Modeling and Analyzing Adaptive Energy Consumption for Service Composition

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Abstract—In this paper, Petri nets are used to model the different components of service composition, and form the energy consumption model of service composition based on the relationship between components, Agent is also introduced in the energy consumption management process. Then, an adaptive energy consumption strategy is proposed to dynamically ensure that service composition can get the lowest energy consumption. The operational semantics and related theories of Petri nets help establish the correctness of our proposed method. We have also performed two simulations to evaluate our proposed approach. Results show that it can help reveal the structural and behavioral characteristics of energy consumption in service composition.

Index Terms—Service composition, Agent, Petri nets, energy consumption

I. INTRODUCTION

Service composition provides a mechanism for distributed software integration, which primarily concerns the requests of users that cannot be satisfied by any available service[1]. This increased usage of service composition, together with the increasing energy costs[2]. The energy management is highly complex. First, energy consumption is inherently complicated due to the scale, heterogeneity, and concurrent user services that share a common set of service. Second, the operating environment of service composition is dynamic, it is difficult to plan energy consumption schema at design time. When service composition starts to execute, composition can not achieve the goal because of wrong design of composition or can not meet the required energy consumption. The failure will result in a waste of computing resources and increase energy consumption. Therefore, it requires that energy consumption management of service composition must have a certain adaptive ability, which means that service composition can dynamically select the service, in order to complete its execution successfully and meet the required energy consumption.

Contributions. This paper investigates how to model and analyze the energy consumption of service composition based on user requirements. Below summarizes our main contributions: (1) Petri nets[3] are used to model different components of service composition. Agent[4] is introduced in the energy consumption management process. (2) We evaluate the energy consumption of service composition from the operational level (in addition to service, component, connector and Agent). Based on the model, we propose an adaptive energy consumption strategy to dynamically ensure that service composition can get the lowest energy consumption. (3) The operational semantics and related theories of Petri nets help establish the effectiveness of our proposed method.

The rest of this paper is organized as follows. Section II presents our energy consumption evaluation, and Section III describes how we model the different components of service composition. Next, we show how to analyze the constructed model (Section IV), and then evaluate the proposed method via simulation in Section V. Finally, Section VI surveys related work, and Section VII concludes.

II. ENERGY CONSUMPTION EVALUATION OF SERVICE COMPOSITION

A. Requirements of service composition

As the function of service composition is composed of a number of independent tasks according to a certain composition rules. Each task has a number of available services. The energy consumption of service under each state can be got by testing and simulation. The interaction between components, services, Agents, and subsystems is defined as the connector, and the connector is viewed as the basic element of service composition, so the connector can be seen as service. The energy consumption of connector is considered.

Definition 1: The energy consumption requirement of service composition is a 7-tuple: Ξ = (WS, AG, AL, RE, TW, RA, OP):

1) The set of service WS = {WS₁, WS₂, . . . , WSₙ}, WS = (type, op, ra, ep, ei), type, op are the type and operations of service, ep(op) = (etp, enp) is the execution time and per unit of energy consumption of the operation. ei = (ty, func) is the set of service interface.

2) The connector AL = {al₁, al₂, . . . , alₙ}, al = (data, oa, nl), data is the transmission content, oa is the associated service or Agent, nl is the energy consumption, li is used to describe the input and output interface.

3) The set of Agent AG = {ag₁, ag₂, . . . , agₙ}, ag = (eg, lg, om, op, gi), eg ⊆ WS, g ⊆ AL is the set of service and connector of ag; om : AG×RA → {Start, Sleep, rev, raV} is the possible operations that Agent can do for service, op is the set of operation of Agent, gi is the set of interface of ag, ag may have several input and output interfaces.

4) The set of component C = {C₁, C₂, . . . , Cₙ}, C = (et, tp, rl), et : C → WS* is the set of available service of C₁, tp : C → op* is the set of operations that need be realized, rl is a relation function between the components, the main
relationship is sequence(>), choice(+), parallel relationship (∥). \( V W(WS_i, C_j) = \{ C_k \mid WS_i \in et(C_k) \cup C_k \in C_j \} \) is the set of operation of \( WS_i \) for component \( C_j \).

In service composition, the service will realize its function by executing a series of operations. Because the operation of service may be different, which will make the energy consumption of service be different too. Therefore, the energy consumption analysis based on service level may cause large errors. This paper will describe the energy consumption of service composition based on the operation level.

**B. Energy consumption evaluation**

Because the component in service composition may invoke different services to realize its function, which will make the reachable states of energy consumption model be different. Let \( C_i \) invoke \( OP(WS_j, C_i) \) of \( WS_j \) to realize its function, we will evaluate the energy consumption in the following.

1) Energy consumption of component \( C_i \)

The energy consumption of the operation \( op_{pf} \in OP(WS_j, C_i) \) of component \( C_i \) is \( en(op_{pf}) = etp(op_{pf}) \times etp(op_t) \).

The energy consumption of component \( C_i \) is:

\[
EN(C_i) = \sum_{op_{pf} \in OP(ac_j, C_i)} en(op_{pf})
\]

(1)

2) Energy consumption of service

The energy consumption of service is:

\[
EN(WS_j) = \sum_{C_i \in C(ac_j)} EN(C_i)
\]

(2)

The average energy consumption that service using to realize the function of component is:

\[
avg_{EN}(WS_j) = \frac{EN(WS_j)}{|C(WS_j)|}
\]

(3)

3) Energy consumption of Agent and service composition

The energy consumption of Agent is composed by service and connector, so the energy consumption of Agent is:

\[
EN(ag_j) = \sum_{WS_j \in WS_{ac} \land WS(j, ag_j)} EN(ac_j) + \sum_{la_j \in A_{ac} \land la_j} en(la_j)
\]

(4)

The energy consumption of service composition is:

\[
EN = \sum_{ag_i \in AG} n(la_i) = \sum_{ac_j \in A_{ac}} EN(ac_j) + \sum_{la_i \in A_{ac}} en(la_i)
\]

(5)

We can quantitatively evaluate the energy consumption of service composition by using the above formula.

**III. MODELING SERVICE COMPOSITION**

**A. Modeling service composition**

In this section, we will use Petri nets to model different components of service composition, then construct the energy consumption model of service composition based on its execution process. In addition, we mark the service, Agent, connector in the front of place and transition.

\[a)\) **Modeling service:** The model of service is modeled as follows, \( p_{s,i}^{1}, p_{s,i}^{2}, p_{o,i}^{1}, p_{o,i}^{2} \) are used to describe the startup, suspending, running and overtime interface, \( t_s, t_e \) and \( t_{ie} \) are used to describe the startup, finished and suspending operation. The execution of \( op_i \) in service is: \( t_{s,i} \) is used to describe the execution of the operation, \( en(t_{s,i}) = etp(op_{i}) \) is the execution time of operation, \( en(t_{s,i}) = etp(op_{i}) \). If the service is in the overtime or suspended state, then invoke the transition \( t_p \) to make the operation be in the interrupted position \( p_{p,i} \). If the transition can re-execute \( (p_{r,i}) \), then invoke transition \( t_{r,i} \) to make the operation be in the available position \( (p_{w,i}) \).

\[b)\) **Modeling component:** The model of component is shown in Fig.1: First, we introduce \( p_w \) to store the set of available service, \( \forall WS_j \in WS \), there is \( d_{w,i}^{j} = M_0(p_w) \). If \( C_i \) gets the input parameter \( p_{s,i} \), then invoke the transition \( t_{pp,i} \) to allocate the appropriate service for \( C_j \), and the component will be in the waiting for execution\( (P_{w,i}) \). If \( C_i \) gets the input parameter \( p_{s,i} \), then no available service can realize the function of component \( C_i \) and \( t_{fa,i} \) is used to output the fault.

\[c)\) **Modeling connector:** The model of connector is shown in Fig.2, let two basic elements of connector be \( A \) and \( B \). Then the system will introduce two interfaces to send and receive the info from \( A, B \).

\[d)\) **Modeling Agent:** The model contains the execution of component and connector in Agent, that is, the execution environment of Agent. Agent will get the information from the environment and compute the startup service based on the adaptive energy consumption strategy. \( t_{st} \) is used to start the service, while \( t_{ss} \) is used to make the remaining service be in the suspended state. \( t_e \) represents the termination of Agent.
The service will do the related adjustment when it receives the instruction of Agent.

The steps for constructing energy consumption model are. Constructing the model of services based on their attributes. Introducing $t_{st}$ and $p_{st}$ to describe the beginning operation and position. $t_{en}$ and $p_{en}$ are used to describe the termination operation and position of whole application. Computing the set of startup service by using the adaptive strategy, and initializing the place in the model. Setting initial marking $M_0(p_{st}) = \emptyset$, while setting the priority of transition $t_{st}$ and transitions in the system level be 4. In this paper, we divide the priority of transition into 5 level, which can be adjusted according to the actual requirements.

IV. ADAPTIVE ENERGY CONSUMPTION STRATEGY AND ANALYSIS

In this section, we will propose an adaptive energy consumption strategy for service composition based on Agent. Then dynamically compute the set of startup service based on the state and attributes of the current service.

A. Adaptive energy consumption strategy

A series of operations that service $ws$ is used to realize the function of $C_i$ are called the path of $ws$. Let the path that $WS_i$ uses to realize the function of component $C_j$ be $Lat(WS_i,C_j)=[Lat_1, Lat_2, \ldots, Lat_n]$. $Loc=$\{op$_{k,1}$, op$_{k,2}$, \ldots, op$_{k,f}$\}. The energy consumption of path $Lat_i$ is:

$$En(Lac) = \sum_{op_{k,i} \in Lat_k} \text{en}(op_{k,i}) \times \text{ctp}(op_{k,i})$$  \hspace{1cm} (6)

The average energy consumption that service $WS_i$ uses to realize the function of component $C_j$ is:

$$\text{Avg}_{en}(wsi,C_j) = \frac{\sum_{Lat_k \in \text{Lat}(ac_i,TK_j)} \text{en}(Lat_k)}{|\text{Lat}(ac_i,TK_j)|}$$  \hspace{1cm} (7)

B. Analysis technique

In this section, we will verify the correctness of proposed method based on the reachable states of energy consumption model and the operation semantics of Petri nets.

Theorem 1. Let $R(\Omega)$ be the reachable state of energy consumption model $\Omega$, $\forall S \in R(\Omega), \forall WS_i \in WS$, the set of startup service is $WS_{ac}$, then:

1. If $WS_i \in WS_{ac}$, $\exists S \in R(\Omega)$, which makes $|M(WS_i\ast p_{st})| = 1$.
2. If $WS_i \not\in WS_{ac}$, $\exists S \in R(\Omega)$, which makes $|M(WS_i\ast p_{st})| = 1$.

Proof: If $WS_i \in WS_{ac}$, we may set $WS_i \in eg(ag_j)$, that is, $WS_i$ belongs to the corresponding Agent. We can set $ag_j, p_{st}^j \in ag_{j\ast st}$ in the modeling process of $ag_j$, therefore, $S_i \in R(S_0)$, which makes $M_1(ag_j\ast p_{st}^j) \neq \emptyset$ and $M_1(ag_j\ast p_{st}^j) = \emptyset$, because $M_0(ag_j\ast p_{st}^j)=\{d_0^1,1\}$ and $ag_j\ast p_{st}^j=ag_j\ast p_{st}^j$, therefore, $M_1(ag_j\ast p_{st}^j)=\{d_0^1,1\}$. Form the modeling process of service, we can get that transition $WS_i\ast t_i$ can be fired, while $WS_i\ast t_i$ isn’t. Therefore, $\exists S \in R(\Omega)$, which makes $|M(WS_i\ast p_{st})| = 1$. Similarly, we can prove (2) establishes from the modeling process that Agent does the suspended operation for service.

Theorem 2. Let $R(\Omega)$ be the reachable state of energy consumption model $\Omega$, $\forall S \in R(\Omega), \forall WS_i \in WS$, then:

1. If $|M(WS_i\ast p_{st})| = 1$, $\exists S' \in R(\Omega)$, which makes $|M'(WS_i\ast p_{st})| = 1$.
2. If $|M(WS_i\ast p_{st})| = 1$, $\exists S' \in R(\Omega)$, which makes $|M'(WS_i\ast p_{st})| = 1$.

Proof: $\forall WS_i \in WS$, because $|M(WS_i\ast p_{st})|=1$, therefore, $ws$ is in the suspended state under $S$. Let $WS_i$ restart after a period of time, We will prove the suspend of $WS_i$ will not affect the restart of it, we can prove it from two two aspects: First, we will prove $WS_i$ can be in the running position again. Because $WS_i\ast p_{st}^j = \{WS_i\ast t_i, WS_i\ast t_j\}$, $WS_i\ast t_r = \{WS_i\ast p_i, WS_i\ast p_j\}$, so $WS_i\ast t_r$ has the right to fire and the priority of $WS_i\ast t_r$ is 0. Therefore, the firing of $WS_i\ast t_r$ under $S$ is effective, we may set that $S_i$ will reach $S_2$ by firing $WS_i\ast t_r$, then there is $|M_2(WS_i\ast p_{st})| = |M_1(WS_i\ast p_{st})| = 1$, because $WS_i\ast t_i = \{WS_i\ast p_i, WS_i\ast p_{st}\}$, therefore, the firing of $WS_i\ast t_i$ under $S_2$ is effective. Second, we can prove that all operations can be executed properly, $\forall op_f \in op(WS_i)$ may be in $p_{a,f}$ or $p_{c,f}$ when $WS_i$ is suspended. Therefore, $\exists S' \in R(S)$ which makes $|M'(WS_i\ast p_{st})| = 1$.

We can prove the sub-proposition(2) in the similar way.

Theorem 2 illustrates that the service and its operations can execute properly when Agent needs to restart the suspended service, thus realizing its function.

V. EXAMPLES

In order to evaluate the effectiveness of proposed method, we will use experimental platform Windows 7, C# language to implement a prototype for analyzing the constructed model. First, we will generate available services as service resource. Then we will use experimental platform Windows 7, C# language to implement a prototype for analyzing the constructed model. The results of Experiment 1 are shown in Fig.3, we can get:

1. Taking 400 services, 50 components, 10 Agents and dividing them into 10 groups, each group corresponds to a Ligo system, then do Step (2)-(3) to each Ligo system.
2. Selecting 10 groups of service, then compute the energy consumption of each Ligo system[5] based on each set of available service;
3. Using adaptive strategy to compute the set of startup service of service composition, then compute the whole energy consumption of each system based on the set of startup service.

The results of Experiment 1 are shown in Fig.3, we can get: (1) the energy composition of the set of service will change when the attributes of service has changed. (2) the overall energy consumption of service composition can be reduced by using the adaptive strategy, the highest reduction is 34.5%, and the lowest reduction is 3%.

Experiment 2. Experiment 2 analyzes the relationship between the state space and available service, the steps are:
the reliable service composition[13]. Almost all of the aforementioned formalisms cover basic and structured activities of service composition, but they are unable to ensure that the constructed model can meet the users’ specific requirements, such as energy consumption. Meanwhile, the approaches defined in the above can not solve the problem of dynamically selecting available service.

VII. Conclusion

In this paper, we proposed new solutions for optimizing energy consumption for service compositions. The special features of the proposed model include: (1) Petri nets are used to describe different components of service composition. Agent is introduce to the energy consumption management process of service composition. (2) The adaptive energy strategy is proposed, which is used to dynamically select the available service that meets the requirement for component, thus reducing the energy consumption of service composition. (3) The operational semantics and related theories of Petri nets help prove the correctness of proposed method. Finally, we conduct several experiments to evaluate the effectiveness of the proposed method.

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