IEEE Access
Multidisciplinary ⁝ Rapid Review ⁝ Open Access Journal

Received December 1, 2017, accepted December 28, 2017, date of publication January 3, 2018, date of current version February 28, 2018.

Digital Object Identifier 10.1109/ACCESS.2017.2789222

An Analytical Method of Network Service Scalability

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This work was supported by the National Natural Science Foundation of China under Grant 61370206.

ABSTRACT The research of network service scalability is essentially the research of the capability of providing service, which is based on services and the relationship among the services. However, most of the researches ignore the systematic research on analytical methods of service scalability in network systems, owing to the complexity and the diversity of the network system. In this paper, we propose an analytical method of network service scalability, which is composed of a network description model and a service evaluation model. The method uses the network description model to describe services and the relationship among them. After presenting the network description, the method uses the service evaluation model to analyze the network service scalability. For analyzing and simulating purposes, we select three P2P network models, which are different with each other in network topologies as an example. Our simulation results which are in accord with the results of the example analysis verify the correctness and applicability of the analytical method.

INDEX TERMS Analytical method, description model, evaluation model, network service, scalability.

I. INTRODUCTION

In the early stage of network technology, more research focused on how to avoid the complex design of communication protocols so as to provide a guarantee of better network performance. Along with the rapid development [1]–[3] and popularization [4] of network, the capability of providing service is constantly bombarded with new challenges [5], [6]. For the present situation of the network development [7], [8], the reason can be drawn that the scalability of Internet service is poor, which is mainly reflected in two points: the traditional network architecture can't support the dynamic deployment of the new protocols well and there are functional redundancies among the layers of the traditional network architecture. Therefore, many research organizations began to pay close attention to the network service scalability. Owing to these studies, there are a number of typical achievements [9]–[12]. And then, it is a requirement to analyze the service scalability of these research results. However, there is not yet an effective method for analyzing the network service scalability of these research results. It can be seen that the analysis of network service scalability is an urgent and important task.

The research of network service scalability is essentially the research of the capability of providing service, which is based on services and the relationship among the services. Therefore, we should grasp the essence to explore the analytical method of network service scalability. We propose an analytical method of network service scalability in this paper. The method is composed of a network description model and a service evaluation model. The reason for the requirement of the network description model: All behaviors of a network system can be represented as services and the relationship among services (such as interactive relation, dependency relation etc.); The services and the relationship among services will fully embody the function and performance of the network; Therefore, we present a network description model which can describe services and the relationship among services. The reason for the requirement of the service evaluation model: The services and the relationship among the services will be modified frequently due to the changes of network (such as network topology, network architecture or network technique etc.); And then, network service scalability will be influenced in the network system; Therefore, we present a service evaluation model which can analyze the network service scalability.

In brief, when the network service scalability is influenced by the changes of network topology, network architecture or network technique etc, the analytical method can be used. And, the analytical process of the method is shown in fig.1: (1) The services and the relationship among services are described by using the network description model in the network system, and the dynamic change rules is set. (2) After presenting the description of the network system, the evaluation index and the evaluation strategy is determined by using the service evaluation model. (3) The service scalability of the network system can be obtained through the calculation and analysis of the network service scalability.

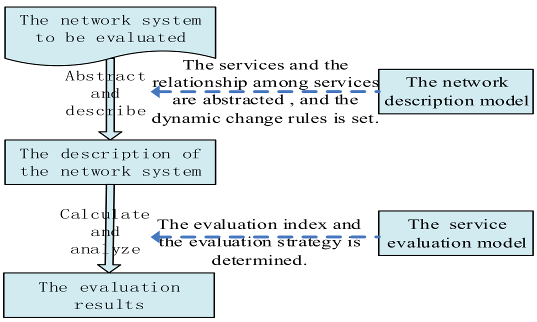

FIGURE 1. **The analytic process of the analytic method.**

The rest of this paper is organized as follows: In section 2, we analyze and summarize the related research work; in section 3, we present a network description model; and then, we present a service evaluation model in section 4; in section 5, we give an analysis example which is about the network service scalability of the three peer-to-peer (P2P) models; and the related simulation and analysis is carried out in section 6; finally, section 7 concludes the paper and points out the future research directions.

II. RELATED RESEARCH WORK

The existing research results about the analysis of network service scalability are rare. And, they use different description methods, analytical methods and evaluation standards for different network applications.

Scalability is defined from the aspect of the changes of system in the paper [13], but the definition is not comprehensive enough to express the network service scalability. The analytical method for evaluating Internet multi-dimensional scalability based on multiple constraints is proposed in the paper [14]. However, it lacks the expression of network characteristic itself. The cost model which is proposed in the paper [15] is mainly concerned with the demand of network resources and the cost of data transmission. The cost model can be used to design and evaluate the multiple services in the data transmission system. But, there are still many deficiencies in the work. For example, the model only pays attention to the cost of network service providers (or Internet service providers) without the consideration of the satisfaction of users. Hence, this model can't effectively evaluate the network service. The report [16] provides the concepts of full scalability, optimization scalability and weak scalability in network but it can't thoroughly express the factors which influence the scalability. The scalability of the routing protocols in Ad Hoc network are analyzed and evaluated through the simulation in the paper [17]–[19]. The simulation results can explain some problems in the network system, but the process and results of simulation are often limited to specific application scenarios. Thus, it can't enable researchers to understand the protocol itself, the constraints of the related system parameters and environmental characteristics. An analytical method of network service scalability is proposed in the paper [20], which is an inspiration to explore the scalability analysis method of network services. However, this method does not describe the dynamic changes of the network effectively. Furthermore, this method doesn't analyze the service scalability with different kinds of evaluation indicators. Therefore, it can't analyze the actual network service scalability well. In addition, certain researchers [21]–[23] focus on proposing computational methods of network service scalability. These computational methods can hardly tell the differences of the service scalability among several network models because the unified descriptive methods and evaluated strategies are lacked.

In summary, because of the complexity and the diversity of the network system itself, it lacks of a systematic and feasible analytical method about the research of network service scalability.

III. NETWORK DESCRIPTION MODEL

The network service scalability is that the capability of providing service will not decrease obviously along with the change of the network (such as the changes of network topology or network technique etc.). In order to evaluate the network service scalability better, it is the first work to build a network description model which is used to describe services and the relationship among them.

The network description model consists of two basic elements: the services and the relationship among services. The service S is described as $S = \{A, c\}$. Where A is an attribute vector, $A = (a_1, a_2, \ldots\ldots, a_n)$, a_i indicates the i-th attribute; c is the service type which is defined according to the type of the service function. J is the change rules in the network system. f is defined as mapping relationships among services. There are many mapping relationships among services in the network description model. Dependency relation and interactive relation are the most basic mapping relationships among them. Interactive relation is used to describe the services which are in one service interaction. Dependency relation is used to describe the manner of dependence among services when there is a service interaction. The dependency relation is defined as $D = \{< c_1, c_2 >, \vec{r}, v\}$, where c_1 and c_2 are the types of service, $< c_1, c_2 >$ is the constraint for the two types of services in the dependency relation; v is the cost of the dependency relation; $\vec{r}$ is a vector for dependency rules which is the description of the dependency relation in logic, and it is optional. If $\vec{r}$ exists, the dependency relation is directed. Otherwise it is undirected. $\vec{r} = (r_1, r_2, \ldots\ldots, r_n)$, r_i is the i-th dependency rules. The interactive relation is defined as $I = \{S_1, S_2, \ldots\ldots, S_m\}$.

S_set(t) indicates the set of services at time t, *D_set(t)* denotes the set of the dependency relations at time t, *I_set(t)* represents the set of the interactive relations at time t and $J(t)$ is the set of the change rules at time t. The definition of the network description model can be expressed as $M(t) = \{S\_set(t), D\_Set(t), I\_Set(t), J(t)\}$.

$$M(t+1) = J(M(t)) = \begin{cases} S\_set(t+1) = J(S\_set(t)) \\ D\_set(t+1) = J(D\_set(t)) \\ I\_set(t+1) = J(I\_set(t)) \end{cases} \quad (1)$$

From the the point of view of set theory, $J(t)$ can be decomposed into the changes of the *S_set*, the *D_set* and the *I_set* as shown in formula (1); from the microscopic perspective, $J(t)$ can be decomposed into the changes of the service attributes A, dependency relation R and interactive relation I, as shown in formula (2).

$$\begin{cases} A_i(t+1) = J(A_i(t)) \\ D_i(t+1) = J(D_i(t)) \\ I_i(t+1) = J(I_i(t)) \end{cases} \quad (2)$$

As mentioned above, the basic definition of the elements of the network description model is depicted. The relationships among the elements in the model are shown in figure 2.

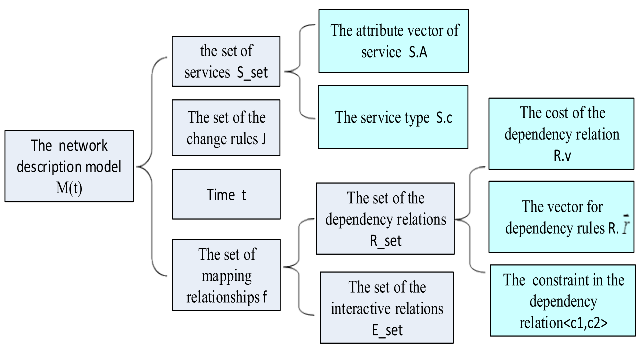

FIGURE 2. The relationship of the elements in the network description model.

IV. SERVICE EVALUATION MODEL

After presenting the network description, we can analyze and evaluate the network service scalability by using the service evaluation model.

We must select the evaluation indicator of the network service scalability before we calculate the network service scalability using the service evaluation model. The evaluation indicator is a performance indicator which reflects the network characteristics, such as the total load of a network system or the average efficiency of resource location etc. Which evaluation indicator is needed can be determined according to the analysis of the network system. When there is only one evaluation indicator (that is $F(t)$), the changes of the indicator $(F(t+1)-F(t))$ can be directly used to represent the network service scalability in this aspect. If multiple evaluation indicators which belong to the same kind (to become better or worse along with the network changes) are selected, the calculation of the weighted sum will be necessary in order to represent the multidimensional network service scalability in these aspects. So, the comprehensive variation coefficient (*CCOV*) of the multidimensional network service scalability can be calculated as shown in formula (3). Where α_i denotes the weight of the evaluation indicator $F_i(t)$ in comprehensive evaluation coefficient, and $\sum_{i=1}^{L} \alpha_i = 1$.

$$CCOV = \sum_{i=1}^{L} ((F_i(t+1) - F_i(t)) \bullet \alpha_i) \quad (3)$$

The value of the evaluation indicator will become better or worse along with the change rules in network. If multiple evaluation indicators belonged to the different kinds are selected, it is difficult to judge the network service scalability with only one formula. In such a situation, it ought to be divided into two parts to depict the network service scalability: the capability of keeping the network performance characteristics (Keep_capability) and the capability of evolving the network performance characteristics (Evo_capability).

Assume that a network service is expressed as T and the i-th evaluation indicator is expressed as $F_i(t)$ in the initial state. After L times of dynamic changes, T is changed into T' and $F_i(t)$ is changed into $F_i'(t)$. *diff* denotes the average variation coefficient of the network system after several changes, and the calculation of *diff* is shown in formula (4). Where α_i denotes the weight of the i-th evaluation indicator, L denotes the times of the changes.

$$diff(T, T') = \frac{\sum_i \alpha_i (F_i'(t) - F_i(t))}{L} \quad (4)$$

Keep_capability needs to be calculated when the network performance becomes worse along with the extension of the network service. Because the network performance is not hoped to be too worse after L times of service extension, it is better that the difference between $F_i'(t)$ and $F_i(t)$ is little. Therefore, the calculation of Keep_capability can be shown as formula (5). The value of Keep_capability is always less than 1. If it is closer to 1, Keep_capability is better.

$$\begin{cases} Keep\_capability(T) = \frac{1}{diff(T,T')}, \; diff(T, T') > 1 \\ Keep\_capability(T) = diff(T, T'), \; diff(T, T') < 1 \end{cases} \quad (5)$$

Evo_capability needs to be calculated when the network performance is optimized along with the extension of the network service. In contrast with Keep_capability, it is better that Evo_capability is larger. Therefore, the calculation of Evo_capability can be shown as formula (6). The value of Evo_capability is always larger than 1. If it is closer to 1, Evo_capability is weaker.

$$\begin{cases} Evo\_capability(T) = diff(T, T'), \quad diff(T, T') > 1 \\ Evo\_capability(T) = \frac{1}{diff(T,T')}, \quad diff(T, T') < 1 \end{cases} \quad (6)$$

The analysis process of Keep_capability and Evo_capability is analyzed, as shown in fig.3.

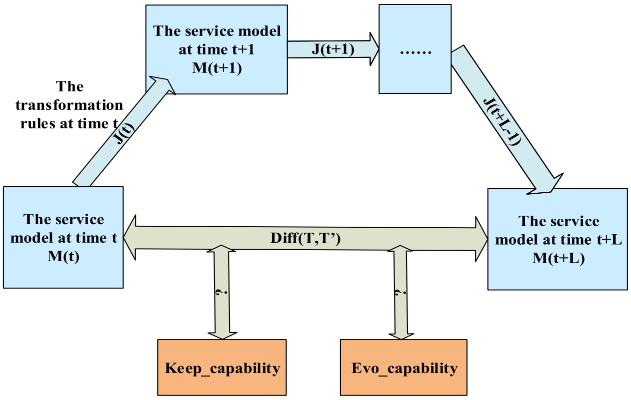

FIGURE 3. Schematic diagram of network service scalability.

V. EXAMPLE ANALYSIS

The mapping relationship among services is embodied particularly prominent in the three kinds of P2P networks (centralized, distributed and mixed). Hence, the three P2P networks which are different with each other in network topologies are selected as an example to verify the analytical method of service scalability. There are two types of service nodes in the centralized P2P, namely ordinary service node (*Sc*) and the super service node (*Ss*). There are all ordinary service nodes (*Sc*) in the distributed P2P. As well as in the centralized P2P, there are ordinary service nodes (*Sc*) and the super service nodes (*Ss*) in the hybrid P2P. The service topology is shown in fig. 4.

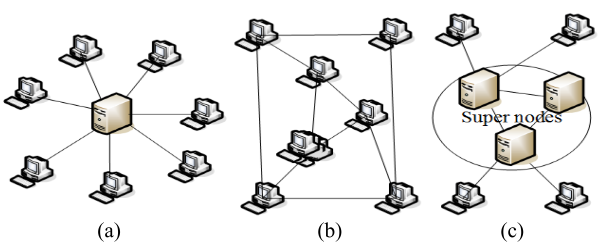

FIGURE 4. Three types of service topology. (a) Centralized P2P. (b) Distributed P2P. (c) Hybrid P2P.

A. THE DESCRIPTION OF NETWORK SYSTEM

We describe the three P2P models by using the network description model. Dependency relation and interactive relation are the most basic relationships among mapping relationships. The relation between the service nodes is a logical relation. The dependency relation (*D*) is embodied as transmission relation between service nodes. The interactive relation has tow types: the interactive relation for resources (*Ir*) is defined as a set of services with the same kind of resources in every interaction process; the interactive relation in every querying process (*Ic*) is defined as a set of services which are needed during querying the resources. Thus, the network description model can be described as follows:

$$
\begin{aligned}
&\mathrm{S} = \{\mathrm{A}, \mathrm{c}\};\ \mathrm{A} = (\mathrm{M}, \mathrm{a}, \mathrm{p});\ \mathrm{c} = \text{“Sc”} \quad \text{or “Ss”}\\
&\mathrm{D} = \{<\mathrm{Sx}, \mathrm{Sy}>, \mathrm{v}\};\ \mathrm{Sx.c} = \text{“Sc”} \quad \text{or “Ss”},\\
&\qquad \mathrm{Sy.c} = \text{“Sc”} \quad \text{or “Ss”}\\
&\mathrm{Ir} = \{\mathrm{S}_1, \mathrm{S}_2, \ldots\ldots, \mathrm{S}_{n0}\}\\
&\mathrm{Ic} = \{\mathrm{S}_1, \mathrm{S}_2, \ldots\ldots, \mathrm{S}_{n0}\}
\end{aligned}
$$

Where *M* denotes the maximum of resources which can be held in a service node; *a* denotes the efficiency of resource retrieval in a service node; *p* denotes the quantity of resource which a service actually contains (if the service is provided by an ordinary service node, *p* denotes the quantity of the resources in the ordinary service node; if the service is provided by a super service node, *p* denotes the quantity of resources which can be indexed by the super service node). *v* denotes the cost of transmission time required for an interaction.

In the practical application of P2P networks, the quantity of resources in each peer will not change too much during a service interaction. Generally speaking, what affects the performance of the entire P2P network is mostly the modification of structures and resources caused by a newly added peer. So, the change of the network system size should be mainly considered when setting the change rules. In the initial state, the quantity of the services is set as n0, the quantity of queries per second is set as u, the quantity of the resources is set as m, and the change rules J are set as follows:

(1) One service node is added to the network model in each change, and the attribute vector of the newly added service node is randomly set in a fixed domain.

(2) Sc is the only type of the service node which can be added in the centralized P2P model and in the distributed P2P model.

(3) In the hybrid P2P model, the type of a newly added service node is determined according to the quantity of resources held in the service node.

(4) A new service node is randomly connected to an existing *Ss* in the centralized model and in the hybrid model.

(5) A new service node is randomly connected to an existing *Sc* in the distributed model.

The comparison of the description of the three P2P models is shown in Table 1, where *fv* stands for "fix value," *rv* stands for "random value," *Y* stands for "yes," *N* stands for "no."

B. THE CALCULATION AND ANALYSIS OF SERVICE SCALABILITY

We evaluate and analyze the service scalability of the three P2P models by using the service evaluation model. The efficiency of resource location and the total network load are selected as evaluation indicators because they are the core

TABLE 1. The description of the three P2P systems.

Parameters / Network systems	S				Mapping Relationship f				Change rules J				
	A			c	D		I		r1	r2	r3	r4	r5
	M	a	p		<Sx,Sy>	v	Ir	Ic					
centralized P2P	fv	fv	rv	Sc or Ss	<Sc,Ss>	fv	rv	rv	Y	Y	N	Y	N
distributed P2P	fv	fv	rv	Sc	<Sc,Sc>	fv	rv	rv	Y	Y	N	N	Y
hybrid P2P	fv	fv	rv	Sc or Ss	<Sc,Ss>	fv	rv	rv	Y	N	Y	Y	N

issues which should be paid more attention in P2P network. Assumption that all resources are not sequentially numbered and they are different with each other in network. *eff* is used to indicate the efficiency of resource location.

Resources are allocated to ordinary nodes, and the index of the resource location is stored in the super service node in the centralized P2P model. As shown in fig.4a, resources can be indexed through only once interaction between *Sc* and *Ss*. All of the *Sc* are connected with the *Ss* logically, so the efficiency of resource location depends only on the efficiency of the server. Hence, it can be included that the efficiency of resource location is inversely proportional to the total cost of the resource location. And it can be calculated as shown in the formula (7). The *Ss* are in the interactive relation for each query in the centralized P2P model, so the calculation of the total network load is shown as formula (8).

$$\begin{cases} eff = 1/(R.v + Ss.p/a) \\ Ss.p = m \end{cases} \tag{7}$$

$$Mtotal = Ss.M \tag{8}$$

Because resource location can be quickly achieved according to a certain logic algorithm in the structured distributed P2P model, the non-structured situation is only considered. Flooding Traversal is used when locating resources in the distributed P2P model: in the best case, the service node with target resources can be found through only one interaction, and the cost of the resource location is $R.v + Sc.p/Sc.a$; in the worst case, the service node with target resources can be found through traversing the entire network, and the cost of the resource location is $(x-1)\, R.v + (x-1)\, Sc.p/Sc.a$, where x denotes the number of *Sc* in the model. Hence, the average efficiency of resource location can be derived, as shown in formula (9). The total network load equals to the sum of all service nodes' resources, as shown in formula (10).

$$\begin{cases} eff = 2/(xR.v + xSc.p/a) \\ Sc.p = m/x \end{cases} \tag{9}$$

$$Mtotal = \sum_{i=1}^{x} Sc_i.M \tag{10}$$

The hybrid P2P model holds the characteristics of non-center and fast retrieval. When a service node (*Sc*) wants to query resources, it will have an interaction with a super service node (*Ss*) which is in the same cluster firstly. The *Ss* has the index of the resources in the cluster. If the resources are detected, the location of the resources will be directly returned. This is the best case, and the cost of the resource location is $R.v + Ss.p/Ss.a$. If any resources can't be found in the Ss, the Ss will access other connected super service nodes and retrieve their resources indexes till the target resources are detected or the entire network is traversed. The worst case is to traverse the entire network, and the cost of the resource location is $yR.v + ySs.p/Ss.a$, where y denotes the number of *Ss*. Hence, the average efficiency of resource location in the hybrid P2P model may be derived, as shown in the formula (11). The total network load equals to the sum of the resources in all super service nodes, as shown in formula (12).

$$\begin{cases} eff = 2/[(y+1)R.v + (y+1)Ss.p/a] \\ Ss.p = m/y \end{cases} \tag{11}$$

$$Mtotal = \sum_{i=1}^{y} Ss_i.M \tag{12}$$

The comparison of the service scalability of the three P2P models is shown in table 2. The efficiency of resource location belongs to the performance characteristic which is hoped to be kept, so it is analyzed according to the formula (5). Since the quantity of resources becomes larger along with the expansion of the models (that is the value of m becomes larger, and $x > y > 1$.), the change of the value of *eff* in the distributed P2P model is the smallest one among the three P2P models. Thereby, Keep_capability in the distributed P2P model is the best one in terms of the efficiency of resource location. The total network load belongs to the performanc characteristic which is hoped to be evolved, so it is analyzed according to the formula (6). Because there is only one service node in the centralized P2P, there is no Evo_capability in the centralized P2P in terms of the total network load. Since the value of x and the value of y ($x > y$) become larger along with the expansion of the models, the change of the value of *Mtotal* in the distributed P2P model is the largest one among the three P2P models. Consequently, Evo_capability in the distributed P2P model is the best one in terms of the total network load.

TABLE 2. The service scalability of three P2P systems.

Service scalability / evaluating indicators / Network system	Keep_capability (eff) $\begin{cases} \frac{1}{diff(T,T')}, diff(T,T') > 1 \\ diff(T,T'), diff(T,T') < 1 \end{cases}$	Evo_capability (Mtotal) $\begin{cases} diff(T,T'), diff(T,T') > 1 \\ \frac{1}{diff(T,T')}, diff(T,T') < 1 \end{cases}$
centralized P2P	$eff = 1/(R.v + Ss.p/a)$	$Mtotal = Ss.M$
distributed P2P	$eff = 2/(xR.v + Sc.p/a)$	$Mtotal = \sum_{i=1}^{x} Sc_i.M$
hybrid P2P	$eff = 2/[(y+1)R.v + (y+1)Ss.p/a]$	$Mtotal = \sum_{i=1}^{y} Ss_i.M$

VI. THE RELATED SIMULATION AND ANALYSIS

There are some simulators for P2P network, such as P2Psim, Peersim etc. [24], [25]. These simulators do not support the underlying network protocols, so the simulation results may deviate from the actual networks. While NS2 [26] provides a support to the underlying network, and it can simulate the actual networks better. At the same time, it adopts the modular design with good code extensibility. Therefore, NS2 is selected as the simulator in the experiment. The description parameters of the three P2P models are set as follows.

(1) The maximum of resources in a service node is set as $M = 100$;
(2) The efficiency of resource retrieval is set as $a = 1/ms$;
(3) The number of resources (p) is assigned randomly, the assignment fit the range (1,100);
(4) The cost of dependency relation is set as $v = 10ms$;
(5) If the value of p in one service node is larger than 65, the service node is determined to be a super service node.

Since the efficiency of resource location and the total network load are selected as evaluation indicators, we analyze the three P2P models with the two evaluation indicators after simulation. And the results of the simulation and compute are given, as shown in fig.5 and fig.6.

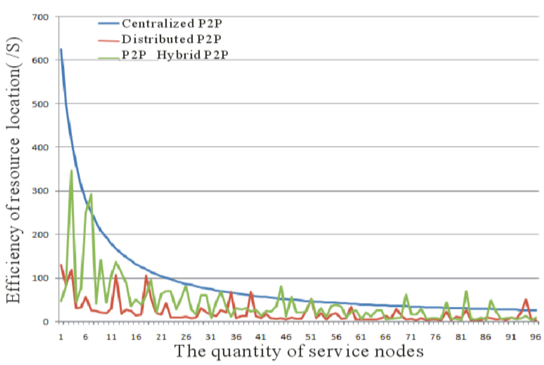

FIGURE 5. The efficiency of resource location in the three P2P models.

It can be seen from fig.5: The efficiencies of resource location in the three models decline along with the increasing

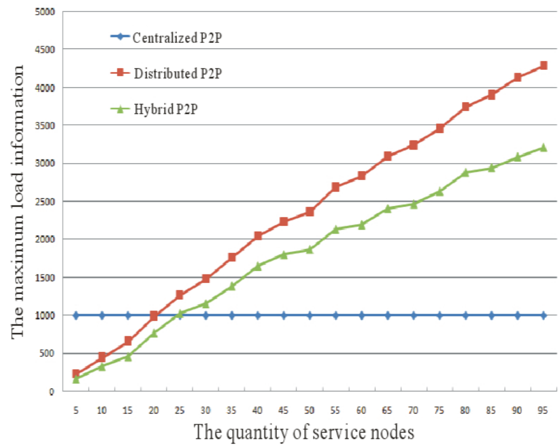

FIGURE 6. The total network load in the three P2P models.

number of service nodes. When the quantity of the service nodes is less, the efficiency of resource location in the centralized P2P model has an obvious advantage over those in the other two P2P models. But the efficiency of resource location in the hybrid P2P model and in the distributed P2P model begin to have superiority along with the expansion of the models. And that in the distributed P2P model is in the slightly lead when the number of the service nodes is more than 91. The reason can be concluded as follows: when the number of service nodes continues to increase, the centralized P2P model will not be able to load too many resources. And Keep_capability in the centralized P2P model is very poor in terms of the efficiency of resource location. Keep_capability in the distributed P2P model and in the hybrid P2P model are better in terms of the efficiency of resource location when the number of resources increases. And that in the distributed P2P model is the best one.

It can be seen from fig.6: the value of the network load in the centralized P2P model is a constant, so the total network load in the centralized P2P model is weakest of those in the three models. The total network load in the distributed P2P model and in the hybrid P2P model are better, and that in the distributed P2P model is slightly ahead. The reason can be concluded as follows: The number of nodes which provide service is unchanged in the centralized P2P model. So, there is no Evo_capability in terms of the total network load. The number of the nodes which provide service is changed both in the hybrid P2P model and in the distributed P2P model. So there is Evo_capability in terms of the total network load in the two models. And that in the distributed P2P model is the best one.

From the example analysis and the simulation, we can draw the conclusion: (1) the distributed P2P model does better in Keep_capability and Evo_capability than the other two P2P models, it is the best one in terms of network service scalability among the three P2P models; (2) the simulation result is in accord with the results of the example analysis which is achieved in the section 5.2. It has been verified that the analytical method of network service scalability proposed by this paper has correctness and applicability.

VII. CONCLUSION

Network Service scalability is a kind of measure for the capability of providing services in network. How to evaluate network service scalability effectively is a problem to be studied. In this paper, we propose an analytical method of network service scalability. The analytical method is composed of a network description model and a service evaluation model. In the method, the network description model is used to describe the services and the relationship among services; After presenting the network description, the service evaluation model is used to compute and analyze the network service scalability. Finally, we select three P2P network models which are different with each other in network topologies as an example. Our simulation results which are in accord with the results of the example analysis prove that the analytical method of network service scalability has correctness and applicability.

As the shortages of Internet are becoming more and more serious, the research about the next generation of Internet system has been paid much more attention. It is our next step to research on the next generation network architectures with the analytical method of network service scalability.

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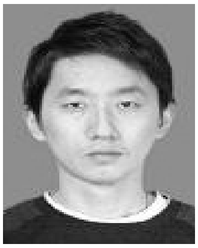

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