Comparison and Analysis of Simulation methods for TSN Performance

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Abstract. Network simulation method is one of the important methods to study the performance of TSN. However, different methods have different characteristics in the study of TSN. Therefore, before carrying out the research on the performance of TSN, it is particularly important for researchers to choose the appropriate simulation method. In this paper, firstly, the main network simulation methods are summarized, and the requirements of simulation methods for TSN performance research are analyzed. Finally, the adaptability of different network simulation methods for TSN performance research is obtained. The evaluation results provide a reference for the proper selection of simulation methods in the study of TSN performance.

1. Introduction

Time sensitive Networking (TSN) is a new type of network which improves the quality of flow by adding flow control mechanism to traditional Ethernet. TSN has definite delay and is suitable for time sensitive applications. The complex network operating environment makes the network performance of TSN highly dynamic, and the network simulation method has become an effective methods to study the performance of TSN.

At present, many kinds of effective network simulation methods have been developed and widely used. The typical network simulation methods are: physical simulation, hardware-in-the-loop simulation, software simulation, Monte Carlo simulation and so on. Physical simulation, hardware-in-the-loop simulation and software platform simulation are introduced and analyzed in reference [1]. There are many kinds of simulation tools, which require researchers to master comprehensive simulation technology. Therefore, researchers need to make appropriate choices in many simulation methods for practical research problems.

As a whole, the research results of TSN performance simulation technology are relatively few. In view of this situation, this paper focuses on the characteristics of several typical network simulation methods, analyzes the requirements of TSN performance research, and compares the adaptability between the existing simulation methods and TSN research requirements. The research results provide a valuable reference for the selection of simulation methods for TSN performance.

2. Network simulation method

2.1. Method Classification

In order to effectively study the network behavior and its changing rules, we can use a variety of different network simulation methods. For example, analytical model method, software simulation,
physical simulation and actual network test method. In order to describe simply, simulation and emulation are called simulation in this paper. The main network simulation methods are classified as shown in Figure 1.

![Fig.1 Classification of network simulation methods](image)

Next, we mainly describe the software simulation and physical simulation in detail.

### 2.2 Physical Simulation

The method of physical simulation refers to the process of using the actual network equipment and communication link to form the network system, and carrying out the network simulation research on the system. The concrete form of physical simulation can be small laboratory network environment or large-scale actual network system. In the network simulation, we call the simulation with real equipment as the physical testbed.

### 2.3 Hardware In The Loop Simulation

In order to improve the flexibility of the simulation environment and ensure the authenticity of the simulation content, the hardware in the loop simulation realizes the organic combination of the physical simulation system and the software simulation model, and improves the overall efficiency of the simulation system.

### 2.4 Software Simulation Platform

Software simulation can be further divided into discrete event simulation, tracking based simulation and Monte Carlo simulation. Among them, the software platform based on discrete event simulation is dominant. Typical network simulation platforms include OPNET, OMNeT++ and NS series.

#### 2.4.1 OPNET

The core of OPNET simulation is event scheduler driven by discrete events, which adopts hierarchical modeling mechanism and is divided into three layers: network topology layer, node layer and process layer. The three-layer modeling mechanism corresponds to the actual topology, equipment and network protocol one by one, which completely reflects the relevant characteristics of the network. OPNET is widely used in performance simulation of all kinds of networks. In reference [2], OPNET is used to simulate IEEE 802.1Qbv and 802.1Qci flow control mechanisms in TSN, and its delay characteristics are analyzed.

#### 2.4.2 OMNeT++

OMNeT++ is an open-source discrete event simulation tool, which provides the mechanism to model and simulate any type of network. OMNeT++ itself only provides building blocks of nodes in the network and modeling their behaviors and interactions, which are mainly used in the field of communication network simulation. A real-time simulation demonstration based on OMNeT++ and a simple network simulation example are mentioned in [3]. [4] uses OMNeT++ simulation platform to study the application of TSN flow control mechanism in industrial automation and mobile forward network. A TSN simulation framework based on OMNeT++ is proposed by [5],
and different simulation scenarios are implemented.

2.4.3 NS-2/NS-3
NS-2 is a widely used open source discrete event network simulator, whose goal is Internet simulation. Therefore, NS-2 has rich Internet model base. NS-2 kernel is written in C++, researchers can use C++ to create new network models or protocols, and OTcl to create scripts for controlling simulation and configuration.

NS-3 is not an extension of NS-2, but a new simulator, mainly used to simulate IP based networks. NS-3 simulation scenario is created by C++ or python, which has better expansibility and better software integration ability than NS-2. According to literature [6], NS-3 is helpful for TSN simulation.

2.4.4 Other Platforms
In addition to several general software simulation platforms mentioned above, scholars have also developed other network simulation platforms for different purposes. A variety of network simulation tools are mentioned in reference [7], such as: QualNet, NIST net, SSFnet. However, from the perspective of the universality of applications, these simulation tools are not the mainstream methods of network simulation.

2.5. Matlab Simulink Simulation Toolbox
Simulink is an integrated environment for dynamic system modeling, simulation and analysis, which supports discrete event simulation. MATLAB and Simulink are integrated together, researchers can modify the functions in the toolbox, and simulate, analyze and modify their models in two environments. A MATLAB discrete event simulation toolbox for NoC router design is proposed by [8], which gives full play to the modeling and computing capabilities of Simulink. The set of modules mentioned in the literature is helpful to the performance simulation of TSN.

2.6. Monte Carlo Simulation
Monte Carlo simulation is also known as random sampling or statistical simulation method, which generally refers to all the numerical calculation methods based on statistical sampling. Monte Carlo simulation is generally implemented by MATLAB, C and C++. In reference [9], the robust error analysis based on Monte Carlo simulation in optical fiber sensor network is proposed, which improves the practicability of the model, and verifies the feasibility of Monte Carlo simulation in analyzing network performance.

2.7. Collaborative Simulation
In addition to several typical simulation methods mentioned above, there is a large class of simulation methods called collaborative simulation. As the simulation system becomes more and more complex, the simulation process needs the cooperation of simulation subsystems in different fields. Reference [10] refers to the collaborative simulation of power grid and communication network, which is closer to the real system in hardware.

3. TSN Simulation Requirements
Through the classification description of network simulation methods, it can be seen that different simulation methods have different characteristics, which determines the application occasions of different simulation methods. When analyzing and evaluating the functional requirements of TSN performance simulation, we need to consider several factors. First of all, TSN evolved from Ethernet, inheriting the basic performance characteristics of Ethernet; second, performance simulation needs to focus on the delay and jitter characteristics of data frames in network equipment, focusing on the simulation of flow control mechanism; third, the maturity of TSN related standards is insufficient, and the new flow control mechanism is still in draft state, so a more flexible simulation hand is needed; finally, we have to focus on the performance simulation of TSN, which is mainly focused on the network nodes, rather than the whole network.

In view of the above reasons, the requirements of TSN performance simulation can be summarized into five aspects: completeness, flexibility, ease of use, repeatability and economy. The following analysis and comparison of network simulation methods are mainly based on these five basic principles.

• Completeness: The network simulation method supports the TSN function, including the MAC layer traffic generation device, priority queue, supporting gating structure, supporting frame preemption
mechanism and performance statistics function and so on.

- Expansibility: When the TSN performance simulation requirements can not be fully met, the simulation method must provide sufficient scalability and means to ensure the realization of the simulation goal.
- Ease of use: When researchers carry out TSN performance simulation, they do not need advanced mathematical theory and do not need to spend too much time learning to model and simulate TSN.
- Repeatability: The ability to achieve repeatable experiments and obtain consistent results in TSN simulation.
- Economy: The cost of establishing TSN simulation environment is small and the economic cost is low.

4. Comparison And Evaluation Of Simulation Methods

Choosing the appropriate simulation method is the primary task to carry out TSN performance simulation. According to the TSN simulation requirements, we can follow the above five criteria to compare different simulation methods, and make adaptability evaluation, in order to provide reference for the appropriate selection of simulation methods.

4.1. Comparative Analysis

The physical testbed can accurately reproduce the real system, and simulate with the actual traffic and real network facilities, so it has high simulation performance. The physical testbed has good completeness and repeatability. The simulation results obtained by the testbed are more real and accurate than those obtained by the software simulation tools. However, the application scope of the testbed is limited, it can not provide a flexible implementation environment, and it has limitations in expansibility, and it needs a lot of capital investment. On the other hand, the traditional network equipment is too closed, which often requires a lot of manual configuration process in use, thus reducing the flexibility and automation of simulation. Because TSN is in the stage of continuous development and improvement, its technology maturity is not high, so it is difficult to establish the physical simulation environment of TSN. The physical simulation method is not suitable for the performance simulation of TSN.

The combination of software and hardware gives full play to their advantages, makes up for each other's shortcomings, provides good repeatability and expansibility, and ensures the authenticity of the simulation process to a certain extent. However, only some of them are real devices. Compared with the physical simulation, the support for TSN is relatively low. Therefore, the completeness of the hardware in the loop simulation is lower than the physical simulation. Moreover, the simulation method has large investment and limited flexibility.

OPNET can get highly reliable results in a highly complex network environment. OPNET provides a complete and multi-level network simulation model library, so it has completeness and flexibility. The simulation language of OPNET is C++, which is easy to use. But compared with physical simulation and hardware in the loop simulation, OPNET has low repeatability. OPNET is a commercial software, the source code is not public, the purchase of software is expensive, suitable for some network research and development departments to use, which greatly limits the number of users.

OMNeT++ is an open source simulation platform. The INET model library in OMNeT++ provides a general simulation management and result evaluation tool. The simulation model is easy to expand and has new functions, so it has a high degree of support for TSN functions. So far, OMNeT++ has not been fully suitable for TSN simulation framework, but the closest one is Core4INE, the extension framework of INET in OMNeT++, which has good completeness. The network topology description language of OMNeT++ is ned language, which requires researchers to master two simulation languages. This is more demanding for researchers, so OMNeT++ is less easy to use.

NS-2 and ns-3 are open source discrete event network simulators. NS-2 lacks many tools and infrastructure components provided by OMNeT++, such as supporting hierarchical model, graphical editor, GUI Based execution environment and so on. Moreover, NS-2 is also a dual language simulation platform, which has low usability. The functional modules of ns-3 are implemented by C++ or Python language, and the simulation efficiency is very high. Researchers can extend new functions by programming. However, NS-3 only supports some functions of TSN, and does not support full duplex communication and gate structure in TSN. Therefore, researchers need to develop relevant functions of TSN by themselves.

Simulink discrete event simulation in MATLAB is a simple and easy-to-use simulation tool with
strong scientific calculation and data processing capabilities. Simulink's visual modeling method can quickly build the block diagram model of dynamic system, and the block set is easy to expand. However, the support of TSN function is not high, so it needs to be expanded on the original basis.

Monte Carlo simulation method is also called random model method. It can simulate the time delay of TSN in the process of link transmission, and finally get the distribution of time delay in the whole link, and then analyze the time delay of TSN. Because the simulation process is a mathematical expression, so the completeness is low, but it has certain expansibility. Monte Carlo simulation has a strong demand for the mathematical ability and programming ability of researchers. Monte Carlo simulation is a random sampling method, the results are random, only through a large number of repeated experiments can we get the final results, so the repeatability is low. It is worth noting that Monte Carlo simulation is a static method, and the conclusion is the average value of repeated tests, so there are limitations in the performance simulation of TSN.

Collaborative simulation is a kind of simulation method in many different technical fields that cooperates with each other to achieve the comprehensive simulation goal. Its main characteristics are large scale, complex interaction and difficult to realize. For the performance simulation requirements of TSN, collaborative simulation is not adaptive.

4.2. Method Evaluation

According to the above analysis, we can evaluate the adaptability of nine main network simulation methods. The evaluation results were qualitatively described as high (H), medium (M) and low (L). "High (H)": can meet the requirements of the evaluation criteria "well"; low (L)": can meet the requirements of the evaluation criteria" badly "; when the evaluation result is between H and L, it is "medium (M) ". The evaluation results are shown in Table 1.

| Method                | Completeness | Expansibility | Ease of Use | Repeatability | Economy |
|-----------------------|--------------|---------------|-------------|---------------|---------|
| Physical Simulation   | M            | L             | M           | H             | L       |
| Hardware in the loop simulation | H           | M             | H           | H             | L       |
| OPNET                 | H            | M             | M           | M             | M       |
| NS-2                  | H            | M             | M           | M             | M       |
| NS-3                  | H            | M             | H           | M             | M       |
| OMNET ++              | M            | M             | H           | M             | M       |
| MATLAB Simulink       | L            | H             | H           | M             | H       |
| Monte Carlo           | L            | M             | M           | L             | H       |
| Collaborative Simulation | H           | M             | L           | M             | M       |

4.3. Result Analysis

It can be seen from table 1 that different simulation methods present different performances for the five evaluation criteria, which provides reference for choosing appropriate simulation methods for different simulation scenarios. We can analyze the evaluation results given in Table 1 from different perspectives.

(1) From the perspective of network simulation method. It can be seen from table 1 that any method has its advantages and disadvantages. For example, physical simulation and Hardware in the loop simulation have better completeness and repeatability, but they have disadvantages in economy. On the contrary, matlab Simulink and Monte Carlo simulation have advantages in economy, but disadvantages in completeness and repeatability. This shows that it is necessary to compare and analyze the simulation methods before the performance simulation of TSN.

(2) From the perspective of evaluation criteria. It can be seen from table 1 that different methods have different performance according to different evaluation criteria. The methods that perform well in completeness include hardware in the loop simulation, software simulation platform and collaborative simulation. The better methods in ease of use are hardware in the loop simulation and part of software simulation platform. The basic methods, such as OMNeT++, Matlab Simulink and Monte Carlo simulation, perform well in economy.

(3) Adaptability analysis of TSN performance simulation. Considering the maturity of TSN technology and the attention to the performance of network equipment, physical simulation, hardware
in the loop simulation and collaborative simulation are not suitable for TSN performance simulation. Because the performance of TSN depends on the adjustment and optimization of flow control mechanism, Monte Carlo simulation method is not suitable for the performance simulation of TSN. The software simulation platform and MATLAB Simulink are alternative schemes. Compared with OPNET, NS-2 and NS-3, OMNeT++ is widely used in TSN simulation. MATLAB Simulink has good expansibility, ease of use and economy, and has good flexibility. It is suitable for the simulation of TSN performance.

5. Conclusion
In this paper, through the demand analysis of TSN performance simulation, the evaluation criteria of completeness, expansibility, ease of use, repeatability and economy are determined, and used to evaluate different network simulation methods. The evaluation results can be used as a reference for the selection of TSN performance simulation methods.

The choice of simulation methods needs to be weighed from many aspects. Through the comparative analysis of several simulation methods, the analysis results can provide the basis for the further use and development of researchers. In addition, when choosing the simulation method, researchers should pay attention to the problems other than the performance of the simulation method itself, such as the use of simulation method, technical support, development prospects, etc., as well as the user's own background knowledge.

6. Acknowledgments
This work was supported by State Grid Zhejiang Electric Power Co., Ltd. Shaoxing power supply company in the project Time Sensitive Network Technology Research And Its Application in Distributed Energy Regulation (No.: 5700-201919238A-0-0-00)

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