Performance Analysis of FC-AE-ASM Based on CPN

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Abstract. Fibre Channel Avionics Environment has been applied widely in the integrated avionics system, with high compatibility, low latency and high reliability. Estimate the performance of the FC-AE-ASM, one of upper layer protocols of FC-AE, has a significant meaning when designing the integrated avionics system. In this paper, a model of FC-AE-ASM protocol is proposed based on the Colored Petri Net. Hierarchical modeling mechanism is applied when modularize the components of FC-AE network. And through the simulation, obtain the performance parameters as bus load and delay, by which we can provide theoretical basis for designing and estimating the integrated avionics system.

1. Introduction

In last decades, Fibre Channel Avionics Environment (FC-AE) has been the most popular bus technology for integrated avionics system, which meet the requirements for high speed, determinism, low error rate, and strong anti-interference. It has become the first candidate for advanced integrated avionics system and it has been implemented on military aircraft such as F-35, Apache.

American National Standards Institute (ANSI) developed the Fibre Channel Avionics Environment into several kinds of upper layer protocols, such as Anonymous Subscriber Messaging (ASM), Fibre Channel Lightweight Protocol (FCLP), Remote Direct Memory Access (RDMA), and FC-AE-1553 to meet different requirements.

FC-AE-ASM is designed to support full-duplex data transmission and real time control/response with high reliability, fault tolerance, and deterministic behavior in severe and constrained environment, military avionics applications typically. For more details, every message in FC-AE-ASM is originated in a unidirectional exchange. The recipient expects the message to arrive at a predetermined rate but does not know where the message is generating[1-3].

Estimate the performance of FC-AE network or FC-AE-ASM protocol has a significant effect when designing the integrated avionics system. There are quite a number of relevant studies analyze it, and most of them use software to simulate the FC-AE network.

Some researchers simulate the FC-AE network by OPNET, which is the most common network simulation software. Ref.[4] build a queueing model of the network. According to M/G/1 model of queue theory, analyze the queue length, service time and so on. Through the simulation by OPNET, the relationship between end-to-end delay and nodes of FC Network is studied. Ref.[5] propose the network structure model and a control algorithm of data transmission. Through the node model and fibre channel switch model setted in the OPNET Modeler, simulate and analyze the performance of FC-AE network.

Ref.[6-8] construct there own simulation platform. Ref.[6] build a software platform based on the
discrete events system simulation mechanism, and provide performance parameters such as throughput, delay and real-time characteristics. Ref.[7] construct a platform combine software and hardware present the method of data transmission on FC-AE network, through which can test the network performance. Through the simulation, analyze the relationship between delay and length of message. By semi-physical simulation, [8] focus on the network layer of FC-AE-ASM, attain the delay and throughput, Validate the consistency.

These methods can simulate the FC network with high accuracy. However, the poor operability and complex configuration will result in the shortcomings like high cost, tedious process. Petri Net is an model tool, which not only have sufficient simulation capability and abundant analytical methods, but also easy to operate.

Ref. [9, 10] adopting Deterministic and Stochastic Petri Net (DSPN) to simulate the FC-AE-ASM protocol, and performance parameters such as bus load and delay are analyzed. What’s more, the simulation is easy to implement.

This paper provides a model of FC-AE-ASM protocol based on the Colored Petri Net (CPN), which can describe the dynamic process of data transmission. Through the simulation on TimeNet, we can obtain the performance index such as bus load and delay. Analysis the performance parameters can guide the design and usage of avionics system.

2. Colored Petri Net

2.1. Basic Petri Net

Basic Petri Net [11] is a graphical and mathematical tool for modeling concurrent or asynchronous system. The classic Petri Net is a directed bipartite graph with two node types called places and transitions. The nodes are connected via directed arcs. Connections between two nodes of the same type are not allowed. Places are represented by circles and transitions by bars. Places may contain zero or more tokens, drawn as black dots. The number of tokens may change during the execution of the net. A place $P$ is called an input place of a transition $T$ if there exists a directed arc from $P$ to $T$. A place $P$ is called an output place of a transition $T$ if there exists a directed arc from $T$ to $P$. A transition is called enabled if each of its input places contains at least the number of tokens equal to its weight. In other words, a transition is enabled if all input places contain (at least) the specified number of tokens. An enabled transition can fire. Firing a transition $T$ means consuming tokens from the input places and producing tokens for the output places. The number of tokens produced for each of the output places is equal to the weight of the corresponding arc. A state of a Petri net is a distribution of tokens over the places. Many authors use the term marking to denote the state of a basic Petri net.

2.2. Colored Petri Net

The CPN[12-14] can be described through a tuple with 9 parts, where $CPN = (\Sigma, P, T, A, N, C, G, E, I)$ specifically.

1. $\Sigma$ is the set of colorsets;
2. $P = \{P_1, P_2, ..., P_m\}$ is the set of places;
3. $T = \{T_1, T_2, ..., T_n\}$ is the set of transitions;
4. $I \subseteq (P \times T) \cup (T \times P)$ is the set of arcs;
5. $N : A \rightarrow (P \times T) \cup (T \times P)$ is the set of node Function;
6. $C : P \rightarrow \Sigma$ is the Color Function, which maps $P$ to $\Sigma$;
7. $G : T \rightarrow Expressions$ is the Guard Function;
8. $E : T \rightarrow Expressions$ is the Arc Function;
9. $I : P \rightarrow ClosedExpressions$ is the Initialization Function.

A Colored Petri Net can be described in terms of a net structure (just as basic Petri Net), colorsets (eg, data types), initial marking, and enabling and occurrence rules. The colorsets determine the types of the tokens in the CPN model, and the Color Function maps each Place to a colorset, which means
that every token in the is belong to this colorset. Guard Function maps each transition to a boolean expression, only the boolean expression is true, the transition will be enabled. Arc Function maps each arc to an expression, which control the result or condition of the transition. Initialization Function maps each place to an expression, which doesn’t have variable.

3. CPN model of FC-AE

The In order to simplify the model, make the following assumptions:

1. The N-port can generate messages instantaneously;
2. Ignore the time that switch handles the message;
3. Each message is transported just in one frame, which means that the frame can be arbitrarily long, so that use a single token to represent the message;
4. Add an Ack frame, which doesn’t exist in the FC-AE-ASM protocol, to calculate the delay.

Based on the assumptions above, we can attain the CPN model as followed.

3.1. Analysis of Model

Based on the Fig.1, there are four N-ports, N1, N2, N3 and N4 specifically, in four corners; two switches, S1 and S2, in the middle. Fibre Channels link the N-port and switch. The N-port can send data-frames and receive ack-frame. The attributes of the message are configured in the N-port, more details can be seen in character 2.2.

Fig.1 Topological Structure

Inside the substitution transition of N1, as Fig.2 shows, there are two parts. The upper part, including a Message substitution transitions-M1, a place named Delay1 and an immediate transition, represent the send part of the N-port. For every message, a similar constitution should be added in the N-port. The lower part, including 2 immediate transitions T1, T2 and a place named Rec. represent the receive part of the N-part.

As shown in Fig.2(b), is the structure of M1. The right part of M1, including P1, P3 and T3, control the period of the message. At the original state, there is a token in the Message1, for which we can define the number, sender, receiver and the length of this message.

Fig.2 Structure of N1(a) and M1(b)

Fig.3(a) shows the model of Fibre-Channel. Tokens that represent data frame, will transfer through P22, T12 and so on, while tokens represents Ack frame will transfer directly to the P23. Finally, tokens will transfer to the P1 or P8 according guard function define in T13 and T14. The Place Load1 will calculate the load of the Fibre Channel, while the substitution transition can calculate the transfer time of each token.

The left part of Fig.3(b) represents the input of the switch, while the right represent the output. In immediate transitions as T4, T5 and T6, define corresponding guard function to transfer the tokens to right place.
To illustrate place and transition about the model more, a table given as followed.

### Table 1 Detail of P&T

| Item       | Description                          |
|------------|--------------------------------------|
| N1-Delay   | Calculate delay                      |
| N1-Rec     | Frame buffer                         |
| N1-TD      | Transfer Ack frame                   |
| M1-Message | Token of message                     |
| M1-P1      | Token of period                      |
| M1-T1      | Start transfer                       |
| M1-T3      | define                               |
| FC1-P0     | Input of FC1 from N1                 |
| FC1-P22    | Wait to be transfer                  |
| FC1-Load1  | Load of FC1                          |
| FC1-T13    | Tranfer token to N1                  |
| FC1-P1     | Output of FC1 to N1                  |
| S1-P2      | Token buffer                         |
| S1-T5      | Tranfer token to N2                  |

### 3.2. More Details

In the model, define a colorset named packet, which has 4 attributes: no, sen, rec and ack.

The guard function determines which transition to be enabled.

### Table 2 LocalGuard

| Transition | LocalGuard          |
|------------|---------------------|
| N1-Td1     | x.ack == 1 && x.no == 1 |
| N1-Td2     | x.ack == 1 && x.no == 2 |
| N1-T5      | x.ack == 0          |
| S1-T1      | x.rec == 1          |
| S1-T2      | x.rec == 2          |
| S1-T3      | x.rec == 3 || x.rec == 4 |
| FC0-T1/T2  | x.ack == 0          |
| FC0-T3/T4  | x.ack == 1          |
| FC0-T6     | x.rec == 3 || x.rec == 4 |
| FC0-T7     | x.rec == 1 || x.rec == 2 |

Timed transitions are drawn as empty rectangles. Their firing delay is given as a timeFunction. In the model, using the firing delay to represent the transmission time of message, and different timeFunctions are provided according to different messages. For example, message 1 is 500 Bytes, and the transmission time is calculated as followed:

\[ Time_1 = \frac{500 \text{Bytes}}{1 \text{Gbps}} = \frac{500 \times 8 \text{bits}}{1.0 \times 10^9 \text{bps}} = 0.004 \text{ms} \]
3.3. Process of Message Transmission
To illustrate the model, we will describe the transfer process of a token, which represents the message 1, whose no = 1, sen = 1, rec = 2, ack = 1.
At the initial state, message 1 is defined in the N1-M1-Message (the place Message that in substitution transition M1, which in substitution transition N1). At first, the transition T1 is enabled, so the token in place Message is transferred to place P2 (in follow description, I will omit the term place or transition), and the token in P1 is transferred to P3. At the same time, Delay attains a new token to calculate the delay. For the token in P2, it will be transferred immediately to P0, and Message will get a copy of it, preparing the next round of transition. For in token in P3, it will be transferred after the delay, which is defined by the timeFunction of T3.

The token in P0 will be transferred to substitution transition FC1, which represent the fibre channel. Since the token represent a data frame, T8 is enabled, and token is transferred to P22. Then the token will waiting in Load1 since TranTime contains TimeTransition, which determine the time that message transmission on the fibre channel. Finally the token will transferred to P8, which link the switch1.

In the model of switch1, the token will transfer to P2, then T5 is enabled, and toN2 get the token.
In the model of FC2, the process is similar to FC1, and finally the token is transferred to P2, which is also in the model N2 (the structure of N2 is exactly same as N1).
When N2 get the token, N2-T1 is enabled, and token is transferred into N2-Rec. Then N2-T2 is enabled, and the output arc of N2-T2 will change the token attributes to make the data frame into a ack-frame. And the ack-frame will be transferred to N1-Delay in a reverse process. Finally, the ack-frame will arrive N1-P1, and Td is enabled, which make the both token in N1-Delay and N1-P1 disappear.

4. Simulation Result
For In this character, we use TimeNet as simulation platform. The message configuration as followed

| no | sen | rec | len | T(ms) |
|----|-----|-----|-----|------|
| 1  | N1  | N2  | 500 | 5    |
| 2  | N1  | N3  | 2000| 10   |
| 3  | N2  | N3  | 500 | 5    |
| 4  | N2  | N4  | 2000| 10   |
| 5  | N3  | N4  | 500 | 5    |
| 6  | N3  | N1  | 2000| 10   |
| 7  | N4  | N1  | 500 | 5    |
| 8  | N4  | N2  | 2000| 10   |

For the different tendencies of SHS and RHS appeared, the modified DSM is divided into two parts and further details are shown in Figure 7, from which it is clear that the modified DSM agrees well with the finite element ones.

4.1. Bus Load
The bus load is the ratio of the actual data transfer rate to the theoretical maximum data transfer rate. It reflects the allowed expansion capacity of the system.
Bus load can be shown by the number of tokens (the total number of data words to be transmitted at the moment) of FC0-Load0. (# means count the number of tokens): BusLoad = #FC0[0].Load0.

4.2. Delay
The delay is the time that a frame spends transfer from one N-port to another N-port. It reflects the speed of a system to process the frames, which is critical for the real-time transmission tasks on the
avionics network.

The delay time can be expressed by the ratio of the number of tokens in place. For example, the average number of tokens in Delay1 indicate: \( \text{Delay1} = \#N1[0].\text{Delay1} \times T1 \)

### 4.3. Simulation Result

Through simulation, we can obtain the performance index defined above in the following figure. The bus load of FC0 is 0.008, and the delay of message 1 is 0.015ms.

![Simulation Results](image)

### 5. Conclusion

Based on CPN, provide a model of FC-AE-ASM protocol, which can describe the topological structure of the avionics system and the dynamic process of the message behavior both effectively. Through the simulation, obtain the bus load and delay parameters, which are important to evaluate avionics system. The model is easy to understand and has good operability. And the result can provide theoretical foundation to design, evaluate and improve integrated avionics system.

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