TDMA and p-CSMA the proposed DRCC protocol can improve the throughput by 5% and 50%, respectively. And the average delay can be reduced by 4% and 10%.

Keywords: Wireless avionics intra-communication · Ultra wideband · Reservation · Contention

1 Introduction

With the increasing interconnection of subsystems in cabin avionics communication system (CACS) and the increasing demand for data exchange, the structural

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complexity of CACS increases significantly. Avionics full duplex switched ethernet (AFDX) [1] based cabin aviation bus network is used in the new generation of large aircraft. The AFDX aviation bus communication network requires a large number of cables and connectors, which not only increases aircraft weight and integration costs, but also poses structural and fire risks to the wired CACS network, which reduces reliability and increases the difficulty of maintenance in chunks. In recent years, wireless communication technologies such as wireless local area network (WLAN) and Bluetooth have made rapid development, bringing a lot of convenience to people's life and study. However, wireless communication technology has not been widely used in avionics systems.

In 1995, the concept of wireless technology was introduced in specific areas of aerospace and the fly-by-wireless working group was formed in 2007 [2]. This group, which brings together industry leaders from Airbus and the National Aeronautics and Space administration, is discussing the latest applications of wireless communications for aerospace applications. Recently, an avionics communication solution based on wireless technology was proposed to add non-critical onboard functions such as in-flight entertainment network, in-flight communication and aircraft health monitoring. The U.S., France, Germany and other big aircraft manufacturers, as well as the aviation industry and the International Telecommunication Union (ITU), are pushing forward the development of Wireless Avionics Intra-Communication (WAIC) systems. In the early days of the 2015 international radiocommunications conference, the participating countries jointly deliberated and approved a topic to support "spectrum allocation through aviation mobile (airline) services and promote the application and expansion of airborne internal wireless communications in the aviation sector" [3]. ITU-R group and the coherence of the various countries mainly explores the plan to use on WAIC spectrum (4200 MHz to 4400 MHz), to explore with the electromagnetic compatibility problem existing between the airborne radio altimeter. The research results show that after the relevant technical means, WAIC will not produce interference to the existing airborne radio altimeter [3].

Akram *et al.* devised a CACS network based on WiFi wireless networks [4], which is suitable for ethernet backbone network. Pangun Park and Woohyuk Chang believe that the adaptability of MAC protocol is a key aspect of WAIC network [5]. Literature has proved that the UWB TDMA network with fixed time slot allocation can meet the aviation network communication requirements of a certain scale to determine the maximum delay after reasonable configuration [6].

Although many researchers have been carried out the wireless communication of avionics in airborne cockpit, few valuable research results have been published. At present, it is unknown that there is an onboard cockpit aviation wireless network that has been put into use by the aircraft. Although there are still many difficulties in using wireless in-plane communication in avionics system, with the rapid development of various wireless communication technologies, it has provided possible solutions for in-plane wireless communication.

Aiming at WAIC networks in the demand of low data transmission delay and high network utilization, this paper puts forward a distributed reservation and contention combined (DRCC) TDMA protocol for WAIC networks. The proposed DRCC TDMA multiple access control (MAC) protocol based on ultra-wide band (UWB) is designed. Based on the features of AFDX network, this paper improves the UWB MAC protocol using fixed allocation TDMA, proposes a hybrid TDMA protocol of fixed allocation and competitive allocation, and designs the MAC scheduling process of airborne wireless network based on UWB.

The rest of this paper is organized as follows. Section 2 introduces the advantages and key technologies of the wired airborne networks, e.g., AFDX. And then the airborne wireless networks in cockpit has been carried on the demand analysis, and evaluation of existing short distance wireless communication technology, e.g., UWB. Section 3 presents the system model and motivation. Section 4 introduces the core idea of DRCC-TDMA protocol, then gives the detailed design and protocol flow description, as well as the designed frame structure. Section 5 verifies and analyzes the performance of the proposed protocol through simulation. Section 6 concludes this paper.

2 Related Works

According to the network connection form, the existing airborne in-cabin network can be divided into wired CAC network and wireless CAC (WCAC) network, which will be introduced one by one.

2.1 Wired Cabin Avionics Communication Network

Wired CAC network is also known as airborne in-cabin aviation bus, and the most widely used aviation bus technologies include ARINC429 [7], 1553B [8,9] and AFDX [1].

ARINC429 aviation data bus standard [7] makes clear rules for the format of digital information transmission and requirements between the aircraft airborne avionics and avionics systems. All of the transmitting device and receiving device adopt shielded twisted-pair cable to transmit data between information, transmission mode for one-way broadcasting transmission, modulation method for bipolar three state code modulation. ARINC429 aviation bus structure is relatively simple, and the performance of small network is very stable and has a very strong anti-interference level. Its high reliability in the aviation field has been proved over the past decades. However, the bus bandwidth of ARINC429 is small and the interface does not support the new processor, which leads to the increasing delay. Therefore, with the increasing number of sensors in the new generation of aircraft, the information interaction content is more and more complex. ARINC429 aviation bus has been unable to meet the requirements of the new generation of aviation communication.

1553B aviation data bus [8,9] is a serial, multiplexed based aviation data bus, whose working mode is time-division data/response multiplexing transmission.

The 1553B aviation bus adopts redundant backup bus topology layout, which has the advantages of high timeliness and reliability. Half-duplex is adopted to complete data transmission by Manchester encoding, and its effective data transmission rate is only up to 1 Mbps. The 1553B bus has played an important role in the development of aviation communications over the past decades. Even now, in some indexes, such as real-time, reliability, it still can satisfy the active part of the model. But as the number of a new generation of aircraft sensors increase, the interactive information is exchanged more frequently. Furthermore, because the centralized bus controller for avionics systems may cause the plane's security from a single point of failure, this becomes a serious security threat.

AFDX is an avionic full-duplex switched Ethernet suitable for deterministic network communication in the new generation of avionic systems, which has been officially included in ARINC664 [1]. AFDX can support the transmission rate of physical layer up to 100 Mbps, and the transmission medium can take both optical fiber and coaxial cable. AFDX network is a static network, regardless of the number of nodes in the network or between nodes interconnected, including data transmission path and the flow rate is fixed or is strictly controlled. The AFDX network technology can support a large amount of important data transmission, and the switching is based on its exchange and the concept of Virtual Link (VL), for each of the transmission of data flow to ensure a reservation for the transmission bandwidth.

The realization of VL in AFDX network is based on the transmission mode of Time Division Multiplexing (TDM). In setting up each VL, two important parameters are given as follows: Bandwidth Allocation Gap (BAG) and maximum Frame Size (MFS). Wherein, after the BAG sends out a frame, it needs to wait for at least one BAG to send the next frame, while MFS is the maximum frame length defined in AFDX network that can be transmitted on VL, with the size of 64 1518 Byte. If BAG and MFS are determined, the maximum available bandwidth of VL can also be calculated. Assuming that the maximum bandwidth of link is B_{max}, MFS is denoted by L_{max}, then $B_{max} = L_{max}/BAG$. AFDX network sets BAG and MFS for each VL, which also restricts the maximum bandwidth of VL network. The data that cannot be sent is cached first, and the later data is discarded when the buffer is full.

Even if each end system (ES) sets BAG for all VLs, it may have multiple VLs that need to send data and at the same time have their own sending time. At this time, ES must ask each VL in order according to its scheduling algorithm, and send the data on each VL that meets the sending conditions from the same physical port in turn. This causes a delay in the VL data sent later, known as Jitter. Jitter is unavoidable and is constrained in the AFDX network by setting the maximum permitted Jitter of ES (max jitter, not greater than 500us). If the default max jitter value is exceeded during transmission, the frame is discarded. The avionics system have two sets of each redundancy backup hardware equipment, each of the VL ready to send the data to be copied for exactly two, at the same time sent to the two physical port of backup, and then sent to their respective AFDX network, the destination ES also uses Redundancy Management (Redundancy Management, RM). If it receives two data at the same time, then according to the “first come effective” way of judgment, receives the arrival of the first effective data frames, and then to discard the latter one. This double redundancy network system can guarantee the high reliability of AFDX network data transmission.

2.2 Wireless Cabin Avionics Communication Network

With the development of wireless communication network technology, more and more researchers believe that wireless communication technology in airborne cockpit can meet the communication needs of CAC system. Airborne equipment requiring communication in the cabin is mainly concentrated in the two avionics cabins of the aircraft nose, and the maximum linear distance between any two points in each cabin is less than 6m. Considering the transmission characteristics of airborne equipment and comparing with the existing AFDX airborne network, if wireless communication technology is to be used for communication in the onboard cockpit, the following requirements need to be met in the transmission radius of 6 m.

– Sufficient stable transmission network bandwidth between avionics should be provided
– End-to-end information transmission delay and maximum delay must be guaranteed;
– It cannot tolerate any information errors and must have high reliability.
– It can adapt to electromagnetic compatibility, different temperature and humidity, vibration and other environments in the engine room.

Based on the analysis of application scenarios in airborne cockpit, this paper considers that the wireless network transmission distance in airborne cockpit is relatively short, so we only discuss several possible short-range wireless networks. Through a large amount of research literature [10,11], it can be known that in recent years, short-range wireless networks that have been widely used or studied mainly include Bluetooth, ZigBee, WiFi, UWB and 60 GHz millimeter wave communication technologies.

Bluetooth operates in the 2.4 GHz band and is a time division based full-duplex wireless communication. It has a maximum transfer rate of 1Mbps (higher rate Bluetooth actually uses transport protocols and technologies such as IEEE 802.11). Generally speaking, the effective transmission distance of Bluetooth is within the range of about 10m, but by increasing the transmission power, the maximum transmission distance can reach 100m. In addition to the fact that the working frequency of Bluetooth is in the working frequency band of the avionics wireless equipment, which is easy to interfere with the existing avionics system. Bluetooth is also confronted with such problems as too complex protocol, excessive protocol consumption, low transmission rate and inflexible networking mode, which limit the application of Bluetooth in the cabin wireless communication.

WiFi, like Bluetooth, belongs to a short-range Wireless communication technology used in home or office. IEEE 802.11 protocol group is the protocol standard of Wireless Local Area Network (WLAN). With the development of WiFi nowadays, the transmission speed is fast, but its working frequency is easy to disturb the existing avionics system, which is not suitable for the future development of wireless transmission technology in the cabin.

ZigBee adopts Frequency Hopping Spread Spectrum (FHSS) technology, which works in the 2.4 GHz frequency band and has a transmission rate of only 250 Kbps with a transmission distance of 10 m–100 m. ZigBee's entire network is based on independent nodes, which form a star-shaped, tree-shaped or mesh network through wireless links. Not all nodes have the same function. As a wireless communication technology, ZigBee is characterized by low cost and low power consumption. However, its disadvantages include low bandwidth, large transmission delay, and easy to interfere with the existing avionics system, which is difficult to meet the future needs of wireless transmission technology development in the cabin.

UWB is a new wireless carrier communication technology that uses nanosecond to microsecond non-sinusoidal narrow pulses to transmit data. UWB can support several hundred Megabits per second (Mbps) data transfer speeds in the range of 10m or so, mainly due to its ability to transmit very low power signals over large bandwidth. UWB has strong anti-interference ability, high transmission speed, very large bandwidth, less energy consumption, small transmission power and other advantages, mainly used in indoor communication, high-speed wireless Local Area Network (LAN), security detection, radar and other fields. UWB communication technology has a high transmission rate and good anti-jamming and safety characteristics, which makes it a possibility for future airborne cabin wireless network technology.

As an important short-distance communication technology in the future, 60 GHz millimeter wave communication has the advantages of high transmission rate and wide frequency band occupancy. Many countries have successively opened the spectrum resources of 5–7 GHz near 60 GHz for the research and application of 60 GHz millimeter wave high-speed wireless communication technology. In March 2005, the 802.15.3c working group was established, believing that 60 GHz millimeter wave works in the 57 GHz–64 GHz licensed band, supporting high data transmission applications of at least 2 Gbps. In 2009, the IEEE 802.11ad research working group was established for better research. Benign modifications have been made to IEEE 802.11 (2007) PHY and MAC to enable them to be adapted to transport up to 7 Gbps in the 60 GHz operating band.

Based on Ref. [12,13], the performance and characteristics of several mainstream wireless communication technology are compared, including Bluetooth, ZigBee, WiFi, UWB and 60 GHz millimeter wave (MMW). Comparison results show that UWB and 60 GHz MMW technology and high transmission rate and high security and good anti-interference. These technical indicators can meet the demand of the design of the on-board wireless communication network in cockpit. However, due to the enclosed cabin environment and possible artificial occlusion, airborne cabin wireless communication network needs to be designed with a certain penetration capability in mind. However, 60 GHz MMW has a large attenuation and poor penetration ability during transmission. In addition, the ITU-R group and the relevant national key research plan for airborne in cockpit 4200 MHz to 4400 MHz band and existing problem of electromagnetic compatibility between airborne radio altimeter, the study shows that after a certain technical means, the spectrum airborne equipment communication will not produce interference to the existing airborne radio altimeter [3]. Therefore, it is possible to select UWB as the main technology for onboard cockpit wireless communication network.

3 System Model and Motivation

3.1 System Model

As analyzed in Sect. 2.2, the maximum linear distance between any two points in each airborne cabin is less than 6m, and UWB communication technology can provide a physical layer transmission rate of 200 Mbps over a distance of 6 m. Therefore, the UWB-based wireless network topology in the airborne cockpit can be abstracted as Fig. 1.

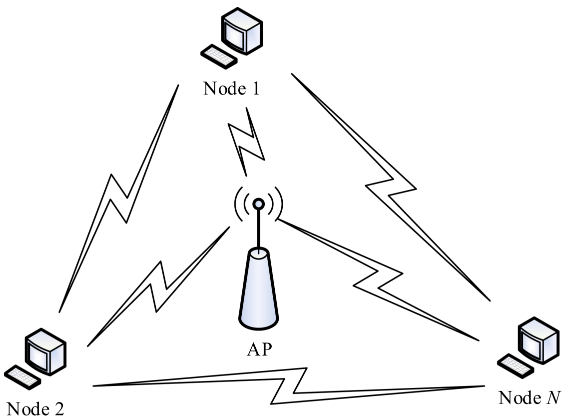

Fig. 1. Wireless network topology based on UWB in airborne cockpit

The entire network is deployed in an airborne cabin confined space within 6m, centered on an access point (AP) responsible for control. There are N terminal systems in the network (referred to as “nodes” in the following description for convenience), and data transmission between terminal systems can be carried out directly at a rate up to 200 Mbps. AP is mainly responsible for time synchronization and slot allocation scheduling, and does not participate in data forwarding between various nodes in the cockpit. The data that needs to be sent from the nodes in the network to the MAC layer does not arrive in cycles, but more in Poisson distribution. At this time, the data that cannot be sent in time will enter the buffer and wait for sending.

In UWB network based on TDMA protocol, time is divided into continuous and periodic frames. In the MAC protocol based on fixed allocation TDMA, since all time slots have been fixed periodically, each node can only send data within the time slots allocated to it. The MAC scheme based on fixed allocation TDMA can guarantee the maximum delay of end-to-end transmission, but the overall network utilization is relatively low.

3.2 Motivation

The traditional UWB network is a competitive wireless network, which can not guarantee the QoS of the wireless network in the cabin. Ref. [14] studies the UWB MAC based on frame, which sets aside 5 MAS and 8 MAS for DRP scheduling in a frame respectively, and obtains the maximum delay of about 300ms and 190ms respectively, indicating that the use of fixed allocation scheduling protocol can effectively reduce the upper bound of delay.

Therefore, Ref. [6] proposed a TDMA MAC protocol based on fixed allocation, the traditional UWB super frame was improved, the entire cycle of super frame TDMA cycle in addition is to be used to synchronize time slot, the rest of the time slots are assigned to all nodes in the network of the fixed, where the network nodes and the time slots are one-to-one correspondence. All of the network node can only transfer data within fixed time slots assigned to it. The whole frame cycle adopts the TDMA scheduling mechanism based on fixed allocation. Therefore, all terminal systems in the cluster are subject to static TDMA scheduling, and fixed time slots have been allocated for each TDMA scheduling cycle of the cycle. In each cycle of TDMA scheduling cycle, each ES can only be assigned to the transfer of information transmission within the TDMA time slot. If there is need to send data, but not assigned to the time slot, or a time slot in the current time remaining is not enough to transfer the information to complete a full, it cannot compete with access networks, and can only wait until assigned to its next time slot transmission.

Therefore, in a network based on fixed allocation TDMA, if the data that the network inner ES needs to be transfer in each TDMA cycle is not uniform, part of the time slot will be wasted and the network utilization will be low. Moreover, with the increase of the network end system and the longer TDMA cycle, the more time slot waste may be caused. This motivates us to design a distributed reservation and contention combined TDMA protocol for airborne cockpit.

4 Proposed Distributed Reservation and Contention Combined TDMA Protocol

4.1 Basic Idea of DRCC-RDMA

The proposed DRCC-TDMA protocol is a combination of traditional fixed allocation TDMA protocol and competitive access protocol. Traditional TDMA protocol for all terminal system based on distribution of fixed distribution based on time of channel resources, can effectively guarantee the maximum time delay, to avoid conflict, but the channel utilization rate is low. The DRCC-TDMA protocol allows other nodes to access the free time slot through p-probability competition, which is beneficial to reduce the waste of idle time slot, in improving the utilization ratio of network at the same time reduce the network system of the whole or part of the node time delay.

In DRCC-TDMA protocol, except AP broadcast time synchronization and slot allocation, the entire frame TDMA cycle is firstly allocated to each node in the network in advance. In the frame TDMA cycle, all nodes in the network are allocated fixed length and time slots, and all nodes are fully synchronized, so that the time of sending data can be determined. All nodes have absolute priority to send data in the time slot assigned to them. However, if a node has no data to send in the time slot fixed to it, other nodes can access the network through p-probability and carry out data transmission in the idle time slot.

4.2 Detailed Description of DRCC-TDMA

Frame Structure. The DRCC-TDMA protocol in this paper is designed based on UWB frame. It should be noted that there are static and dynamic frame structures. Static frame structure refers to the cycle with fixed length allocated by the network system integrator. Dynamic frame structure means that AP dynamically changes the frame length according to the result of slot allocation. Because of the airborne cockpit wireless network studied in this paper, the maximum delay accepted by each node can be determined, and the TDMA scheme based on fixed allocation can ensure the maximum delay. Static frame structure is selected in this paper. As shown in Fig. 2, it is an improved UWB static frame structure based on DRCC-TDMA protocol.

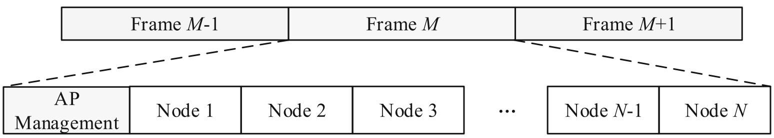

Fig. 2. UWB static frame structure based on DRCC-TDMA protocol

Figure 3 is the schematic diagram of DRCC-TDMA protocol. Since frames are used as the unit of time slot management, this paper defines that each frame consists of N+1 time slot. The first slot 0 of each frame is the management slot issued to AP, and the remaining N slots are used by each node in the network to transmit data business. The number of slots is determined by the total number of nodes in the network. Based on the fixed-allocated TDMA, this protocol allocates one or more fixed-size time slots for each node (in this paper, only one fixed-size time slot is allocated for each node) as the main time slot of this node, which is the Master node of this time slot. Other nodes competing for access to this time slot are called Slave nodes.

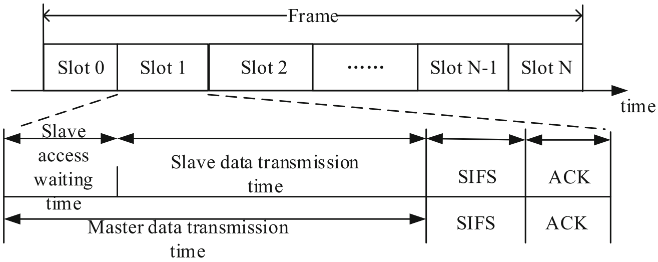

Fig. 3. UWB static frame structure based on DRCC-TDMA protocol

Each TDMA slot is fixed. For the Master, the slot may contain at least one Short Interframe Space (SIFS) and an ACK acknowledgement in addition to the Master data transmission. The maximum value of the data transfer period is the difference between the time slot size and the SIFS and ACK acknowledgement periods. For Slave, the fixed-size time slot can be divided into Waiting time (WT), Slave data transmission time, SIFS and ACK confirmation period, where the maximum value of the time slot is determined as the difference between the time slot and the WT, SIFS and ACK confirmation period. No matter for Master or Slave, the maximum value of the data transmission period is fixed, but the maximum value of the Master data transmission period is greater than the maximum value of the Slave data transmission period.

Slave detection channel busyness is determined according to the channel energy detection. Then only during PLCP preamble when no channel busyness is detected, other nodes can wait for SIFS time to access the network channel with p-probability. Therefore, the setting of Slave access waiting period in this paper is determined by PLCP Preamble cycle and a SIFS. Its value is not less than the sum of the two. Of course, the smaller the value is, the longer the data transmission time of Slave can be.

In order to ensure the reliability of each data in the onboard wireless network, immediately ACK is adopted in this paper. Considering the transceiver conversion and data processing time of the receiving node, a node needs a SIFS waiting time to reply to an immediately ACK frame after receiving the data frame.

DRCC-TDMA Protocol Flow Description. If AP in charge of broadcasting network allocation starts to work, it will occupy the first time slot within the frame cycle, publish the network status and broadcast it to all nodes in the network. Each node gets the current time and slot allocation from the management (MGT) frame released by AP. AP repeatedly publishes MGT frames in each frame cycle.

In each time slot, Master enters its allocated slot, while other Slave nodes enter the waiting period and detect the channel status. Master has absolute priority in this allocated slot. If Master decides to use its allocated slot, the data will be transmitted directly to the destination. The other nodes will not access the network after Master sends out the data. Otherwise if Master does not send data in its allocated slot, other nodes, if there is a need to send, then wait for WT to access into the network with p-probability. In order not to affect the transmission of the next fixed allocation slot, the maximum data that Master or Slave can transmit in this slot cannot exceed the maximum data transmission period that can be allowed.

In the DRCC-TDMA protocol, when a node in the network has a generated information flow that needs to be transmitted, it should first judge whether it is in the main time slot allocated to it. And then determine whether it should send data directly or wait for the end of the access waiting time to access the network. The specific transmission conditions are mainly divided into the following seven categories.

1. Master: A single time slot can complete the data transmission and the transmission is successful.
   Since it is Master, this node can directly monopolize the time slot to send data, and other terminal systems will not access the network after detecting Master sending. This node completes the DATA transmission in this time slot. If the Master receives the ACK frame correctly responded by the destination node after sending the DATA frame, then the DATA transmission is successful and the sending process of this node ends. Figure 4 shows that Master successfully sends the DATA timing diagram. The DATA frame length is variable, and the maximum frame length that can be transferred can be calculated according to the fixed slot size allocated.
2. Master: A single time slot can complete data transmission but the transmission fails.
   When the node does not receive an ACK frame from the destination after sending the DATA frame, it means that the DATA may fail to be sent and the DATA frame needs to be resent. If there is enough time left in the current slot (to complete data sending and receive an ACK frame), the Master can

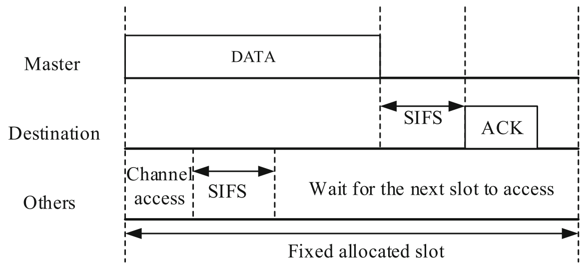

Fig. 4. Timing diagram that Master successfully sends the DATA

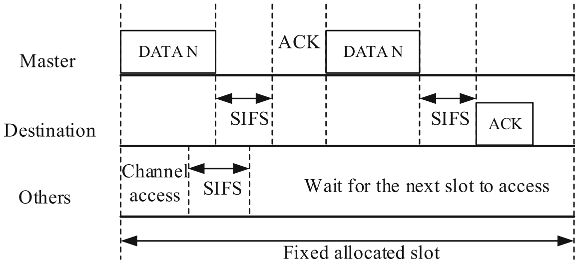

Fig. 5. Timing diagram that Master failed to send but the remaining time of the time slot can complete the retransmission

retransmit in the current slot. Otherwise, Master can attempt to access the idle slot of another node as Slave, or wait for the next allocated slot. Figure 5 is the timing diagram in which Master failed to send but the remaining time of the time slot can complete the retransmission.

3. Master: A single time slot is not sufficient to complete the data transfer.
   This case means that the node still has DATA to send after the exclusive time slot has sent the maximum DATA frame that can be transferred. If the node receives the ACK frame responded by the destination node after sending the DATA frame, it means that the DATA is sent successfully. Otherwise, the DATA frame failed to send and needs to be retransmitted. The remaining DATA to be sent or DATA frame retransmission, the node can use Slave identity to try to access the other node's idle slot or waiting for the next allocated slot.
4. Slave: After successfully accessing into the network, a single time slot can complete the data transmission and the transmission is successful.
   Figure 6 is the timing diagram that Slave successfully sends in a single time slot. As this node is not in its allocated time slot, thus it should detection the channel status. If the channel is not detected to be busy after the WT, the current time slot is judged to be idle, and p-probability is used to randomly access into the network. If the access is successful, i.e. deciding to access, it can use that time slot to transmit data. The node completes DATA transmission in this time slot. If the node receives the ACK frame correctly responded by the destination node after sending the DATA frame, the DATA transmission is successful and the sending process of ends.
5. Slave: After successfully accessing into the network, a single time slot can complete the data transmission but the transmission fails.
   If the Slave successfully accesses into the network, then the node can complete the data transmission in the remaining time of the slot. However, after sending the DATA frame, the node does not receive the ACK frame feedback from the destination node, indicating that the DATA may have failed to be sent and the DATA frame needs to be resent. If there is enough time left in the current slot, then retransmit in the current slot. Otherwise, the node can continue as Slave to try to access the idle slot of another node or wait for the next allocated slot of that node.

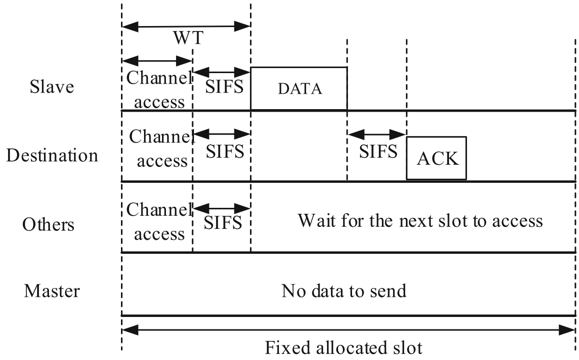

Fig. 6. Timing diagram that Slave successfully sends in a single time slot.

6. Slave: After successfully accessing into the network, a single time slot is not enough to complete the data transmission.
   If the Slave successfully accesses into the network, the node can complete the data transmission in the remaining time of the slot. If the node directly monopolize the time slot to send DATA, after sending the maximum DATA frame that can be allowed to transmit, there are still remaining DATA to send. Then for the remaining DATA to send or DATA frame retransmission, the node can continue to use Slave identity to try to access the idle slot of other end system or wait for the next main slot of the node.
7. Slave: unable to access the network. If it is not in the allocated slot, and the Slave is unable to access the network in an idle slot competition. Then it waits for the subsequent idle slot to try to compete to access, or waits until its own primary slot arrives to send data. If no slot is competed throughout the frame cycle, the worst-case scenario is to wait for the next allocated slot to be sent.

5 Performance Evaluation

In this paper, the performances of the proposed DRCC-TDMA protocol, fixed allocation TDMA (Fixed TDMA) protocol and p-CSMA protocol are evaluated and compared through NS3 simulation software. And the simulation results are presented and analyzed. Simulation parameters are presented in Table 1.

Figure 7 shows the throughput comparison of three MAC protocols under different traffic loads. Simulation results show that when the traffic load is low, the throughput of the three MAC protocols increases as traffic load increase. But the throughputs of Fixed TDMA protocol and DRCC TDMA reach the saturated point when the traffic load is larger than 180 Mbps. However, the throughput of p-CSMA protocol falls down after reaches a maximum peak value at about the traffic load of 140 Mbps, as the increasing of the traffic load. This is because when there are many nodes want to transmit their packets the collision probability

Table 1. Simulation parameters setting

Simulation parameters	Value	Simulation parameters	Value
# of nodes	30	Physical data rate	200 Mbps
Size of data	4096 Byte	Traffic load	170 Mbps
Maximum transmission radius	10 m	Total simulation time	10 s
SIFS	10 us	Waiting time	19.5 us
Lifetime of data	50 ms		

between these packets increase. This can increase the network throughput at a level before the network peak throughput is reached. However, when there are more and more packets are transmitted, the collision probability of the packets continues to increase and thus the network throughput is reduced. Thanks to the carrier sensing capability of p-CSMA, the collision probability will not reach to 1 but to a particular value according to the value of p. And finally, the throughput of p-CSMA become to a constant value when the traffic load is larger than $160Mbps$. In general, the throughput performance of DRCC-TDMA is better than that of Fixed TDMA, and p-CSMA is the worst.

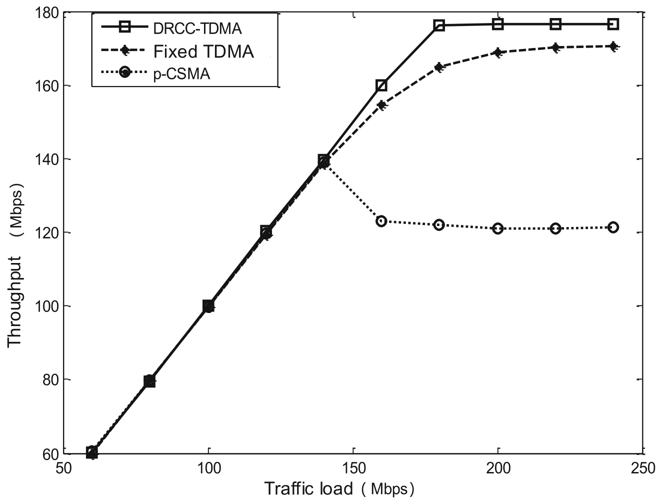

Fig. 7. Throughput comparison under different traffic loads

Figure 8 shows the average delay comparison of three MAC protocols under different traffic loads. The simulation results show that when the network load is small, the competition conflicts between network nodes are small. The delay of p-CSMA is smaller than that of Fixed TDMA. When the traffic load is small, the average delay of p-CSMA and DRCC-TDMA is smaller than that of fixed-allocation TDMA. However, with the increase of the traffic load, the competition among network nodes is gradually intensified. When the maximum throughput of p-CSMA protocol is reached, its delay performance deteriorates sharply, and the average delay is greater than that of DRCC-TDMA and fixed-allocation TDMA. DRCC-TDMA, which combines the advantages of Fixed TDMA and p-CSMA, shows the minimum average delay.

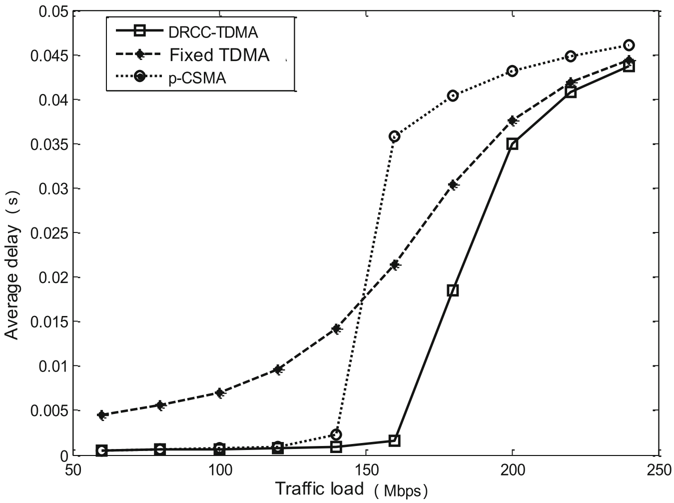

Fig. 8. Average delay comparison under different traffic loads

Figure 9 shows the maximum delay comparison of three MAC protocols under different traffic loads. The simulation results show that the maximum delay of p-CSMA is smaller than that of Fixed TDMA when the service load is small. The maximum delay performance of DRCC-TDMA is smaller than that of p-CSMA when the service load is small. However, with the increase of service load, the competition among network nodes gradually intensified. When the saturation point was reached, the maximum delay of p-CSMA and DRCC-TDMA also increased sharply, and the value of maximum delay was equal to the data life cycle. However, on the whole, the maximum delay of DRCC-TDMA was small.

Figure 10 shows the ratio of packet loss of three MAC protocols under different traffic loads. The simulation results show that when the traffic load is small, the packet loss rate of data transmission under the three protocols is 0, and there is no packet loss. But with the increase of traffic load, the packet loss rate will increase gradually. But DRCC-TDMA has a low packet loss rate among the three protocols. Among them, because the data life cycle is set, when more than 50ms has not been sent, it is destroyed, which also leads to packet loss.

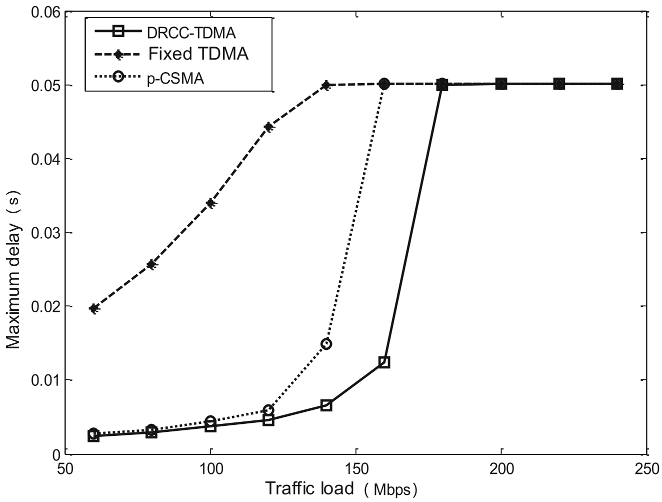

Fig. 9. Maximum delay comparison under different traffic loads

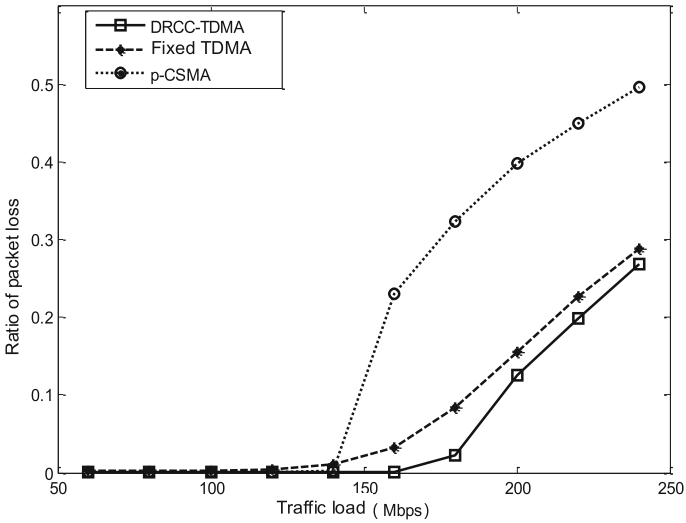

Fig. 10. Ratio of packet loss under different traffic loads

In summary, this paper conducts simulation and analysis on the performance of three protocols under different traffic loads. By comparing the performance of throughput, average delay, maximum delay and packet loss rate, the DRCC-TDMA protocol performs the best on the whole, which also benefits from its combination of advantages of Fixed TDMA and p-CSMA.

6 Conclusion

Wireless Avionics Intra-Communication (WAIC) networks can be used to reduce the structural complexity of the cabin avionics communication system and meet the increasing demand for data exchange. This paper proposes a Distributed Reservation and Contention Combined (DRCC) TDMA protocol to guarantee the maximum data transmission delay and improve the channel utilization. The proposed DRCC-TDMA protocol is a combination of traditional fixed allocation TDMA protocol and competitive access protocol. It allows other nodes to access the free time slot through p-probability competition, which is beneficial to reduce the waste of idle time slot, in improving the utilization ratio of network at the same time reduce the network system of the whole or part of the node time delay.

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