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Modeling and Analysis on Time Management Performance for Time Stepped Hla Federation

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Abstract: This study deals with the modeling and analysis on time management performance for time stepped HLA federation. Firstly, the colored interaction petri net is proposed to describe the complex information and based on the colored interaction petri net, the time management model of HLA federation is established. Then, the time management performance test platform for HLA federation is realized by Stateflow. Thirdly, the influencing factors such as Delay, Lookahead and Step are analyzed by the platform and several general conclusions are obtained so as to improve the time management performance of time stepped HLA federation. Finally, the conclusions were validated in acoustic counterwork simulation system which verified the proposed model and conclusions.

Key words: Time management performance, HLA federation, colored interaction petri net, parallelism

INTRODUCTION

Time is an important parameter in the simulation and there are many time management performance issues in the running process of simulation systems. Therefore it is valuable to study the time management of simulation systems. So far, there are a lot of literatures on time performance in simulation, for example, Hong *et al*. (2009) proposed node resource optimization strategy for distributed simulation so as to improve the simulation efficiency. As HLA (High Level Architecture) is an advanced architecture in simulation its time management performance and optimization are not only an important problem in practical application but also the focus and difficulty in the simulation. HLA time management derived from the parallel discrete event simulation (Parallel and Distributed Event Simulation, PDES) research, in which the time management performance and optimization is the research focus. The research includes influencing factors of PDES performance, synchronization protocol optimization and performance test platform (Park *et al*., 2004). To solve this problem, two solutions are proposed, that is, to improve the RTI (Run Time Infrastructure) algorithm and to improve parallelism of federations. The former realized the optimization by improving the RTI performance and reducing the response time of RTI to achieve the time management performance improvement. And there have been a large number of references, for example, Park *et al*. (2004) and Zhang *et al*. (2006) studied RTI performance from different aspects such as improved buffer management and RO algorithm etc. Cai *et al*. (2005) proposed a new causal ordering protocol to improve the efficiency of HLA time management and Boukerche *et al*. (2007) provides a RTI design, to meet the real-time requirement. The latter comes from PDES research, namely the time management performance can be improved through improving the parallelism. Though this is a new research field, the results show that this method is very effective. For example, Zhao and Huang (2004) utilized the relationship between agents to conduct group management, coordinated time advance by simulation Agent and improved the efficiency of federations; Liang *et al*. (2005) improve the real-time federations by coordinating the time of nodes. Zhao *et al*. (2008) improved Liang time management performance by dynamically adjusting the Lookahead of federates. These studies coordinated HLA simulation federation as a whole to realize time advance, thus improved the parallel simulation federation and realized time management performance improvement of HLA federation. As increased parallelism can improve the performance of HLA Federation of time management, how to measure the parallelism of simulation federates? How to effectively illustrate the parallelism? And what extent the parallelism is improved to? These are problems to be further studied. The parallelism affects the time management performance

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of HLA federation. In the meantime, the time management performance of HLA federation is a measure of parallel performance, thus it can be used as a quantitative standard to measure the parallelism of federation. However, at present the time management performance of HLA federation is usually obtained after the completion of federation and is quantitatively characterized through the operating results which cannot improve parallelism by adjusting the main influencing factors at this point. Therefore, if the time performance management model of HLA federations can be established, then the time management performance can be predicted through model and the parallelism of federation can be measured under different conditions. In addition, various measures can be taken to improve the parallelism, thus the time management performance of HLA federation can be improved.

In this study, based on the colored interaction petri net, a time management performance model of HLA Federation is established, as well as the test platform. Then, from the perspective of improving the parallelism of the federation, factors influencing the time management performance are analyzed and conclusions are drawn, in the meantime, the model and analysis are applied to the real HLA simulation, so as to verify the proposed methods.

TIME MANAGEMENT MODEL

Introduction to time management in HLA: Time management is an important service provided by HLA, specifically by RTI and its purpose is to ensure that the control, coordination between each federates on the logic time axis. Time management in HLA includes time control and restriction mechanism, time advance and time related request service, achieves a variety of time advance methods and their mixed use and meets the time management requirements of different simulations. HLA federates cannot advance logical time independently but only explicitly propose to RTI time advance request, can implement after being identified by RTI. A time management "cycle" can be described as follows:

- Federate 1 send messages to other federates n through RTI
- RTI does not immediately send messages but list messages in the message queue of federate n
- Federate n call RTI time advance request service
- Time management service compute the minimum timestamp limit of federate n (GALT), if the conditions of the message are met, RTI sends messages to federate n
- if the messages in queue satisfying conditions are completed and GALT is greater than the time required by federate n, RTI recall federate time advance service (TAG), allowing the time advance of federate n

Colored interaction petri net: Colored Petri Net (CPN) is a kind of high-level petri nets. In CPN, tokens are given color and defined with attributes, so that they can carry complex information, thereby they can describe complex systems. However, the colored petri nets can not describe the interaction of information exchange due to the change of token color. Unfortunately, in the practical system, there is information interaction in internal system, namely, state changes in one part of the system will cause state change of other parts. For example, in underwater acoustic simulation system, the equipment didn't work, sonar system didn't need to deal with the interference signal but when the equipment began to work, sonar system must process equipment interference signal and target signal. Therefore, the token carrying information should be changeable and these changes not only occur when the token is transited but also occur when other tokens are transited. According to the situation of actual system, the colored petri net is extended and the colored interaction petri net is proposed as follows.

Definition 1: Colored interaction petri net can be defined as a 7-tuple:

$$N = \{P, T, I, O, C, M_0, A\}$$

where, $P \cap T = \Phi$, C is the set of color, as to any $p \in P$, $t \in T$, C(p) and C(t) are nonempty Finite set, $\overline{P} = \{(p, c) | p \in P, c \in C(p)\}$, $\overline{T} = \{(t, c) | t \in T, c \in C(t)\}$, $I: \overline{P} \times \overline{T} \to NT$ is input function, $O: \overline{T} \times \overline{T} \to N$ is output function. $\forall \overline{p} \in \overline{P}$, $\exists \overline{t} \in \overline{T}$: $I(\overline{p}, \overline{t}) \neq 0 \vee O(\overline{t}, \overline{p}) \neq 0$, $\forall \overline{t} \in \overline{T}$, $\exists \overline{p} \in \overline{P}$: $I(\overline{p}, \overline{t}) \neq 0 \vee O(\overline{t}, \overline{p}) \neq 0$.

M_0 is initial marking, A: F(T), A is defined on the set T and represents the internal interaction, that is, when transit $t \in T$ is induced, the token color is changed.

In the colored interaction petri net, the position and the color of token are used to describe the actual state of the system and interaction is used to describe the interaction between different parts of the system and their interaction results. These interactions occur with events which belongs to the action but not a condition. Therefore, in colored interaction petri net, interaction is defined on transition and the effect of interaction is reflected in the token.

HLA time management model: In HLA Federation, there is no overall logical time but each federate is responsible for maintaining its local logic time and each federate must submit an application to RTI for time advance. RTI is responsible for the logical time coordination between federates and determines whether to approve the federate

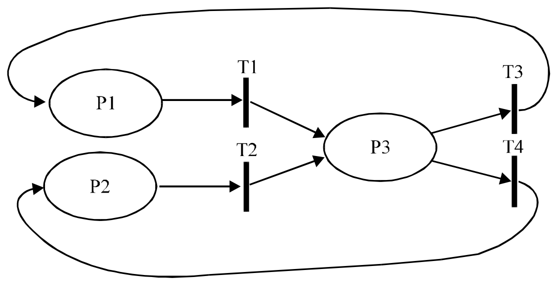

Fig. 1: HLA time management model based on colored interaction petri net

logic time advance request. Therefore, the logical time between federates mutually interacted. The situation where there are many similar components and each component is of independence as well as mutual influence which is very suitable for colored interactive petri to describe. Therefore, according to the analysis on HLA time management, the colored interaction petri net is used to build HLA time management model as shown in Fig. 1.

As shown in Fig. 1, P1 represents the exception handling (remove deadlock / rollback) state, P2 represents time approval state, P3 represents the time advance state, T1 represents exception handling is completed, T2 represents the time advance is applied, T3 represents abnormal (deadlock/receive outdated message) occurs, T4 represents time advance is approved. In the model, when the token transits, tokes which carry temporal information will change.

After the establishment of time management model of HLA federation based on colored interaction petri net it can be simulated and the simulation results of the model can be utilized to discuss the parallelism of the federation. In actual HLA federation, measures can be taken to improve the parallelism.

TIME MANAGEMENT PERFORMANCE TEST PLATFORM

Stateflow in Matlab can provide a graphical modeling and simulation tool based on finite state machine theory. It can update data, generate events and realize the operation and simulation by applying state process and event, thus can be used to realize the time management performance model. The time management model of HLA federation is realized by Stateflow as shown in Fig. 2.

Establishment of test platform: Advanced Petri net generally adopts the centralized management to simulate, thus, the time management performance model can be established by centralized management and decentralized execution. In time management model, each federate is realized through a state and every state has the run right. By virtue of state and transition, the actual simulation model computes the wall clock time consumption, applies for the time model and finally transfers operation right. All these state of time management model are centrally managed by a separate state which controls the run, stop, initial parameter setting, simulation of RTI (for example, default detection and treatment, GALT calculation, time propulsion approval). The state turns over initial operation right to other state and receives the returned operating rights, meanwhile it is used to simulate the interaction between the federates and to change the color of token when transition is excited.

As the running time of actual model is influenced by the computer software and hardware configuration and load, we use the pulse generator to excite the model running and assume that a pulse excitation is a wall clock time units (designated as 0.1s in this study) or a cycle. Thus the time of the model simulation can be strictly controlled as to variance of each parameter and each simulation has the same operational conditions which makes the simulation results more credible.

The time management performance test platform containing three federates by Stateflow is shown in Fig. 3 which can accomplish the number change of federates by increasing or decreasing the state. These three states (named A, C, T) promote simulation time by time stepped method and they are all time control and time constrained federates. The platform can realize the time management model and initialization, GALT computing, deadlock detection and other functions such as unlocked. It can conduct simulation calculation under the external pulse excitation and can observe the time advance process by oscilloscope.

Under the external pulse excitation, the time management and time advance process are simulated by A, C, T and the interaction between federates in the time management is explored. In this process, some specific functions such as parameter initialization, GALT calculation, federate logic time setting, deadlock detection and unlock function are realized by SetPara (.), ComptGALT (.), SetOverTime (.), DetectLock (.).

Time management performance evaluation: As to specific applications, the time management performance is reflected by how much time logic time is advanced under certain wall clock. Therefore the logical time advance rate is defined to quantitatively evaluate the time management performance of HLA federation.

Definition 2: The logical time advance rate RLT is defined as follows:

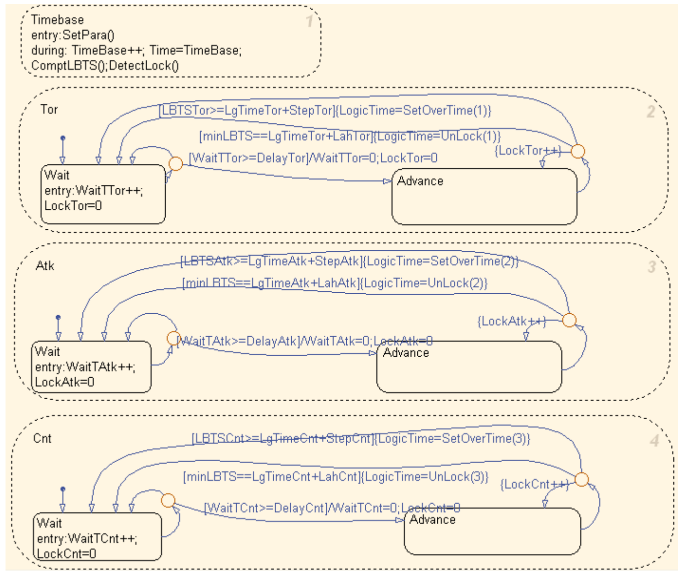

Fig. 2: Time management performance model

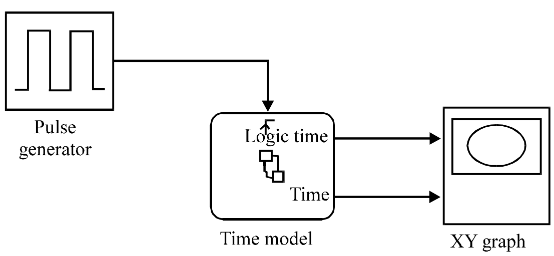

Fig. 3: Time management performance test platform

$$RTL = TW/TL$$

where, TW is the wall clock time; TL is the logical time of HLA simulation federation in TW and it is the minimum value of all federate logic time. When the wall clock time is fixed, TL represents the advance rate of the logical time.

ANALYSIS OF INFLUENCING FACTORS

The factors influencing the time management performance of HLA simulation federation mainly consists of the Delay due to computational load, federate Lookahead and Step etc. We discuss the influence of these three factors on the time management performance. In order to clearly observe the effect of each factor, we only change the values of one factor and make other factors fixed.

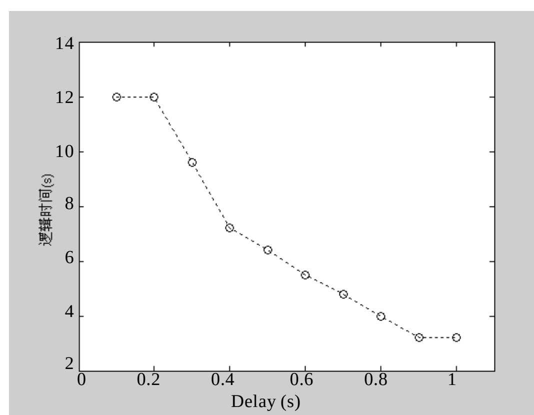

Fig. 4. The influence of Delay on the simulation 1

Table 1: Parameter setting on the discussion of delay

	Step	Lookahead	Delay
T	0.8	0.8	0.1~1.0
A	0.5	0.8	0.1 C
	0.8	0.8	0.1

Effect of delay: Based on the model simulation, the influence of Delay on logical time advance rate is analyzed and parameters of the model in the simulation are shown in Table 1. And the Delay of the federate A and C are set 0.1s, the Delay of federate T is gradually increased from 0.1s to 1.0s and the logical time advance rate is shown in Fig. 4.

Seen from Fig. 4 with the gradual increase of Delay, the logical time advance rate has been reduced. According to the simulation results, the conclusions can be obtained.

Conclusion 1: The time management performance of HLA federation is influenced by federate delay (Delay) and if the Delay of the time control federate is gradually increased, the logical time advance rate will decrease, that is, the time management performance continues to decline. Similarly, Step and Lookahead of all federates remain unchanged and Delay of federate T is set 0.9s, A and C federate Delay are increased from 0.1s to 0.9s, the simulation is conducted under the same conditions, the logical time advance rate as shown in Fig. 5.

As can be seen from Fig. 5, when the Delay of T differs greatly from the Delay of A and C, the logical time advance rate did not change with the two which shows the Delay changes of A and C cannot influence the time management performance but when Delay of the two is close to that of T (approximately half of the T), the Delay of the two starts influencing the time management performance, therefore, the following conclusion can be obtained.

Conclusion 2: In HLA federation, under the similar step conditions, if the Delay of a time control federate doubles that of the other federate or more, the time management performance is mainly influenced by Delay of this time control federate.

Effect of step: Based on the model simulation, the influence of Step on the logical time advance rate is analyzed and the parameters of the model in the simulation are shown in Table 2. And the Step of federate C is set 0.7, 0.8, 0.9 sec, respectively, Step of federate A is gradually increased from 0.1s to 1.4s and the logical time advance rate is shown in Fig. 6.

Seen from Fig. 6 with the gradual increase of Step, logical time advance rate has been increased but when the maximum value is reached with the Step increase of federate A, the logical time advance rate will decline slightly. When the Step value of A is small, Step of C has little effect on the time advance rate. However, the Step value of A is large, the Step effect of C increased. The maximum logical time advance rate is obtained when the Delay of A and C is approximate to Step. According to the simulation results, the following conclusions can be obtained.

Conclusion 3: Time management performance of HLA federation is influenced by f Step. And increasing the Step of the time control federate can improve the time management performance. If the delay time of each federate is relatively close, the logical time advance rate can obtain an optimal value under the condition of all time control federates with the similar Step.

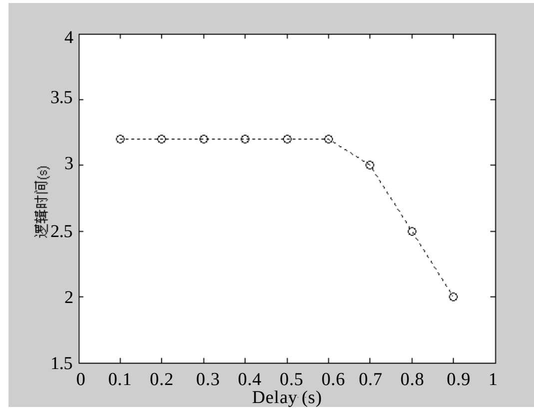

Fig. 5: Influence of delay on the simulation 2

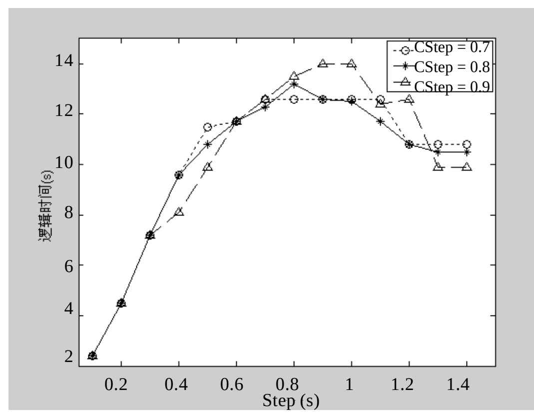

Fig. 6: Influence of step on the simulation

Table 2: Parameter setting on the discussion of Step

	Step	Lookahead	Delay
T	0.9	0.9	0.1
A	0.1~1.4	0.5	0.1
C	0.7, 0.8, 0.9	0.8	0.1

Effects of lookahead: Based on the model simulation, the influence of Lookahead on the logical time advance rate is analyzed and the parameters of the model in the simulation are shown in Table 3. And Lookahead of the federate A and C are fixed, Lookahead of federate T is gradually increased from 0.1s to 0.9s and the logical time advance rate is shown in Fig. 7 and 8.

Seen from Fig. 7 and 8 with the gradual increase of Lookahead, the logical time advance rate has been

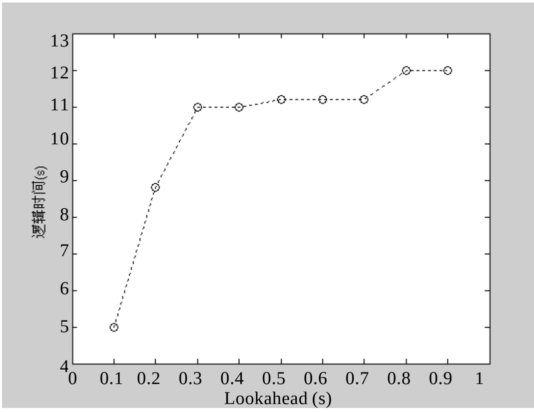

Fig. 7: Influence of Lookahead on the simulation 1

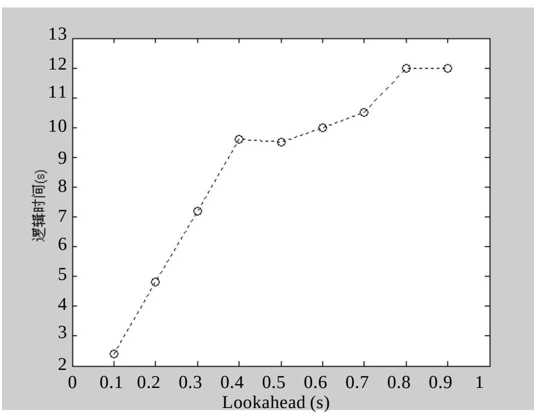

Fig. 8: Influence of Lookahead on the simulation 2

Table 3: Parameter setting on the discussion of lookahead

	Step	Lookahead	Delay
T	0.8	0.1~0.9	0.1
		0.1~0.9	
A	0.5	0.8	0.1
		0.1~0.9	
C	0.8	0.8	0.1
		0.8	

increased, that is, the time management performance is positive related with Lookahead of federates. However, when the Lookahead value reaches a certain degree (in this case is about 0.5), the logical time advance rate slows down. According to the simulation results, the following conclusions can be obtained.

Conclusion 4: The time management performance of HLA federation is influenced by Lookahead and if the Lookahead of the time control federate is gradually increased, the logical time advance rate will increase.

In the simulation, small Lookahead is easy to make federation enter a deadlock state, thereby reduced the time management performance. However, larger Lookahead can reduce the influence of other federate on the time advance, make other federates advance their time and improve the time management performance of federation. Therefore, in the step federation, the Lookahead of federates should choose the larger value.

EXAMPLE

The acoustic counterwork simulation system is a distributed system for underwater attack and defense simulation and evaluation, in which each object works in a variety of working state. The simulation should satisfy the computing needs; meanwhile, the system should conduct repeated simulations in a situation so as to evaluate the combat results. Thus the time management is an urgent need to optimize the performance of the underwater acoustic counterwork simulation system, in order to minimize the time required by the simulation. According to the above conclusions, time management parameters of the simulation system are optimized by the following steps to improve the time management performance.

Process 1 time management performance optimization:

Step 1: According to Conclusion 1 and 2, the maximum delay time of the control federate is the main factors that influence the time management performance. Therefore, as to the control federate with the maximum delay time, various hardware and software measures are adopted to reduce Delay and improve the time management performance

Step 2: According to Conclusion 3, the Step of each federate should be coordinated under different working conditions with the time management performance improvement, a smaller Step should be chosen to improve the accuracy of simulation

Step 3: According to Conclusion 4, a larger Lookahead can improve the parallelism of the simulation, thus to improve the federal time management performance. Therefore, Lookahead of each time control federate should be equal to the value of the Step

Figure 9 shows the time management performance of the acoustic counterwork simulation when optimizing Step under a work state (Step value of each federate is same). When Step is 0.4s, the maximum logical time advance rate is 4.8, compared with the minimum value (4.5) and there is a difference of 6.7%. Fig. 10 is the time management performance under another work condition, When Step is

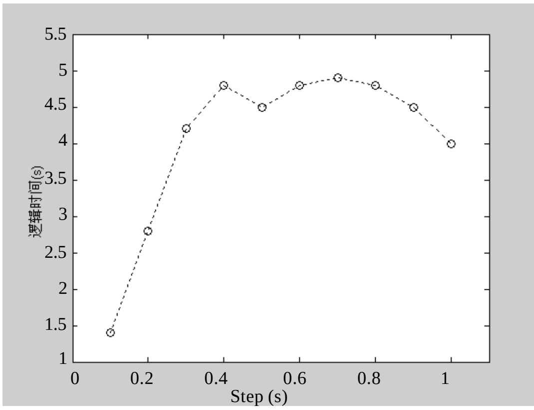

Fig. 9: Influence of Step on the acoustic counterwork simulation 1

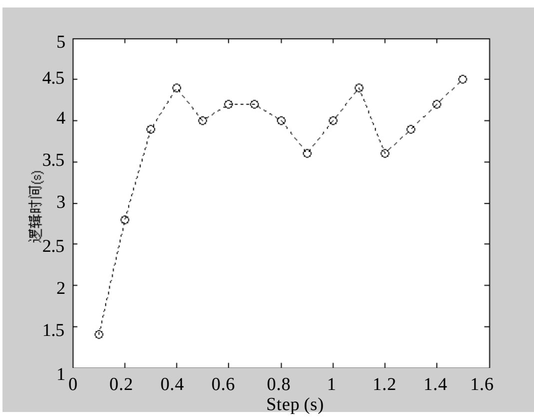

Fig. 10: Influence of Step on the acoustic counterwork simulation 2

0.4 sec, the maximum logical time advance rate is 4.4, compared with the minimum value (3.5) and there is a difference of 25.7%. Similarly, according to the relevant conclusions as well as the time management performance test platform, other time management parameters can be optimized to improve time management performance.

CONCLUSION

It is a valuable and important to improve the time management performance of HLA federation. Therefore, based on the color interaction petri net model of HLA time management, the time management performance test platform for HLA federation was established by Stateflow. From the perspective of improving the parallelism in simulation federation, the influence of Delay, Lookahead and Step in simulation federation on the time management performance were discussed. And some general conclusions to improve the time management performance of HLA federation were obtained. Through the time management parameter optimization in the acoustic counterwork simulation system, the time management performance of the simulation system was improved which also validated the conclusions of the study. These results shows that the parallelism of simulation federation can be improved through the coordination of time management parameters among federates, so as to improve the time management performance which can be used in the time management performance optimization in a variety of HLA federations.

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