Analysis of AFDX Network Delay Based on NS2

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Abstract. AFDX network simulation is of great significance for evaluating and determining whether AFDX can meet the real-time requirements of avionics networks. Compared with theoretical analysis methods such as network calculus, network simulation can better understand the true behavior of the AFDX network. In this paper, we build an AFDX network simulator based on NS2, where AFDX switches, end systems and virtual links are properly modeled. Using this simulator, the end-to-end delay of an AFDX network under different scheduling strategies is studied. Some key performance measures of the system are also analyzed.

Keywords. AFDX; NS2 network simulation; scheduling strategy; end-to-end delay.

1. Introduction

With the continuous growth of aviation service demand and the continuous upgrading of avionics systems, the new generation of aviation technology must solve the problems of complex data types between avionics subsystems, large data transmission requirements, strict real-time requirements, and high concurrency. Traditional avionics data buses such as ARINC429, ARINC629 and 1553B have low transmission bandwidth and high cost, and are no longer considered in modern aviation systems [1]. Avionics Full-Duplex Switched Ethernet (AFDX) is formed by the industrial standard Ethernet communication protocol through adaptive improvement, which has relatively higher reliability, stronger adaptability to harsh environments and higher real-time performance. Its transmission rate can reach 100 Mbit/s, and it has been applied to Airbus A380, A350, Boeing B787, COMAC ARJ21 and other types of aircraft.

AFDX network introduces virtual links to provide a relatively lower communication transmission delay, and proposes redundancy management to solve the problem of frame loss caused by network fluctuations. For each virtual link, the frame is transmitted through two redundant networks, and the "first arrival effective" strategy is applied such that when the first frame reaches either of the two networks, the second frame is discarded. This redundancy management ensures that normal communication is still possible when a certain network component fails.

In AFDX network communication, end-to-end delay and delay jitter are two important parameters to measure network performance. The end-to-end delay describes the time for the data packet to be transmitted from the sender to the receiver, and the delay jitter describes the jitter of the network delay. In data transmission, end-to-end delay is inevitable, which is mainly composed of transmission delay, propagation delay, processing delay and scheduling delay. Transmission delay describes the delay from data generation to transmission from the sending port, propagation delay describes the delay of data packets passing through the link, processing delay describes the delay of data packet storage and forwarding in the switch, and Scheduling delay describes the queuing delay for the
transmission port to receive data packets and send them out. Transmission delay, propagation delay and processing delay are generally fixed, and scheduling delay is variable, which depends on the current network load. Delay jitter describes the change of packet delay. Therefore, the smaller the delay jitter, the higher the network stability. If the network is congested, the delay jitter will change sharply. For real-time tasks, the delay jitter must be limited to a certain level to ensure the quality of service of the network.

In the AFDX network, a core problem that needs to be solved is the accurate estimation of the end-to-end delay of the data packet. For the aviation network system, which has strong real-time requirements on tasks and data processing, an important design criterion is whether data packets can reach the set destination system within the specified time under the condition of specific resources.

Liu et al modeled and simulated the AFDX network using OPNET, and discussed AFDX based on the network layer model, the node layer model of the avionics terminal system, and the process layer model. A simulation network is established to get the end-to-end delay and delay jitter under the general state of the AFDX network [1]. Hu used network calculus to theoretically analyze the transmission delay of AFDX network, and then built the AFDX network through the True Time simulation toolbox to simulate the end-to-end delay of the data flow under different scheduling strategies [2].

The main contribution of this paper includes: modeling and simulating of AFDX based on NS2, comparing and analyzing the end-to-end delay under three different scheduling strategies of switches, and showing that SFQ and DRR scheduling strategies can effectively reduce the delay when the network is busy.

The remainder of this paper is organized as follows. Section 2 introduces the modeling of the AFDX network. Section 3 describes the design and implementation steps of the AFDX simulation system. Section 4 takes the AFDX network configuration as an example to conduct a simulation study. Section 5 concludes this paper.

2. AFDX Network Modelling

The main components of the AFDX network include avionics subsystems, end systems, switches and virtual links (VL) [3], as shown in figure 1.

![Figure 1. The main components of the AFDX network.](image-url)
data packets layer by layer, and deletes the protocol header before sending the data to the avionics subsystem that needs to receive the data. For virtual links, the most important function of the end system is traffic shaping, in addition to system configuration and integrity checking. According to these functions, a terminal system simulation model based on queuing theory is established [4].

The switch connects all terminal systems of the AFDX network with the transmission network to form an avionics system communication network. The main function of the switch is to receive and forward data frames, in addition to filtering, switching, monitoring and configuration table settings. Based on these functions, the simulation model of the switch system is mainly composed of receiving queue buffer (entry), sending queue buffer (export), filtering module, police module and dispatching transmission module (multiplexer queue and routing) [5]. The existence of the switch also indicates that the avionics data bus has changed from a point-to-point connection to a switch mode. Models and related functions of switch and end system are shown in figure 2.

The core of the AFDX network is a virtual link (VL). A virtual link is a logical connection that connects one end system to one or more end systems. The network designer can configure the upper limit bandwidth of each virtual link [6]. Each virtual link is determined by two parameters, one is BAG—the minimum sending time interval of two consecutive frames belonging to a virtual link, and its value interval is $2^k$ ms ($0 \leq k \leq 7$, $k$ is an integer), as shown in figure 3. The other is Lmax—the maximum frame length of the virtual link. The maximum frame length cannot exceed 1518 bytes, and it cannot be less than 64 bytes. In this way, the maximum transmission volume of a virtual link can be determined, and the system integrator can allocate different service bandwidths for each virtual link to ensure its reliable transmission. In this paper, the duplex-link model is used to realize the transmission and queue buffering functions of the virtual link.

![Figure 2. AFDX end system and switch model.](image)

The existence of the switch also indicates that the avionics data bus has changed from a point-to-point connection to a switch mode. Models and related functions of switch and end system are shown in figure 2.
3. Design and Implementation of AFDX Network Simulation System

NS2 (Network Simulation 2) is a discrete event network simulator, which is mainly used for the simulation of various network protocols and network architectures [7]. NS2 uses object-oriented programming, written in C++ and OTcl. The simulator supports the class hierarchy (compilation level) in C++ and the similar hierarchy (interpretation level) in the OTcl interpreter. These two hierarchical structures are closely related, and the classes are in one-to-one correspondence. The operating system it mainly supports is the Linux system, which can be run after installing Ubuntu on the VMware Workstation virtual machine. The simulation process of NS2 is shown in figure 4 [8].

![Figure 4. NS2 simulation process.](image)

It is worth mentioning that writing Tcl simulation code is the most important and indispensable part of NS2. Most of the simulation work of NS2 is writing Tcl code to describe the network structure, network component properties, and control and dispatch network simulation events. After the simulation, relevant tools can be used to conduct data analysis and graphical display of the simulation results. The steps of writing Tcl script files for simulation are shown in figure 5 [9].

![Figure 5. Tcl script file simulation process.](image)

In NS2, the end system and the switch are simulated by creating nodes, and then the nodes are connected through duplex-link, and related parameters are set to realize various functions. In the end system model, the UDP connection is established by setting the Agent, and then the upper application program simulation is carried out through the application layer protocol.

The switch receives the data packet from the virtual link and puts it into the input port buffer. After the input buffer completely receives the data frame, the switch checks the static routing and forwarding table in the switch through the destination address of the data packet, and puts the data packet into the virtual queue corresponding to the destination output port. Then, the queue scheduler of the output port schedules and sends all data packets on the virtual link of the port according to the set scheduling strategy. Different scheduling strategies will affect the service capability of the data stream, thus causing the difference in processing delay between different data streams.

Virtual link (VL) refers to the logical communication relationship between the end systems connected to each other in the AFDX network. A VL can only be sent from one source end system, but data packets can be sent to multiple destination end systems, which can achieve bandwidth
isolation. The VL model can be represented by the duplex-link supported by NS2, which guarantees bandwidth and lower transmission delay [10]. In fact, the VL of NS2 implements the functions of the physical layer, data link layer and part of the network layer at the same time.

4. Simulation Study

The AFDX protocol uses the First-Come-First-Serve scheduling strategy, which treats each data stream fairly, and forwards the corresponding data according to the arrival of the data stream. However, the FCFS strategy does not distinguish the priority of different types of messages, which is likely to cause the transmission of some urgent data streams to time out. In order to meet the real-time transmission requirements of different data streams, the end-to-end delay under different scheduling strategies is simulated and analyzed below. The simulation topology used in this section is shown in figure 6.

In this simulation topology, the end system ES1 sends out the aviation data stream with the highest priority, ES2 sends the multimedia data stream with the second priority, and ES3 sends the best effort data stream with the lowest priority. The minimum packet gap and maximum frame length of each type of data stream are the same. Taking into account the worst extreme case, the AFDX frames on VL are all set to 1518 byte, and the maximum rectification delay is 0.2 ms. At the same time, in order to observe the difference between the scheduling algorithms FIFO (First in First Out), SFQ (Stochastic Fair Queueing), and DRR (Deficit Round Robin), the data stream flow sent by all end systems is set to 100 Mbps which exceeds the processing capacity of the switch.

After running the corresponding Tcl code and processing the data, the end-to-end delay of data under different scheduling strategies is shown in figure 7, the delay jitter is shown in figure 8.

Figure 6. simulation network topology.

Figure 7. End-to-end delay under different scheduling strategies for each data flow.
It can be seen that when the scheduling strategy is FIFO, aviation data flow with strict real-time requirements is significantly lower than the other two types of data flow, but it still does not meet the requirements. When the scheduling strategy is adjusted to SFQ and DRR, the delays of the three types of data flows are significantly reduced, and the delay of the two types of low-priority flows is slightly lower than that of aviation data flows, ensuring the relative fairness of data transmission. Under the latter two scheduling strategies, the end-to-end delay is 2.2ms and 1.5ms on average, which means that the end-to-end delays of different virtual links are within a certain range, conforming to the ARINC664 standard. And the higher the priority, the lower the delay. The maximum delay jitter is 0.08ms, and the result is in line with the ARINC664 standard, which requires a delay jitter of less than 0.5ms. It can be seen that DRR is better than FIFO and SFQ in terms of reducing end-to-end delay and ensuring fairness.

5. Conclusions
In this paper, an AFDX-based network simulating platform is built using NS2. The end-to-end delay of various priority data flows under different scheduling strategies is simulated and analyzed. The reliability of the transmission delay and jitter is also verified. At present, only the AFDX double-hop network has been simulated. The next goal is to design and simulate the delay and jitter of multi-hop networks under different scheduling strategies, which is of great significance to the optimization and improvement of the AFDX network.

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