

# A Large-Scale Device Collaboration Performance Evaluation Approach Based-on Dynamics

Xiaohui Rong

State Key Laboratory of Software Development Environment, Beihang University, Beijing, China

Email: rongxh@nlsde.buaa.edu.cn

Feng Chen, Pan Deng, Shilong Ma

State Key Laboratory of Software Development Environment, Beihang University, Beijing, China

Email: {chenfeng, dengpan, slma}@nlsde.buaa.edu.cn

**Abstract**—The performance of device collaboration is important in the large-scale device collaboration system, so the large-scale device collaboration performance evaluation is one of the main contents of the large-scale device collaboration research. Aiming at the problem of the large-scale device collaboration performance evaluation, the paper presents a large-scale device collaboration performance evaluation approach based-on dynamical system theory. A dynamics model of the large-scale device collaboration performance evaluation is defined and an evaluation approach is provided. Finally, an application example is given to demonstrate the usage of this approach.

**Index Terms**—large-scale device collaboration, performance evaluation, dynamical system

## I. INTRODUCTION

In the recent years, there are many requirements of making numerous devices collaborate in the field of area management, scientific research and emergency rescue. We take Beijing Olympic Central Zone as example; its area is 412.5 hectare. There are about 21000 lighting devices in it. Therefore it is a great challenge for large-scale device collaboration performance in controlling and managing so many lighting devices and making them collaborate in such a large area. And device collaboration performance evaluation is one of the main contents of the large-scale device collaboration research.

The purpose of the large-scale device collaboration performance evaluation is that by quantitatively analyzing and accurately predicting the related indicators of the collaboration model before it executes to instruct in designing the large-scale device collaboration process and optimizing it.

In the large-scale device collaboration system, large-scale device collaboration is a dynamical system which is affected by inside and outside factor and evolves with time [1]. The dynamic evolution process determines that the large-scale device collaboration performance evaluation has the following complexity features:

- **Structural Complexity:** the large-scale device collaboration performance evaluation has structural complexity because of there are many

factors affecting the performance of the large-scale device collaboration. And the large-scale device collaboration system is an updating open system, so the factors affecting the performance of the large-scale device collaboration are updating and extending, and the relations of factors are dynamic evolving.

- **Nonlinearity:** the interactions of factors affecting the performance of the large-scale device collaboration give rise to nonlinearity.
- **Process Complexity:** the large-scale device collaboration system is always in the dynamic evolving process, so the large-scale device collaboration performance evaluation has process complexity.

Therefore the paper solves the problem of the large-scale device collaboration performance evaluation with dynamical system theory and method. A dynamics model of large-scale device collaboration performance evaluation is designed, and a approach of large-scale device collaboration performance evaluation based-on dynamical system theory is presented.

The paper is organized as follows. Section II recalls related work about device collaboration systems and its performance evaluation. Section III presents the dynamics model of large-scale device collaboration performance evaluation and the approach of large-scale device collaboration performance evaluation based-on dynamical system theory. Section IV give an application example to demonstrate the usage of this approach. We draw our conclusions in the Section V.

## II. RELATED WORK

Currently there are some successful device collaboration systems [2]. In this section we briefly review three of them: CIMA [3], NEESgrid [4] and GRIDCC [5].

**CIMA:** Common Instrument Middleware Architecture, driven by an initiative supported by the US National Science Foundation, is targeting on developing a Web-service based middleware stack allowing treating arbitrary instruments as Grid resources. CIMA could become a generic interface to instruments. By

promulgating a common set of concepts and interfaces, increase interoperability between instruments and software. This interoperability will extend along a number of different axes.

A common middleware infrastructure can improve the interoperability and resilience of instrument software systems. Without an encapsulation layer, some—or perhaps even all—components that access the instrument must have complete knowledge of the instrument explicitly built-in. In contrast, with a common instrument middleware, changes to the instrument can be isolated.

**NEESgrid:** NEESgrid will link earthquake researchers across the U.S. with leading-edge computing resources and research equipment, allowing collaborative teams (including remote participants) to plan, perform, and publish their experiments. NEESgrid, the systems integration component of the NEES project, uses the newest and fastest communications technologies to tie the NEES network together.

NEESgrid connects earthquake engineering researchers throughout the United States and the world, is the result of an intensive collaboration effort led by the National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign.

Central NEESgrid services are, for the most part, configurations and deployments of standard NMI software components. These are:

1) Metadata harvesting that can accommodate the variety of metadata generated and used by NEES sites and users.

2) Data discovery tools that support attribute-based location of data sets in NEESgrid repositories.

3) Administrative tools for managing data repositories and access to data. NEESgrid will provide basic tools for managing repositories.

**GRIDCC:** The GRIDCC project provides a well proven technology that can be deployed on top of existing grid middleware, extending the grid e-infrastructure to the control and monitoring of remote instrumentation.

The goal of GRIDCC was to build a geographically distributed system that is able to remotely control and monitor complex instrumentation, ranging over a large number of diverse environments. These applications need real-time and highly interactive operation of GRID computing resources.

The core and novel element of the GRIDCC middleware is the Instrument Element (IE), which offers a standard Web service interface to integrate scientific and general purpose instruments and sensors within the Grid. The second key component of GRIDCC is the Virtual Control Room (VCR), which has been introduced to provide to remote users a virtual area from where they can control and monitor the instrumentation and where they can collaborate with each other, even if located in different physical sites. The third main component of GRIDCC is the Execution Service, which provides a workflow engine able to handle BPEL workflows interacting both with the new features of GRIDCC and with traditional computational and storage grid services.

A few devices are involved in a device collaboration process in GRIDCC project, so there is hardly any device collaboration performance evaluation in GRIDCC. In fact, for some reason there is almost no research of the large-scale device collaboration performance evaluation.

The large-scale device collaboration performance evaluation belongs to the field of processes performance evaluation. Now there are several research issues in process performance evaluation. Reference [6] presents an evaluation index system for business processes that can evaluate the combination performance of business processes. Reference [7] proposes a manufacturing performance evaluation system based-on process. Reference [8] analyzes the performance of work flow based-on generalized stochastic Petri nets. Reference [9] researches the quality and performance of Web service. Reference [10] introduces a performance analysis and evaluation tool of Web service.

### III. LARGE-SCALE DEVICE COLLABORATION PERFORMANCE EVALUATION MODEL

There are a number of device collaboration task in the large-scale device collaboration system, so the device collaboration is affected by many inside and outside factors in the system and the collaboration performance indicators interact. The factors affecting the device collaboration performance consist of internal logic of collaboration process and external constraints.

#### A. Large-scale Device Collaboration Performance Evaluation Architecture

The large-scale device collaboration performance evaluation architecture diagram is shown in Fig. 1. The key elements in the large-scale device collaboration performance evaluation model are introduced as following:

**Large-scale Device Collaboration Process Definition System:** Provides a graphical device collaboration process definition environment, it can support users to use the devices collaboration process modeling language [11] to define a device collaboration process.

**Collaboration Process Definition:** It includes the necessary detailed information that Large-scale Device Collaboration Execution System to execute, including the beginning and end of the process conditions, time-related operations, equipment operation call, the definition of the relevant data.

**Large-scale Device Collaboration Execution System:** Responsible for the interpretation of the collaboration process definition, implied the execution of collaboration process definition, maintain collaboration process definition for each execution context, the multi-tasks scheduling to achieve synergy and avoid conflict of devices to access.

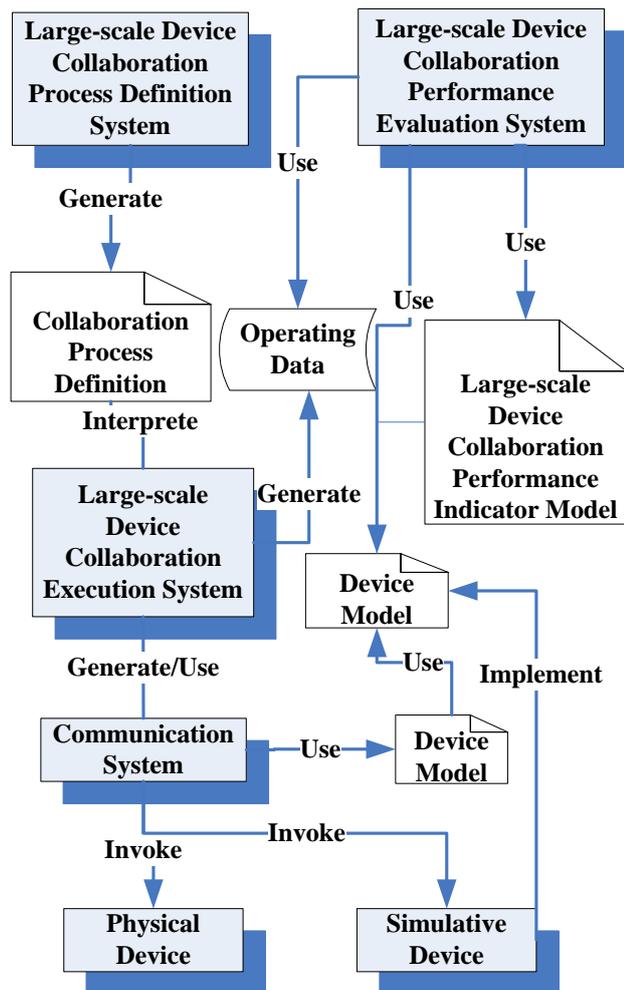


Figure 1. The large-scale device collaboration performance evaluation model architecture

**Large-scale Device Collaboration Evaluation System:** Based on the analyzing the collaboration task execution Operating data, the large-scale device collaboration system evaluation model is used to assess and validate the indicators of the system performance. In LAMS6, we use evaluation system to realize the evaluation of effect of the arts scene and the electricity consumption.

**Large-scale Device Collaboration Performance Indicator Model:** Describe the factors affecting device collaboration performance and the collaboration performance indicators.

**Communication System:** Support the unified communications with devices.

**Device Model:** A mathematical model for the device to describe the inner workings of the device. Device model is a basis for the development of simulation equipment.

**Physical Device:** The real device.

**Simulation Device:** A simulation device is a virtual device that has the same communication protocols and network interface with a physical device. In the Beijing Olympic Central Zone scene lighting device collaboration prototype system, device simulator is used to build a

large-scale device collaboration experimental environment.

*B. Large-scale Device Collaboration Dynamics Model*

According to the above analysis of the factors affecting the large-scale device collaboration performance and the dynamic evolution property of the large-scale device collaboration, the large scale device collaboration performance evaluation model based-on dynamics.

$$F : M \times N \rightarrow N . \tag{1}$$

Where:

- $M$  is the factor space of the large-scale device collaboration process.  $M \subset R^m$ ,  $m$  is the number of factors which are considered.
- $N$  is the indicator space of the large-scale device collaboration process.  $N \subset R^n$ ,  $n$  is the number of evaluation indicators.
- A large-scale device collaboration executing process is defined as  $F = f \circ g$ . Executing process  $F$  is in the form of composite mapping:  $f$  is the internal execution of the collaboration process and  $g$  is the external environment evolution.

The above large-scale device collaboration dynamics model gives the dynamics intention of the large-scale device collaboration.

*C. Large-scale Device Collaboration Performance Evaluation Approach*

The execution of the large-scale device collaboration process can be regarded as the iteration of a dynamical system. The performance of the large-scale device collaboration can be qualitatively evaluated and quantitatively evaluated by analyzing the action trace of the large-scale device collaboration process, that is,  $F^1, F^2, \dots, F^k, \dots$ . And the factors that affect the performance of the large-scale device collaboration can be found to optimize the large-scale device collaboration process.

The process of the large-scale device collaboration performance evaluation is shown in Fig. 2.

The large-scale device collaboration performance evaluation approach based-on dynamics can be divided into the following steps:

1. Build the performance indicators model of large-scale device collaboration according to the requirement of users and the feature of device collaboration process.
2. Analyze the inside and outside factors affecting the performance of large-scale device collaboration. And build the dynamics model of the large-scale device collaboration system according to the factor space and performance indicator space.
3. Design the typical large-scale device collaboration process.

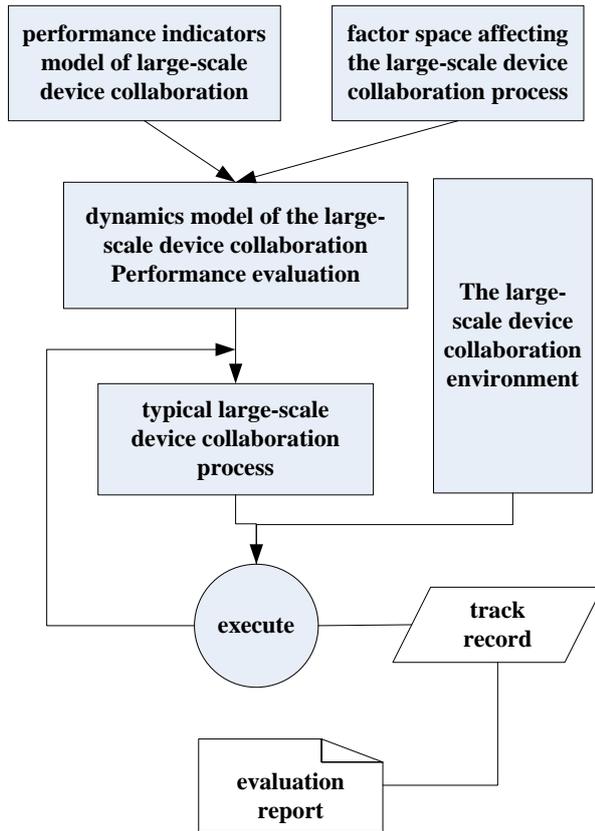


Figure 2. The process of the large-scale device collaboration performance evaluation

4. Record the trace of all performance indicators which evolve with time in large-scale device collaboration system. And analyze the value of these indicators to get the performance of device collaboration.

According to the result getting in step 4, repeat the step 3 to optimize the performance of the large-scale device collaboration.

#### IV. APPLICATION EXAMPLE

In the Beijing Olympic Central Zone scene lighting device collaboration system, it is required to produce artistic lighting effect with device collaboration; meanwhile the device collaboration process is energy-saving as far as possible to realize “Green Olympics”. So energy consumption is one important indicator of the performance of the Beijing Olympic Central Zone scene lighting device collaboration. We take the energy consumption analysis as example to demonstrate how to evaluate the performance of the large-scale device collaboration with the approach based on dynamical system.

The Beijing Olympic Central Zone scene lighting device collaboration performance evaluation model based on dynamic is defined as follows:

$$(x_1^{i+1}, \dots, x_n^{i+1}) = F(x_1^i, \dots, x_n^i, a_1, \dots, a_m). \quad (2)$$

Where:

- $F$  is one step in the execution of the Beijing Olympic Central Zone scene lighting device collaboration task in a unit time.
- $x_k^i$  is the value of indicator of the Beijing Olympic Central Zone scene lighting device collaboration performance at the moment  $i$ .
- $a_l$  is the factor that affects the performance of the Beijing Olympic Central Zone scene lighting device collaboration.

#### A. Lighting Device Energy Consumption Model

In order to quantitatively analyze the energy consumption of the Beijing Olympic Central Zone scene lighting device collaboration, the lighting device energy consumption model is defined as follows:

**Assumption 1:** One step of lighting device collaboration task costs one unit time.

**Assumption 2:** Let lighting device  $s = \{c_1, \dots, c_n\}, n \geq 1$ , there are  $m_i$  lamp in circuit  $c_i$  [12], the energy consumption of  $b_i$  is  $consu(b_i)$  per unit time.

**Definition 1:** Let  $SPr o$  be a lighting device collaboration process,  $STask = (t_0, SPr o)$  is a lighting device collaboration task which is one execution of  $SPr o$  at the moment  $t_0$ .

**Definition 2:** Let  $STask = (t_0, SPr o)$  be a lighting device collaboration task,  $consume(STask, t_0, t_f)$  is the energy consumption model of  $STask$ , where  $t_0$  is the start time of  $STask$  and  $t_f$  is the end time of  $STask$ .

1. If  $SPr o := SF_{empty}$ , then

$$consume(STask, t_0, t_f) = 0. \quad (3)$$

2. If  $SPr o := SB$ , then

- For Device Circuit  $c_i$ , the energy consumption of Device Circuit Operation  $s.loopop(c_i, ON)$  is

$$consume(STask, t_0, t_f) = m_i * consu(b_i). \quad (4)$$

- For Device Pattern

$$p = \{ \langle c_1, stat_{c_1} \rangle, \dots, \langle c_n, stat_{c_n} \rangle \},$$

if  $stat_{c_i} = ON$  then  $mul_{c_i} = 1$

else  $mul_{c_i} = 0$ , the energy consumption of Device Pattern Operation  $s.patternop(p)$  is

$$consume(STask, t_0, t_f) = \sum_{k=1}^n m_k * consu(b_k) * mul_{c1} \quad (5)$$

- For Device Group

$g = \{c_i, \dots, c_j\}, 1 \leq i, \dots, j \leq n$ , the energy consumption of Device Group Operation  $s.groupop(g, ON)$  is

$$consume(STask, t_0, t_f) = \sum_{k=i}^j m_k * consu(b_k) \quad (6)$$

3. If  $SPr o ::= SPr o_1; SPr o_2$ , then

$$consume(STask, t_0, t_f) = consume(STask_1, t_0, t_{f1}) + consume(STask_2, t_{f1}, t_f) \quad (7)$$

$$STask_1 = (t_0, SPr o_1)$$

which,  $STask_2 = (t_{f1}, SPr o_2)$

4. If  $SPr o ::= SPr o_1 || SPr o_2$ , then

$$consume(STask, t_0, t_f) = consume(STask_1, t_0, t_{f1}) + consume(STask_2, t_0, t_{f2}) \quad (8)$$

$$STask_1 = (t_0, SPr o_1)$$

which,  $STask_2 = (t_0, SPr o_2)$

5. If  $SPr o ::= if(B)then\{SPr o_1\} [else\{SPr o_2\}]$ , then

- If B is true, then

$$consume(STask, t_0, t_f) = consume(STask_1, t_0, t_f) \quad (9)$$

- If B is false, then

$$consume(STask, t_0, t_f) = consume(STask_2, t_0, t_f) \quad (10)$$

$$STask_1 = (t_0, SPr o_1)$$

which,  $STask_2 = (t_0, SPr o_2)$

6. If  $SPr o ::= while(B)do\{SPr o\}$ , then

let  $t_i = t_0$ ,

- If B is true, then

$$consume(STask, t_0, t_f) = consume(STask, t_i, t_i + 1) + consume(STask, t_i + 1, t_f) \quad (11)$$

- If B is false, then

$$consume(STask, t_0, t_f) = 0 \quad (12)$$

**Definition 3:** Let  $ATask = STask_1 || \dots || STask_n$  be an area lighting collaboration task, then

$$consume(ATask, t_0, t_f) = \sum_{i=1}^n consume(STask_i, t_{i0}, t_{if}) \quad (13)$$

**Definition 4:** Let  $WTask = ATask_1 || \dots || ATask_n$  be a wide area lighting collaboration task, then

$$consume(WTask, t_0, t_f) = \sum_{i=1}^n consume(ATask_i, t_{i0}, t_{if}) \quad (14)$$

### B. Lighting Device Collaboration Energy Consumption Evaluation

In order to understand and describe the large-scale device collaboration performance evaluation approach based-on dynamics better, in Example 1, we research the type of device operations affects single performance indicator, which is energy consumption, of the device collaboration without considering the collaboration performance indicators interacting.

#### Example 1:

The large-scale device collaboration performance indicators are list in table I.

The factors affecting the large-scale device collaboration process are list in table II.

TABLE I.  
THE LARGE-SCALE DEVICE COLLABORATION PERFORMANCE INDICATORS  
IN EXAMPLE 1

No.	symbol	indicator
1	$x_1^i$	the energy consumption of the lighting device collaboration at the moment $i$

TABLE II.  
THE FACTORS AFFECTING THE LARGE-SCALE DEVICE COLLABORATION  
PROCESS IN EXAMPLE 1

No.	symbol	Factor
1	$a_1$	the number of Device Circuit Operation in the lighting device collaboration
2	$a_2$	the number of Device Pattern Operation
3	$a_3$	the number of Device Group Operation

Then the Beijing Olympic Central Zone scene lighting device collaboration energy consumption evaluation model is defined as:

$$x_1^{i+1} = F(x_1^i, a_1, a_2, a_3). \quad (15)$$

Finally, the large-scale device collaboration performance evaluation experiment is done on a PC, with: CPU Pentium4 2.4G, memory 1G; Windows XP Professional with Service Pack 3.

It is assumed that there is only one lamp, whose power is 1 watt, in one circuit of lighting device in the Beijing Olympic Central Zone scene lighting device collaboration system. Through the system iterating, the energy consumption's trace is shown in the Fig. 3.

Fig. 3 shows the energy consummated by Device Circuit Operation is the lowest and proportional to the number of lighting device participating collaboration when the system produces the same artistic lighting effect. The energy consummated by Device Group Operation is lower than by Device Group Operation in the interval (20%, 80%).

Meanwhile the energy consummated by Device Group Operation showed normal distribution when it rises with the number of lighting device participating collaboration. And the energy consummated by Device Pattern Operation showed linear distribution when it rises with the number of lighting device participating collaboration.

So we can see that designer should choose Device Circuit Operation without considering other factors and collaboration performance indicators interacting when designing the large-scale device collaboration process. And the former should be chosen between Device Group Operation and Device Pattern Operation in the interval (20%, 80%).

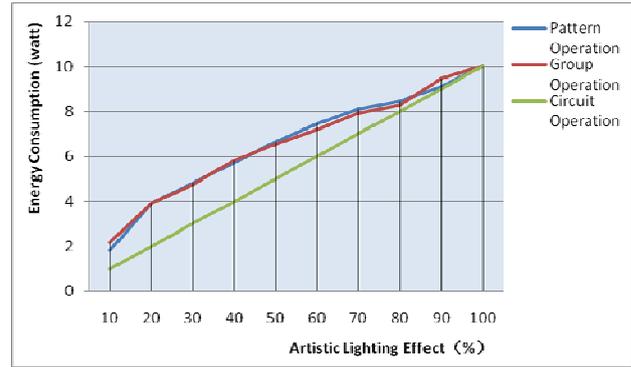


Figure 3. The trace of energy consumption of the system

In Example 2, we research the type of device operations affects two performance indicators, which are energy consumption and executing time, of the device collaboration.

**Example 2:**

The large-scale device collaboration performance indicators are list in table III.

The factors affecting the large-scale device collaboration process are list in table IV.

Then the Beijing Olympic Central Zone scene lighting device collaboration energy consumption evaluation model is defined as:

$$x_1^{i+1}, x_2^{i+1} = F(x_1^i, x_2^i, a_1, a_2, a_3). \quad (16)$$

Finally, the large-scale device collaboration performance evaluation experiment is done on a PC, with: CPU Pentium4 2.4G, memory 1G; Windows XP Professional with Service Pack 3.

TABLE III.  
THE LARGE-SCALE DEVICE COLLABORATION PERFORMANCE INDICATORS  
IN EXAMPLE 2

No.	symbol	indicator
1	$x_1^i$	the energy consumption of the lighting device collaboration at the moment $i$
2	$x_2^i$	the executing time of the lighting device collaboration operation at the moment $i$

TABLE IV.  
THE FACTORS AFFECTING THE LARGE-SCALE DEVICE COLLABORATION  
PROCESS IN EXAMPLE 2

No.	symbol	Factor
1	$a_1$	the number of Device Circuit Operation in the lighting device collaboration
2	$a_2$	the number of Device Pattern Operation
3	$a_3$	the number of Device Group Operation

It is assumed that there is only one lamp, whose power is 1 watt, in one circuit of lighting device in the Beijing Olympic Central Zone scene lighting device collaboration system and the time of one lighting device operation is 10ms. Through the system iterating, the energy consumption's trace is shown in the Fig. 4 and the lighting device operating time's trace is shown in the Fig. 5.

Fig. 4 and Fig. 5 together show that the energy consummated by Device Circuit Operation is the lowest but the lighting device operating time of it is increased with the artistic lighting effect.

The lighting device operating time of Device Group Operation and Device Group Operation is similar and stable. And the energy consummated by Device Group Operation is lower than by Device Group Operation in the interval (20%, 80%).

So we can see that the Device Circuit Operation is no longer the best choose in the case of considering the lighting device operating time. Conversely, because of the stability of the Device Group Operation and Device Group Operation, designer can predict the time of large-scale lighting device collaboration execution which can be used to provide the reliability of execution. So Device Group Operation and Device Group Operation should be chosen when designing the large-scale device collaboration process.

So designer can choose the more appropriate operation according to the evaluation result.

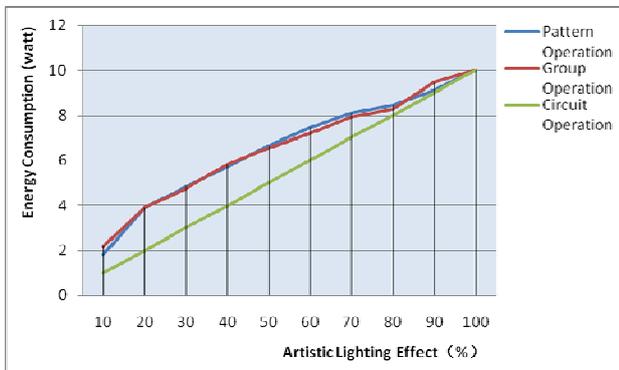


Figure 4. The trace of energy consumption of the system

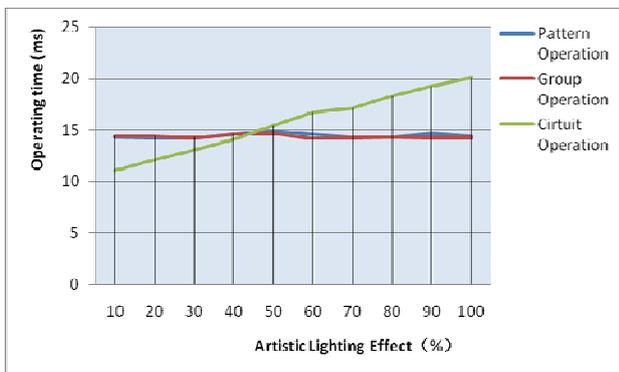


Figure 5. The trace of lighting device operating time

The result of the energy consumption evaluation can instruct the designer to design the device collaboration process better. This is also the purpose of the large-scale device collaboration performance evaluation.

V. CONCLUSION

It is a great challenge for large-scale device collaboration performance in controlling and managing so many lighting devices and making them collaboration in such a large area. And device collaboration performance evaluation is one of the main contents of the large-scale device collaboration research.

This paper presented a large-scale device collaboration performance evaluation approach based-on dynamical system theory. A dynamics model of the large-scale device collaboration performance evaluation was provided. Two experiments were done use the dynamics model of the large-scale device collaboration performance evaluation. The result of experiments shows the large-scale device collaboration performance evaluation can instruct the designer to design the device collaboration process.

The approach given in the paper has been used in Operations Analysis of the Beijing Olympic Central Zone scene lighting device collaboration system. It played a great part in the energy-saving of the system.

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**Xiaohui Rong** (1982 - ) is currently PhD candidate in State Key Laboratory of Software Development Environment, Beihang University, Beijing, China.

Her research interests include Grid, Large-scale device collaboration.

**Chen Feng** (1981 - ) is currently PhD candidate in State Key Laboratory of Software Development Environment, Beihang University, Beijing, China.

His research interests include Grid, Workflow, Large-scale device collaboration.

**Deng Pan** (1983 - ) is currently PhD candidate in State Key Laboratory of Software Development Environment, Beihang University, Beijing, China.

Her research interests include Grid, Uniform High-level Communication Protocol, Large-scale device collaboration.

**Shilong Ma** (1953 - ) is Ph.D. professor, doctoral supervisor, standing deputy director of the National Key Lab for Software Development Environment of the school of computer science and engineering in BUAA, member of the 10th expert appraisal panel under Department of Information Science of the National Natural Science Foundation Committee, member of executive Committee of Asian Software Foundational Federation, standing director of China Artificial Intelligence Society.

His research interests include Grid, Computational Logic, Magnanimity Information Processing, Data Mining.