Study on π-Calculus Based Equipment Grid Service Chain Model*

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Abstract. The development of modern science requires the equipment grid to provide a scientific collaboration research platform, which can realize remote collaboration and sharing with the key instruments and equipment in wide areas. The reliability and high efficiency of a grid service chain model are key points in creation of a grid equipment system. The π-calculus as powerful process algebra has a specific advantage in modeling and testing the grid service chain model. This research investigates and improves a theoretical analysis and algorithm framework for the modeling, correctness checking and analysis of the π-calculus based equipment grid service chain model. It also studies on the analysis of its logistic structure and flexible modeling for the equipment grid. It would be beneficial to open up a new space in the theoretical and applied research on grid technology and formal methodology based on cross-disciplinary cooperation.

1 Introduction

With the development of scientific research and continuous emergency of cross-disciplinary research, it's highly necessary to share the related knowledge and various equipments. However, due to different communication protocols and data formats, information can not be easily integrated and understood with each other and has difficulty sharing with the equipment effectively [1].

The emergence and development of grid computing technology provides a revolutionary way to couple geographically distributed equipment resources and to solve large-scale resource sharing problems in wide area networks [2][3][4][5][6]. The equipment grid provides an abstraction of equipments, then presents and publishes their functionalities in the form of grid service to some granularity. Each service clearly shows its processing flow and value. Any service conforming to the specification can become an element in a workflow, and any change from one participant will not affect its cooperative counterpart. In this way, the unified operation and the cooperative sharing of equipment can be achieved [7][8][9][10].

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Due to the complexity of wide areas distributed equipment, the equipment grid systems require high reliability. In order to accomplish a complicated task, equipment grid application often integrates a large number of grid services and equipment to conduct its inter-operation according to expected flow. On the other hand, with the increase of equipment resources and data, users will meet a large, dynamic and complex decision-making space. It is needed not only to select appropriate equipment service, but also to assure optimization of interoperation flow. Some of the key research problems on the equipment grid flow are as follows.

(1) As for the service chain model, how to check the correctness of its logical structure, such as no deadlock, being reachable to the end of the chain, compatibility between services, and whether the interaction of grid services meets the requirement of the pre-defined protocol, and etc.

(2) How to judge that a certain service chain model has the properties to meet the user's expectation. For example, whether the model can give the correct responses to user's requests, and whether the service in the model can be completed under the given time constraints or not.

(3) How to evaluate the working performance of a service chain, including the efficiency, cost and whether it has any space to perform further improvement or not.

(4) How to find a proper theoretical foundation for the modeling of the dynamic evolution characteristics of the equipment grid environment (service crash, new service and resource registration, alternative resource search tactics, selection of multiple optional services etc.) and depict the dynamical interaction and composition of the service and equipment resource.

Therefore, a complete theory system and related tools are urgently needed to answer the above questions. It is infeasible to analyze the above problems by simple manual methods. Firstly, the equipment grid system structure determines the complex alternative and coupling relations among the massive data, complicate equipment resources and services. Furthermore, the grid applications have their own complexity. Take E-science [11] [12] for an instance. The applications of the astronomical observation grid [13] of the disaster forecast grid [14] [15] are related to thousands of basic services. An equipment grid service chain model and its checking and reorganizing based on π-calculus are proposed in this paper.

This paper is organized as follows. In Section 2, some related work on grid service flow models is discussed. The equipment grid architecture and its 4-tuple are introduced in Section 3. A flexible equipment grid service chain model based on π-calculus is presented in Section 4. In Section 5, a proposal on a layered checking and analysis system for an equipment grid service chain model is explained. This study is a precondition for equipment grid service chain optimization. Finally, the conclusions of this research are presented in Section 6.

2 Related Work

Most existing work in grid service flow area is implementation specific, tailored to a particular grid application; almost every major grid project or system has its own flow language. Today, the idea based on services is the key concept of OGSA (Open Grid

Service Architecture). The OGSI (Open Grid Service Infrastructure) [16] has extended the WSDL (Web Service Definition Language) based on this idea and a defined grid service. The Global Grid Forum is working to develop a Web Services Flow Language (GSFL) that will provide a standard, platform-independent way to specify a grid services flow [17]. GSFL is an attempt to integrate efforts from the grid computing, Web services, and workflow areas. With the introduction of the WSRF (Web Service Resource Framework), the integration of grid computing and Web services has reached a new level.

The grid service flow management is a necessary phase in most grid systems including the Gridflow system by the NASA Ames research centre, the Pegasus system by USC information science association, and the grid workflow system by ChinaGrid (Education and Scientific Research Grid Project) support platform (CGSP) [18]. These systems can be grouped into two methods by the view of flow model validation and analysis. One is the semantic network [19][20] based research method. It is mainly applied in the Service Composition [21] and related service flow model analysis. The other benefits from the conventional workflow model validation method [22] that checks the related logical flow model. However, the above methods are only subset of the grid service flow model validation method. A completely grid service flow model validation system should include the application logical validation, service alternation protocol validation, service behavior and compatibility validation, and data and resource constraint validation, etc.

The π-calculus [23] proposed by Robin Milner is reputed for its powerful expressiveness. Through its mobility, π-calculus realizes the flexible description for the dynamical evolutionary system including grid systems and performs the equivalency analysis for alternative system behaviors. Through the mobility of π-calculus, the grid system dynamical properties such as new service register, service selection broker mechanism and disaster recover can be well described.

The direct support of π-calculus to the model checking technology provides good fundamentals for model analysis and validation. The composition operation defined in π-calculus supports the system structure decomposed and composed from the bottom to the top a natural and flexible description [24]. It is especially suitable to be used to depict the different composition and interaction in the grid service and also to model and optimize equipment grid service chain models.

3 Equipment Grid Service Architecture

The objective of equipment grid is to provide on-demand service according to user requirement. A user may query for a task which has to be carried out by several grid service cooperation together. The equipment grid has to find this set of services and propose a service chain in order to achieve the desired results. The equipment grid can be regarded as a 4-tuple: $DIG = \{U, R, P, M_{\Pi}\}$. Where:

U **:** A set of grid users, including the resource provider and the resource consumer and tagged $U_{\Pr oS}$ and, U_{ConS} respectively. $U = U_{\Pr oS} \cup U_{ConS}$. For there might be some cases that a consumer is also a resource provider, we can see $U_{\Pr oS} \cap U_{ConS} \neq \Phi$.

R **:** Resources in the system, including equipment resource set D and other assistant resource set A (such as network, etc.). The reason of dividing the resources in the system into two parts is that we will emphasize the main entity in the system: the sharing mechanism of equipment resource research. $D=\{T;Op(t\in T,u\in U_{\Pr oS})\}$, T is type set of the equipment resources, u is subset of the resource provider, Op denotes the operation set offered by the t types of equipment resources provided by u. Following the trend of Service-Oriented Architecture (SOA) architecture, each sharing operation of each resource will publish a service in the equipment grid system. Therefore, the equipment resource set D equals the set of operation, that's to say $D=\{Op(u\in U_{\Pr oS})\}$.

P **:** The sharing rule set of the resource set by the resource provider. It can be described as the following mathematical expression: $U_{\Pr oS}*U_{ConS}*OP\rightarrow\{yes,no,N/A\}$, The value will certainly be N/A if a user who does not have the possession right $(U1,U2,op(t1,U1))=N/A$, if $UI\neq U1$, as stated above, it shows that $U1$ does not have the possession right of the equipment resource belonging to UI.

M_{Π} **:** The set of the equipment service chain is based on work flow. It expresses the operation combination mode between the equipments, and it can be a combination of different functional operations of the same type of equipment or of different ones. So we can get $M_{\Pi}=\{op^{+},op\in OP(t,u)\}$. M_{Π} is the key of the research project. It aims to record thoroughly the equipment service chain through the construct of equipment operations in the system using a flexible description to provide high layered service.

4 Flexible Equipment Grid Service Chain Model Based on π-Calculus

Based on the equipment grid 4-tuple model proposed in Section 3 and integrated with OGSI, GSFL and the semantic of π-calculus, a brief overview of our meta-model of the equipment grid service chain is illustrated in Fig. 1.

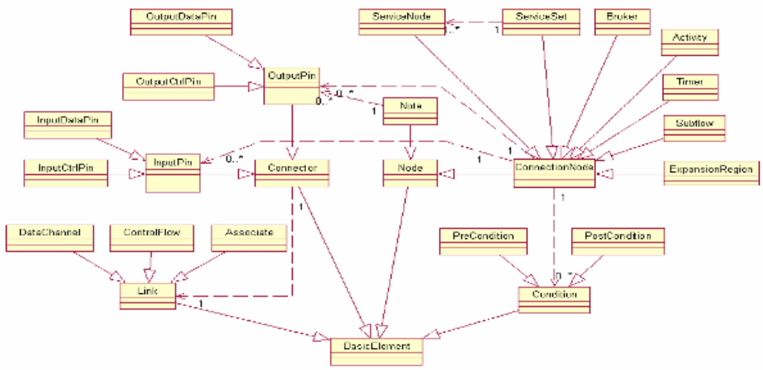


Fig. 1. Equipment gird service chain meta-model

In Fig. 1, *Activities* are the atomic building blocks of a service chain. *ServiceNodes* are bounded with the actual existing services that can be used to fulfill certain functionality of an activity, and it is the *Broker*'s job to select a *ServiceNode* from a set of alternative services to implement an activity.

Consequently, the formal semantics of the above meta-models are captured with π-calculus as a basis for the later process validation and verification. The polyadic version of π-calculus is used here [22] [24], whose syntax is concluded below.

$$\begin{aligned} &P ::= \sum_{i=1}^{n} \pi_i.P_i \mid new \quad x \quad P \mid !P \mid P \mid Q \mid \phi P \mid A(y_1,\ldots,y_n) \mid 0 \\ &\pi_i ::= \bar{x} < y > \left| x(y) \right| \tau \\ &\phi ::= [x = y] \left| \phi \wedge \phi \right| \neg\phi \end{aligned} \tag{1}$$

Limited by the length of the paper, part of the π-calculus formalization of elements in Fig. 2 is as follows.

$Activity:$

$$\begin{aligned} &Act(inctrl, outctrl) = inctrl.new\ complete(Action(complete) \mid complete.\overline{outctrl}.Act) \\ &Action(complete) = \tau.\overline{complete}.0 \end{aligned} \tag{2}$$

$Decision, Fork, Merge, Join:$

$$Decision \overset{def}{=} inctrl.\tau(\sum_{i=I} \overline{outctrl_i}) \tag{3}$$

$$Fork \overset{def}{=} inctrl.\tau(\prod_{i \in I})\overline{outctrl_i} \tag{4}$$

$$Merge \overset{def}{=} (\sum_{i \in I} inctrl_i).\tau.\overline{outctrl} \tag{5}$$

$$Join \overset{def}{=} (\prod_{i \in I} inctrl_i.\overline{ack}).\underbrace{ack.....ack}_{I}.\tau.\overline{outctrl} \tag{6}$$

$Timer:$

$$\begin{aligned} &Timer(inctrl, signal, timeout, outctl) = inctl.signal(message). \\ &\quad ([message = timeout].\overline{outctrl}.Timer + [message \neq timeout].(\overline{inctrl} \mid Timer)) \end{aligned} \tag{7}$$

$DataStore:$

$$Storage_0(put) \overset{def}{=} new\ x_1(put(x_1).Storage_1(in, x_1)) \tag{8}$$

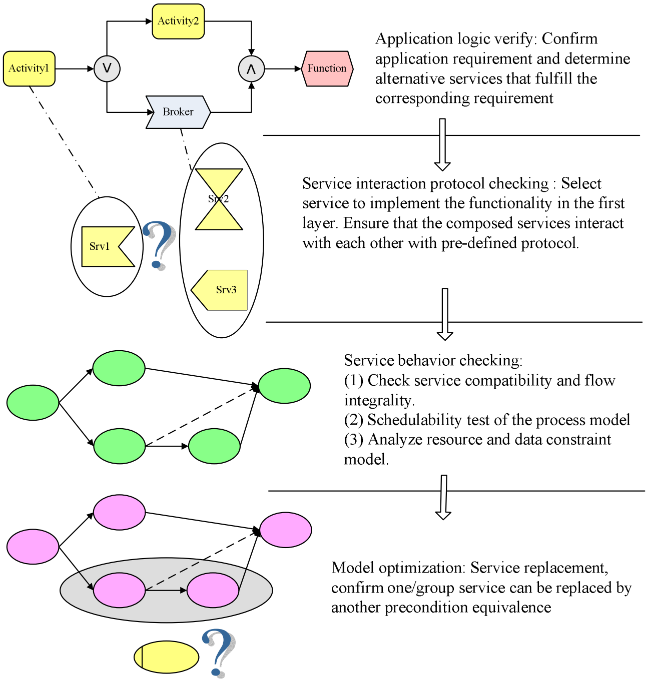
$$\begin{aligned} &Storage_n(put, get, reset, x_1,\ldots,x_n) \overset{def}{=} new\ x_{n+1}(get(chan).\overline{chan} < x_1 > . \\ &\quad Storage_{n-1}(put, x_2,\ldots,x_n) + put(x_{n+1}).Storage_{n+1}(in, x_1,\ldots,x_{n+1})) + reset.Storage_0(put) \quad n \geq 1 \end{aligned} \tag{9}$$

Subflow:

The composition of all the connection nodes in the corresponding sub service chain model, with each name ' inctrl ' *and* ' outctrl ' *in the sub-nodes of the sub-flow being restricted in the scope of the whole composed π-process*.

5 Equipment Grid Service Chain Model's Layered Checking and Analysis System

Model checking techniques are applied to the verification of grid service chain model based on its formalized results with π-calculus as mentioned in the previous sections. The analysis and checking of an equipment grid chain can be divided into 3 levels: correctness checking, temporal constraint checking and equivalence analysis. Correctness checking indicates the logical properties including no deadlock, final state reachability, etc. Temporal constraint checking indicates temporal properties depicted by logical formulas using the formal techniques. Equivalence analysis judges whether there is the same behavior and same property between two models and it forms an important basis for service replacement, flow optimization and model integration.



Application logic verify: Confirm application requirement and determine alternative services that fulfill the corresponding requirement

Service interaction protocol checking : Select service to implement the functionality in the first layer. Ensure that the composed services interact with each other with pre-defined protocol.

Service behavior checking:
(1) Check service compatibility and flow integrality.
(2) Schedulability test of the process model
(3) Analyze resource and data constraint model.

Model optimization: Service replacement, confirm one/group service can be replaced by another precondition equivalence

Fig. 2. Equipment grid service chain model's layered checking and analysis system

Applying model checking techniques in the field of grid systems raises new challenges as opposed to its traditional application domain of hardware design. Conventional model checking technology often counts on a holistic formal model which captures all the states or actions of the system as a whole. However, such a model for a grid system could be rather complicated. For example, it may involve the consideration of different system perspectives such as grid resources, security policies, and etc. Besides, the grid environment is dynamically evolving because of the life-cycle of grid services and the interactions among them.

Therefore, a layered verification architecture for grid environment based on above problem is needed as shown in Fig. 2. The layered verification idea includes not only the usage of model checking technique itself, but also the optimization techniques for the grid service chain model. The functions of each layer are described as follows.

Application logic verify layer: Confirm application requirement and determine alternative services that fulfill the corresponding requirement.

Service interaction protocol checking layer: Get service in accord with interaction protocol among optional services and compose service. In this layer, services are formalized with typed π-calculus and the correctness of the service interaction is thus ensured by the well-typeness of the composition of typed π-calculus processes.

Service behavior checking layer: Check service chain compatibility and integrity with model checking techniques based on the formal models of π-calculus. Schedulability test can also be carried out when real-time constraints are encountered with a timed version of original π-calculus [25].

Model optimization layer: Replace alternative services with the help of bi-simulation analysis in π-calculus. The purposes of the analysis are: (1) to find a safe substitution for an existing service in the service chain in case it is crushed; (2) to find a better service which fulfills the same requirement to replace the existing one.

6 Conclusions and Future Work

Grid system development should be emphasized on service mobility and interaction among grid services. Its correctness, logicality, compatibility, data property and related equipment state need to be checked carefully. The π-calculus as powerful formal specification method can be used to describe a grid complex system and its dynamic property. An equipment grid service chain model's flexible model and its layered checking system were developed based on π-calculus. By adopting the π-calculus based service chain model, we can create virtual equipments that integrate equipment resources distributed across a machine room, institution, or the globe. The study on π-calculus based on the equipment grid service chain model provides strict mathematic foundation. What's more, it can be compatible with other criteria. It would be beneficial to open up a new space in the theoretical and applied research on grid technology and formal methodology based on cross-disciplinary cooperation.

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