

Modeling and Simulation of Avionics Full Duplex Switched Ethernet(AFDX Network) Based on OPNET

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With the rapid development of aviation technology, avionics electric system has gradually become an indispensable part of the system. Avionics electric system is composed of many separate sub-systems. The amount of data needed to be transmitted between subsystems is growing, and the performance and security requirements of Avionics transmission bus are also increasing. The traditional avionics electric system transmission bus standards ARINC429, ARINC629 and IL-std-1553B cannot meet the requirements of modern avionics system because of the small bandwidth, slow speed and high price. In this case, the AFDX (Avionics Full Duplex Switched Ethernet) network standard arises at the historic moment. AFDX network is based on Ethernet standard. The maximum transmission rate can reach 100 Mb/s. At the same time, full duplex link is used for data transmission, which reduces link conflict. At present, AFDX network has been applied to the latest Airbus Company A380 aircraft.

To address the issues of traditional AEST bus standards, we investigate AFDX in this paper by building a AFDX network by building a AFDX network on OPNET. Specifically, in this paper, we explore the AFDX with network layer model, node layer model of avionics end-system and process layer model. And then set up the simulation network and get the end-to-end delay and delay jitter in general state of the AFDX network. Furthermore, we build a star network for comparison. We found that the QoS performance of AFDX is better than general star network.

Keywords—AFDX network, end to end delay, delay jitter.

I. INTRODUCTION

With the increasing demand for aviation services and the continuous development of avionics systems, the new generation of aviation technology must solve the problems of complex data types, large data transmission capacity, strict real-time requirements and highly concurrent between avionics subsystems, meanwhile, because the traditional aviation bus has low transmission bandwidth and high cost, they are no longer considered in modern aviation systems.

Recently, Airbus Company has developed a new full-duplex switched Ethernet transmission standard, Avionics Full Duplex Switch Ethernet (AFDX), on its latest A380 aircraft, and is included in Part 7 of ARINC 664 [1]. Based on the traditional Ethernet model, AFDX uses full duplex link for data transmission, and uses virtual link for logical isolation of communication between avionics subsystems. AFDX is different from the traditional airborne aviation bus. It is not a bus standard, but a network protocol, using TCP/IP protocol stack for packet processing, and it can contain more end system than the traditional method. At the same time, it

greatly reduces the number of cables by using full duplex link. There is no bus controller in AFDX, and star topology is adopted to avoid the problem of centralized control in the bus. AFDX standard can achieve 100 Mb/s or even higher data transmission rate. It has solved the large requirements of modern aircraft for complex avionics subsystem data in communication and passenger data in entertainment.

In network communication, end-to-end delay and delay jitter are important parameters to measure network performance. The network delay describes the time that a packet travels from the transmitter to the receiver. The delay jitter describes the jitter of the network delay. In data transmission, network delay is unavoidable. It mainly consists of transmission delay, propagation delay, scheduling delay and processing delay. The transmission delay describes the delay from data generation to sending out from the sending port, the propagation delay describes the delay of data packet passing through the link, the processing delay describes the delay of data packet storage and forwarding in the switch, and the scheduling delay describes the transmission port receiving the data packet and sending it out. Transmission delay, propagation delay and processing delay are generally fixed, and scheduling delay is variable, depending on the current network load. Delay jitter describes the change of packet delay. The smaller the delay jitter, therefore, the higher the network stability. If the network is congested, the delay jitter will change drastically. For real-time tasks, the delay jitter must be limited to a certain level to ensure the quality of the services of the network.

However, the properties of AFDX is not sufficiently studied in the community. Before this paper, we found lots of papers about algorithms with virtual link, or some improving methods for scheduler, there're no paper about the redundant management. In this paper, according to the characteristics of AFDX network, we construct a double star network structure with two switches, surrounded by several end system nodes which are connected with them. We simplify the virtual link for a clearer understanding. Finally, we measure several groups of delay and delay jitter, comparing with one star network, to verify the stability of AFDX network.

II. STRUCTURE OF AFDX NETWORK

The main components of AFDX network [1] include avionics subsystem, terminal system, switch and transmission link, as shown in Fig. 1.

Avionics subsystems are used in many places around the plane. They are connected together by aviation data bus or airborne network to form an avionics system.

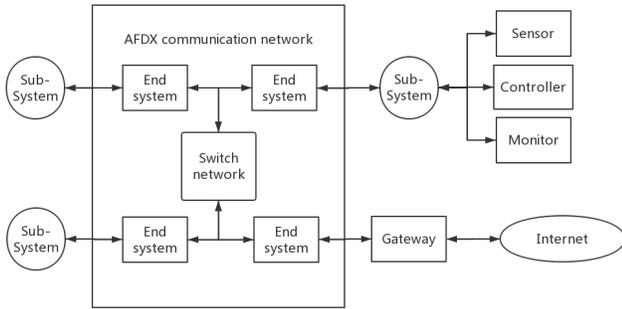


Fig. 1: The main components of AFDX network.

The end system is the interface between the avionics sub-system and the network of the avionics system, including the transmitter system and the receiver system. The transmitter system receives the data generated by the avionics subsystem and encapsulates it in packets that conform to the AFDX protocol specifications. Then, each packet is put into the corresponding virtual link cache according to the virtual link number. In the network, which has redundant management, the packets need to be copied and put into the corresponding sending buffer in the port. At the sending time, the packets are sent to the transmission link. The receiver system receives data packets from the network, drops duplicate packets and checks error, delivers the correct data packets layer by layer up, and then send the data to the avionics subsystem that needs to receive the data after removing the protocol header.

The switch connects all the end systems of the AFDX network together with the transmission network to form the avionics system communication network. Switches mainly perform filtering and control, switching, monitoring and other functions. The existence of the switch also indicates that the avionics data bus has changed from point to point connection to switch mode.

A. Virtual link

Virtual link (VL)[1] defines a logical one-way connection in which data frames are sending from a source system to one or more target systems in an AFDX network. Each VL is assigned a maximum bandwidth and allocated before the start of the system. Bandwidth Allocation Gap (BAG) reflects the minimum time interval between the start bits of two adjacent frames in the same virtual link. In order to guarantee the BAG of each virtual link, flow regulation is needed for each link. For each logical link, the end system should maintain the order of the data whenever in sending or receiving.

If there are multiple virtual links in one end system, the scheduler schedules each of the virtual links to achieve multiplexing. Fixed-interval data frame streams are obtained from the data frames of each virtual link after flow regulation. These data frame streams do not have jitters. After processing by the scheduler, the conflicting data frames are arranged in corresponding order, this step may cause jitters. Then transmitted over the same physical link, as shown in Fig. 2.

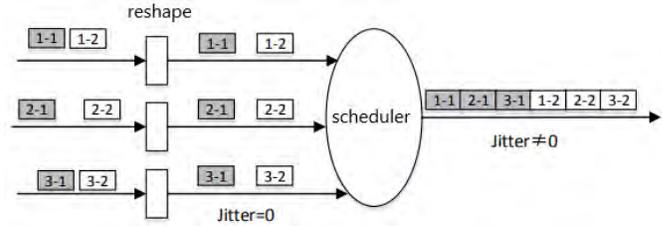


Fig. 2: Scheduler and flow regulation [1].

B. Delay jitter

Delay jitter [1] refers to the time that each packet arrives at the receiver due to network congestion or queuing. Network transmission is a complex process that requires different links and switches. When data leaves the sender and passes through the switch, the uniform interval between adjacent packets formed by traffic shaping at the sender is destroyed. The queue length is long, resulting in an irregular time delay curve. The larger the delay variation, the greater the delay jitter.

Delay jitter describes the change of end-to-end delay in the same link. Unlike network delay, delay jitter can be avoided. The smaller the delay jitter, the more stable the network is. Delay jitter is an important metric to measure network real-time ability and quality of service. For some multimedia applications, delay jitter constraints are stronger than network delay constraints. Multimedia data delay jitter will cause audio or video jitter, affect user experience. Avionics system includes a large number of sensors, such as temperature sensors, height sensors, pressure sensors, angle-of-attack sensors, etc., which constitute a sensor network. The sensors collect data periodically and send them to the master computer. These data need not only low delay but also low delay jitter. If the network delay jitter is too large, the emergency data would fail to be acquired in time. Moreover, more and more entertainment applications are appearing in avionics systems. These multimedia data require relatively little delay, but need to ensure low delay jitter to ensure the smooth sound and picture.

III. MODELING OF AFDX NETWORK

OPNET is an excellent network simulation platform, which can accurately analyze the performance and behavior of complex networks [4], and has been widely used in communication, aerospace, network system integration and so on. OPNET uses three-layer modeling composed of network layer, node layer and process layer.

In OPNET simulation, each network device is a node. The node completes all the work that should do by a network device. The node is composed of multiple node modules, and each node module completes a part of the function. In standard AFDX network, there are four kinds of network devices: avionics subsystem, end system, switch and transmission link.

The avionics subsystem (Fig. 3) generates application data and transmits data flow to the end system.

End system (Fig. 4) is the interface between upper application and communication network in AFDX network. Each end system is represented by a 16-bit binary code. The main

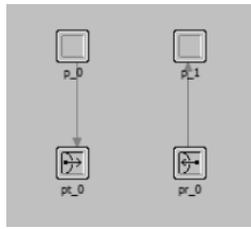


Fig. 3: The node model of avionics subsystem.

tasks of the end system include data receiving, protocol stack processing, traffic shaping, traffic scheduling and data frame sending.

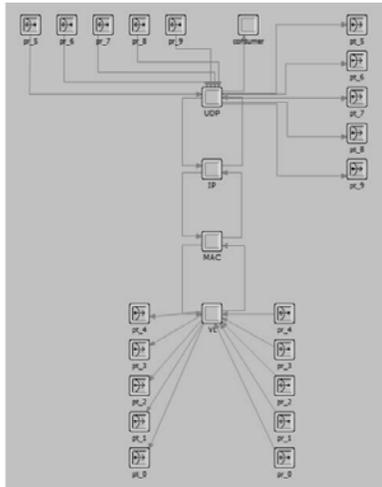


Fig. 4: The node model of end system.

AFDX network is based on IEEE 802.3 standard. In the end system model, UDP module simulates the behavior of transport layer including specifying UDP port number of specified link and adding UDP header to data packet. IP module simulates network layer behavior, specifies the source IP address and destination IP address of the link, if the packet size is too large, then the packet is grouped and the IP header is added. MAC module simulates the behavior of logical link layer and encapsulates IP data packets provided by network layer into AFDX frame format.

Switch (Fig. 5) is the core of AFDX communication network. All switches form switch network to complete storage and forwarding function.

For a clearer presentation, we tailor our model by simplifying the virtual link in this paper [2]. We assume that every end system only have limited sub-system linking with virtual link. For our convenience, we set the inter-arrival time between data much long, so the BAG can be ignored. The network layer is show in Fig. 6.

We use a gateway as an end system and build a node as avionics subsystem. There are two switches working as the redundant network. The nodes can send data to any other nodes. Although the network is simplified, the delay we measure does not change. We still achieve the same goal, that is making the network stable. The node layer and the process layer is not special. We directly choose the templates

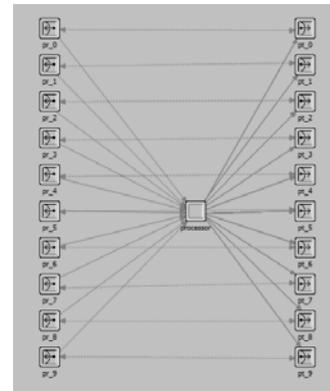


Fig. 5: The node model of switch.

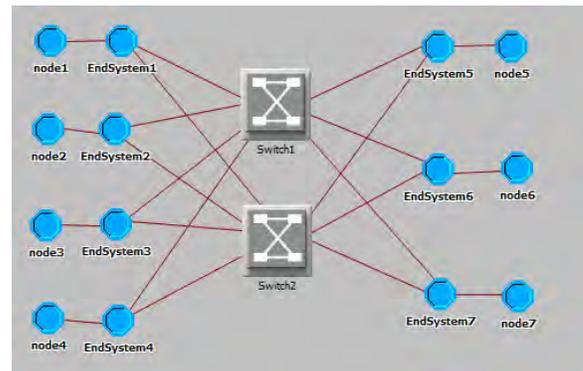


Fig. 6: The network layer.

in the OPNET software. In order to prove that AFDX works better than usual one-star network, we also build a traditional Ethernet with one switch, which is just like the network above but only one switch on center.

IV. SIMULATION AND ANALYSIS OF AFDX NETWORK

The simulation results are shown in Fig. 7 below, which shows the end-to-end delay and delay jitter from node1 to node5 in communication. We use the average value of the data and use curve fitting, so that the results are more intuitive. We can see that the delay curve is very smooth, and the delay jitter is also flat and always at a low level.

At the same time, we measured the delay and delay jitter of the traditional Ethernet with one switch (Fig. 8). We can see that the delay curve is very smooth. Although the average value eliminates the change of the delay variation, the average value shows that the end-to-end delay is stable. In this respect, AFDX network has a little bit advantage (about 20%). By observing the delay jitter, we can clearly see that the corresponding curve of AFDX network is much lower than that of traditional Ethernet with one switch, which proves that AFDX network can guarantee delay jitter. We can also see the same result in packet loss rate (Fig. 9,10). It shows the excellent quality of service of AFDX network again.

V. SUMMARY

In AFDX networks, virtual links are used to logically isolate data from different avionics subsystems, and the maximum

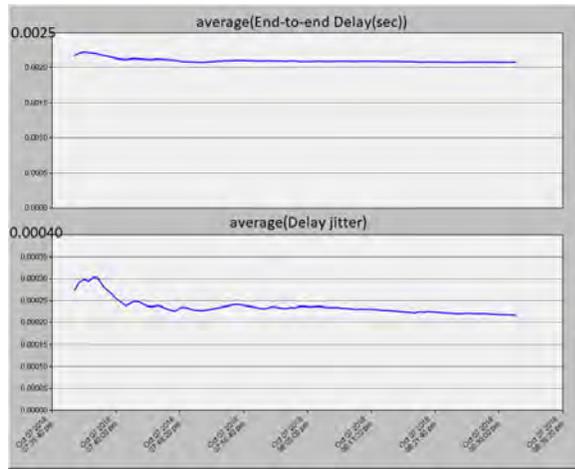


Fig. 7: The end-to-end delay and delay jitter from Node1 to Node5 on average.

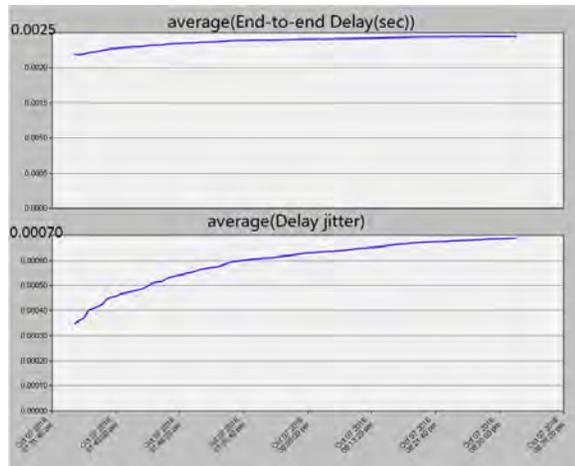


Fig. 8: In traditional Ethernet with one switch, the end-to-end delay and delay jitter from Node1 to Node5 on average.

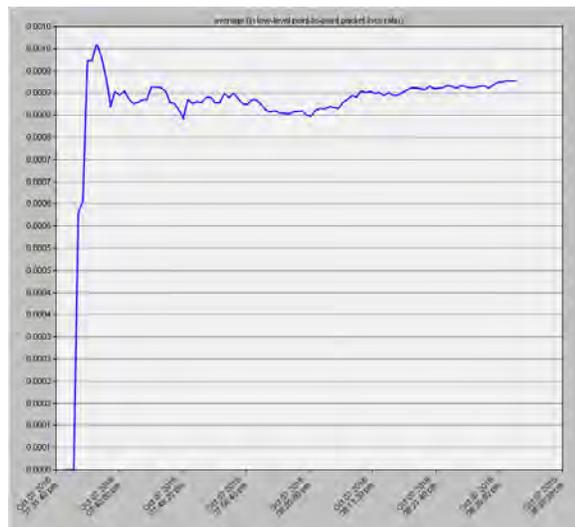


Fig. 9: The packet loss rate from Node1 to Node5 on average (the maximum on Y axis is 0.0010).

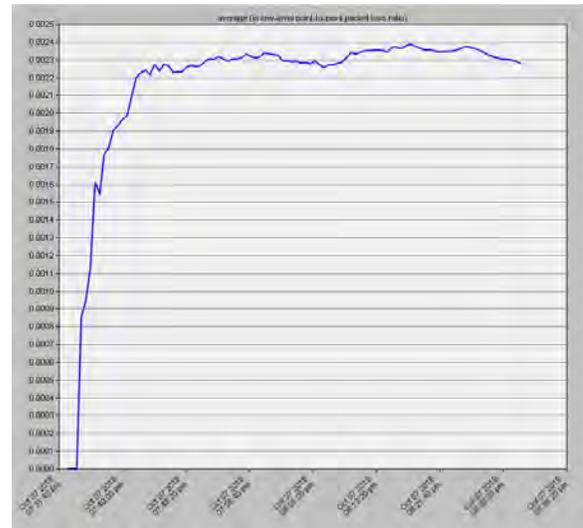


Fig. 10: In traditional Ethernet with one switch, the packet loss rate from Node1 to Node5 on average (the maximum on Y axis is 0.0025).

link traffic is limited by adding the maximum bandwidth allocation gap. The redundancy management is added to enhance the stability of the network. We build a simple model, and test its actual end-to-end delay and delay jitter, then by comparing to traditional Ethernet with one switch, we can easily find AFDX network has a better QoS, it adapts to more real-time tasks.

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