# On P2P-Based Semantic Service Discovery with QoS Measurements for Pervasive Services in the Universal Network

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*Abstract*—**The Universal Network, which promises pervasive services, is well on the way. As the Quality of Service (QoS) grading is a significant feature of the Universal Network, various pervasive services can be distinguished not only by service types, but also by QoS. This characteristic makes service discovery of the Universal Network quite distinct from that of the existing network. A lot of research work takes advantage of the semantic web technology OWL-S (Web Ontology Language for Services) to achieve service discovery. In this work, we propose to append the QoS measurements to OWL-S (named OWL-QoS) to describe pervasive services. Related matching algorithms are also presented. Moreover, we employ the JXTA architecture, which is a suitable foundation to build the future computer systems, to organize network peers and implement a P2P based service discovery prototype system. Experiments highlight the good performance of the P2P based semantic service discovery with QoS measurements.**

*Index Terms*— **P2P, Universal Network, Semantic Service Discovery, OWL-QoS**

## I. Introduction

With the rapid development of Information Network Technology [1-3] and the increasing demand for communication, new network services [4-6] appear continuously. However, in the present Information network, one kind of network mostly supports one kind of service. For instance, telecom network basically faces phonetic business while IP network mainly supports data business. Thus, taking a wide view of the various types of services, we can see that the great distinctions of realization mode, service type and service oriented terminal among different services will lead to such problems as poor compatibility and extensibility. That is to say, it is very difficult to achieve unified control and management of various services. The way of how to give a unified regulation and description of the different services in the new network environment, and providing a pervasive operation platform for the network services, have become more important and exigent. In order to solve such problems, the Universal Network is emerging.

We define Universal Network as a network, based on which diverse services can be presented, organized and handled in a unified manner. The Universal Network, which presents pervasive services, is well on the way. The QoS grading is a key factor to distinguish pervasive services besides service types. Therefore, providing QoS grading for each service is one of the most important features in the service discovery system of the Universal Network.

Recently, great efforts have been made to address service discovery, and most of them focused on centralized approaches, such as UDDI. Metadata about service description are stored in a central repository and used for service discovery. Such centralized approaches introduce single point of failures and expose vulnerability to malicious attacks. For example, the damaged central server may paralyze the whole discovery system. While in the distributed system [7-10], destroying several peers will not have any pernicious influence on the system. Thus, the centralized approaches are not suitable for a large number of pervasive services. In order to achieve high scalability, we try to develop a decentralized discovery approach [11-15], and make use of the P2P infrastructure to prevent the single point of failures and obtain the high scalability in the Universal Network.

There are several P2P systems available, such as Gnutella and Napster; however, most of them are intended for one specific application, like file sharing [16]. In our research, we adopt JXTA, which occupies the middle ground between the centralized Napster and the decentralized Gnutella geometries [17]. It is independent of the platform, the network transport protocols and the programming language.

Manuscript received October 13, 2013; revised January 19, 2013; accepted January 28, 2013. This work was jointly supported by the National Natural Science Foundation of China (No.61305056, No.61300132), Beijing Higher Education Young Elite Teacher Project (No.YETP0702, No.YETP0706), and the Fundamental Research Funds for the Central Universities.


doi:10.4304/jcp.9.8.1914-1921

In our service discovery system, four types of ontological data are utilized: domain ontology, thesaurus ontology, QoS ontology and service description ontology; detailed discussion on them will be found in Section 2. We divide the service discovery process into two steps. The first step is to find query domain through the first two ontologies; while the last two ontologies support the second step to match the registered services with the query.

## II. Preliminaries

### *A. The Universal Network and Pervasive Services*

At present, telecommunication network mainly supports phonetic business, and IP network basically provides data business. Namely, one kind of network principally supports one kind of service in the current Information Network. Due to the limitation of original design, existing networks are essentially difficult to satisfy diversified requirements from network and service essentially. It is very useful to form a universal network which can reduce wastes of different kinds of networks and satisfy diverse requirements.

Mechanisms and principles for completing a variety of network services are very similar, that is, all the services firstly need to establish a connection, and then the connection can complete the data transmission through switching and routing. The major difference among services is the distinct implementing methods due to different service types (data, voice, video, etc). The Universal Network extracts a common mechanism of the diverse patterns of services, and puts forward a pervasive service model. In the new model, a service identifier (SID) is introduced and used for the unified description of the pervasive services. Pervasive service in the Universal Network is defined as: “To handle diverse services in a uniform manner based on one network.” The service mentioned in this definition means an interaction mode, which has a certain QoS grading.

In the present Internet, services are differentiated by port number, which is not convenient and secure, as a result of the increase in the number of services. In addition, the port number lacks service properties such as QoS information. By contrast, the Universal Network makes use of a SID to identify service. The SID is a 160-bits value, so it is very convenient for the incremental number of services. Furthermore, the QoS information is included in it. Different types of services have different QoS gradings.

### *B. Ontological Data*

*(1) Domain Ontology*

Each object property possesses two parts: domain and range. In the domain ontology, we define an object property — hasService, to connect domain classes and service classes. Fig.1 gives a partial graph of the domain ontology. Simply put, this ontology includes six domain classes: entertainment, engineering science, education, physical object, region and sport. Services can be divided into different service classes according to the classification. In Figure.1, boxes represent the classes and ovals denote the instances of the registered services in the network.

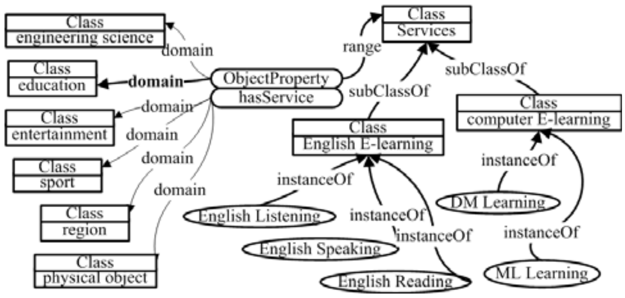


Figure 1. A partial graph of the domain ontology.

*(2) Thesaurus Ontology*

The thesaurus ontology maps synonymous and related terms to each service term of the domain ontology. This can bring a higher degree of accuracy in finding the related groups for service registration [18-19]. Figure.2 gives an example of a partial graph which demonstrates the synonyms of English E-learning within the thesaurus ontology. We make use of WordNet [20,21] to create the thesaurus ontology.

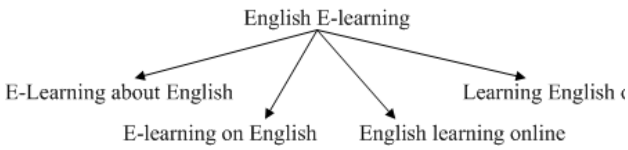


Figure 2. A partial graph of the domain ontology.

*(3) QoS Ontology*

We present a recommended model for the end-user QoS categories provided by ITU-T QoS Study Group [22]. There are eight distinct groupings identified, which encompass the range of applications. Within these groupings there are two areas of error tolerance and four general areas of delay tolerance. In the QoS ontology, we provide QoS with several properties from the network point of view: Latency, Accuracy, Reliability, Scalability, Availability, Capacity, Cost, etc. Latency and Accuracy present the reflections of the delay and error tolerances correspondingly.

*(4) Service Description Ontology*

For the purpose of automatic service discovery, we adopt OWL-S markup for describing services and call the services marked by OWL-S as semantic services. The service discovery with the OWL-S descriptions is refered to the semantic service discovery. The semantic service discovery is a process to locate semantic services that can provide a special class of service capabilities and the specified QoS measurements adhering to some client-specified constraints [23].

In order to satisfy users’ high-level requirements, we append the QoS measurements to the service profile and call such ontology OWL-QoS. We give the structure of OWL-QoS in Figure.3 and the details have been discussed in our previous work [24].

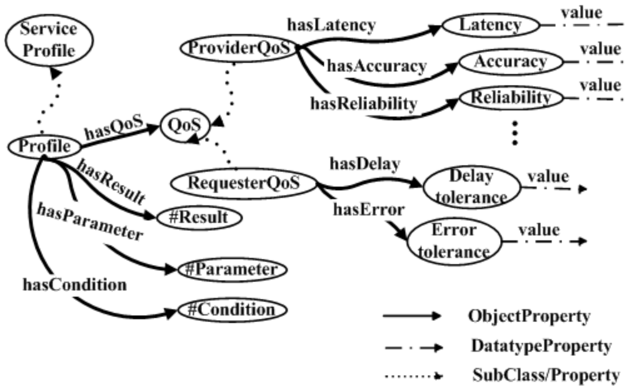


Figure 3. The structure of OWL-QoS.

## III. P2P Based Semantic Service Discovery Prototype

### A. Design of the Prototype System

As Fig.4 shows, the architecture of the P2P based semantic service discovery system is made up of three layers and four elements. The physical network layer is an actual Internet topology; a friend group consists of the service providers who supply similar services with different QoS gradings and all the friend groups constitute a friend group layer; every friend group elects a group leader [25] who has more capabilities, and all these group leaders form a location network. Service requesters, service providers, friend group members and friend group leaders are four elements in the system.

As mentioned above, we combine the JXTA architecture with the prototype to implement our P2P-based service discovery. Figure.4 illustrates that in the JXTA network, the friend group leader has the same effect as a hub, both the provider and the requester act as the JXTA peers; and the friend group plays the same role as the peer group in JXTA. Our prototype system is based on the hierarchical structure. It is a kind of P2P structures, and is able to greatly improve the search efficiency.

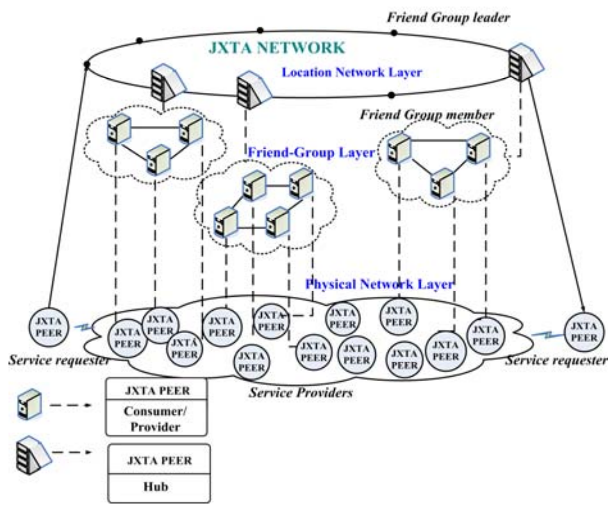


Figure 4. Architecture of the P2P based semantic service discovery prototype system.

### B. Service Registry and Discovery

Service providers need to go through three steps to publish their services. Firstly, the discovery system builds a model of the group position finding for the purpose of locating related friend groups (JXTA groups), which have close relationships with the service; secondly, a provider can publish his service advertisement (including non-functional information) in the related JXTA groups found by step 1; and at last, the service provider needs to upload its service profile to the related friend group leaders. This last step is done for the service discovery process.

According to a requester's service requirement advertisement (including non-functional information), the discovery system firstly locates it in the related friend groups through the model of the group position finding. Then the requester needs to upload a service query description profile to the related group leaders, and it can put inputs, outputs and QoS grading of services into that profile. The QoS grading represents a user's requirement for service quality. After receiving a query description from the requester, the system starts a service matching process by service matching algorithm in the related groups. In the following step, the matching with QoS algorithm is used to select services that have satisfactory QoS grading. Finally, URLs of the matched services will be passed on to the requester. With these URLs, the requester is able to get access to the corresponding services.

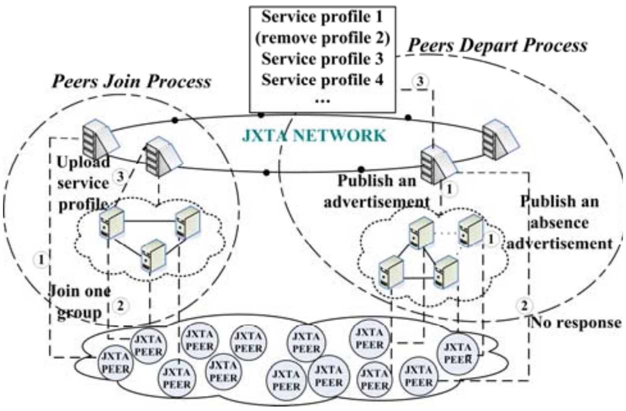


Figure 5. Processes of peers' joining and departing.

### C. Peers Join and Depart

Any peer that wants to join the prototype system can firstly publish its advertisements in the related groups of JXTA network. If the new peer doesn't have any prior knowledge, then the system will locate the advertisement to the related groups by group position finding algorithm. The new peer can publish its advertisements in these related groups and upload a service profile to the group leaders. One peer can join several peer groups as long as the similarities between them are higher than the threshold value.

When a peer departs from the system, it needs to publish an absence advertisement in its groups. The corresponding group leaders will take away the service profile of the absent peer. Each group leader will publish an advertisement to its group members in a given period.

Although some peers depart without publishing any absence advertisements, the relevant group leaders can still remove these peers' service profiles in that those absent peers won't response to the group leader's advertisement. Figure.5 illustrates these two processes.

## IV. Experiments on Prototype System

We have evaluated the performance of the proposed prototype system of the P2P based semantic service discovery in this work. In this section, we report the results of the performance study.

In this study, the following three metrics are observed: efficiency of the searching process, accuracy of the searching results in four evaluating tests, and influences of peer joining and leaving.

### *A. Experiment Setup*

In the prototype system, we used NetBeans 5.5.1, Protégé [26], Jena, JXTA and Apache Tomcat.

Protégé is an open-source development environment for ontologies and knowledge-based systems. Protégé OWL Plugin provides a user-friendly environment for editing and visualizing OWL classes and properties. It has an open-source Java API for developing arbitrary semantic services and allows users to define the logical class characteristics in OWL using a graphical user interface.

Jena is a Java framework for building semantic Web applications. It provides a programmatic environment for RDF, RDFS, OWL and SPARQL, and includes a rule-based inference engine. We adopt Jena in our system because it is a toolkit for developing applications within the semantic web. Jena allows users to query and parse OWL files, and provides many interfaces to access the RDF statements.

### *B. Evaluation for Efficiency*

In this experiment, we examine the efficiency of our prototype system by comparing the average cost time of the distributed and the centralized approach and evaluating the effect of the semantic group numbers.

In the prototype system, we created 1500 service profiles with QoS measurements and divided them into different groups according to their contents. In the distributed approach, we assume the number of the groups is 6, while there is only one group assumed in the centralized approach. As Figure.6 shows, the average query time cost in the distributed system increases slowly when the number of services N is greater than 900. In contrast, the time cost increases almost linearly along with the increasing account of services in the centralized system. From Figure.6, we can also observe that the distributed discovery approach is more effective than the centralized one. This is because in the distributed system, resources are partitioned into different friend groups according to the semantic relations among them, and the matching process only takes place in those semantically related groups.

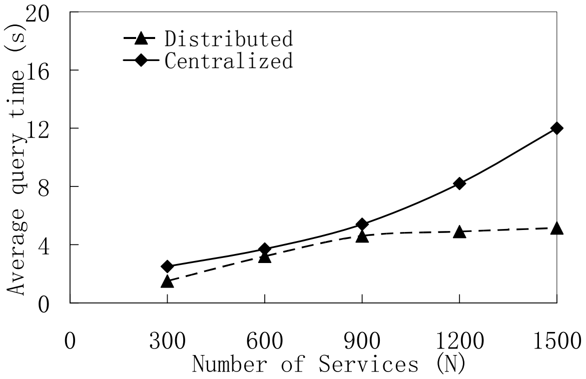


Figure 6. Comparison of efficiency.

With the same settings as in the previous experiment, we evaluated the average query time in the situation of varying the number of the semantic groups M with N=1500. Figure.7 illustrates that the average query time decreases quickly at first, and the reduction speed slows down gradually as M increases. When M is greater than 6, the average query time begins to increase. It suggests that the optimal number of groups is around 6. The reason is that less group numbers make one group comprise more registered services, thus the matching process will cost more time in one related group. However, the increasing group number will make several groups have very close relationship, so the service matching process has to be executed in several related groups.

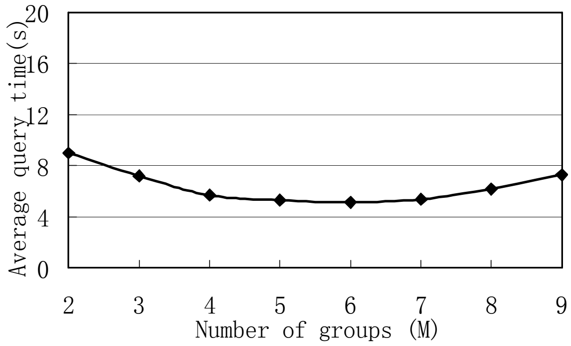


Figure 7. Evaluating the effect of semantic group numbers on efficiency.

### *C. Evaluation for Accuracy*

In this section, we estimate the accuracy of the proposed discovery system from four respects: evaluating the effect of QoS on the discovery accuracy, comparing the accuracy between the distributed and the centralized discovery approaches, making an assessment in the semantic-based and the keyword-based service discovery system, and assessing the influence of the group number on accuracy.

Accuracy is made up of two parts: precision and recall. Precision is defined as the ratio of the number of correct returned services to the total number of all returned services in one query. By contrast, recall is defined as the ratio of the number of returned correct services divided by the number of all correct services. Firstly, we compare the precision of service discovery with and without QoS measurements in our distributed discovery system. Because the QoS measurements can filter out those services which have the same functions but without the unsatisfactory QoS indexes, the average precision increases as Figure.8 shows.

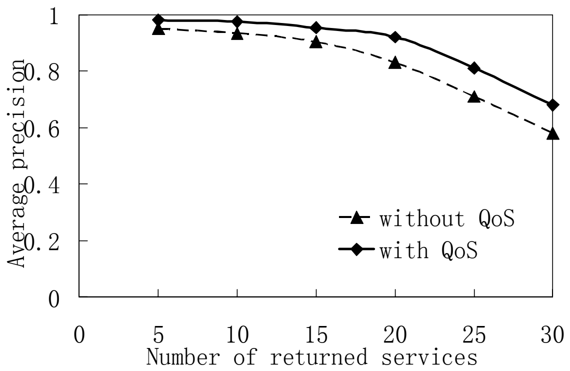


Figure 8. Comparison of precision.

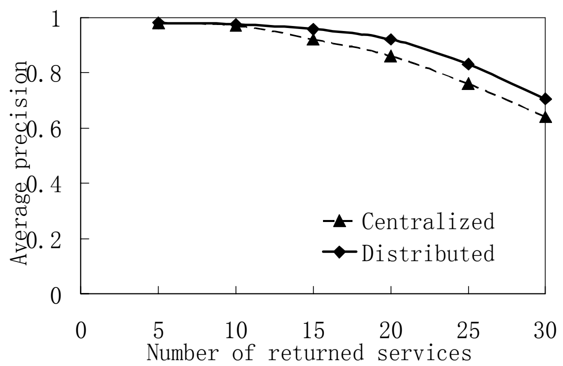


Figure 9. Comparison of precisions between the distributed and centralized discovery system.

Then, we evaluate the performance of the discovery approach in both distributed (M=6) and centralized (M=1) system. We use the number of returned services R={5,10,15,20,25,30} and the number of relevant services S=20. Figure.9 shows that the precision is affected by the number of returned services R and the network organization structures (distributed or centralized). As can be seen, precision decreases very slowly as R increases until R reaches S and then decreases sharply when R is beyond S. Contrary to precision, recall increases sharply when R is small and starts to level off after R reaches S as Figure.10 illustrates. The results show that when R<S, most of the returned services are relevant. It means that R doesn't need to exceed S unless a user wants to get a large number of relevant services.

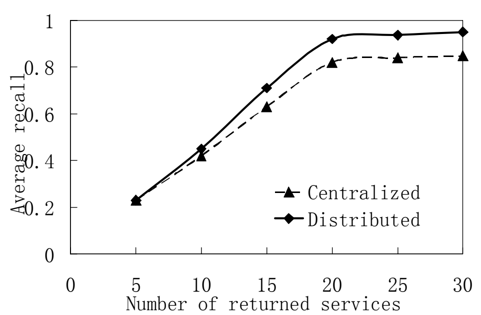


Figure 10. Comparison of recalls between the distributed and centralized discovery system.

From Figure.9 and Figure.10, it can be observed that the distributed discovery approach can improve both precision and recall. With the same amount of returned resources, the percentage of relevant ones in the distributed system is higher than that of the centralized system with the help of the semantic-based related friend groups. Therefore, the precision and the recall of the former system are higher than that of the latter one.

We next make a comparison between the keyword-based and the semantic-based service discovery. It is impossible to ask all users to provide the same description about one service, which is required by the keyword-based discovery system. By contrast, the semantically similar requests can be matched to the same service in our semantic-based discovery system.

For instance, when a user asks for services about English learning online, or English E-learning, or E-learning on English, he will get the same services, namely, English Reading, English Speaking and English listening. That's because the intrinsic meanings of the above ostensibly diverse requests are actually identical. However, in the keyword-based method, such various requests could not be matched to the same relative services. On the other hand, given one request such as computer E-learning, the correlated services such as DM learning and ML learning will be returned in the semantic-based system. But the keyword-based approach, in contrast, can't get any inexact matching results according to the semantics because of its exact matching technique.

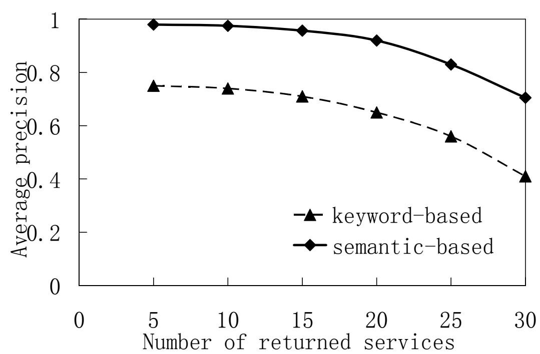


Figure 11. Comparison of precisions between the semantic-based and keyword-based discovery system.

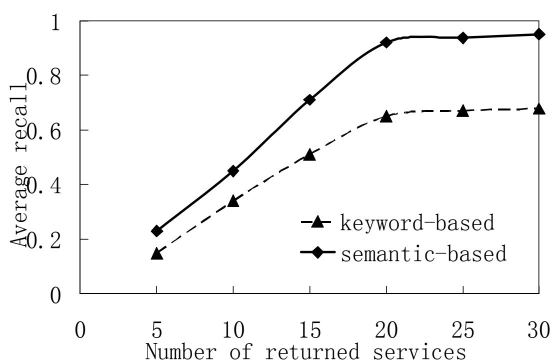


Figure 12. Comparison of recalls between the semantic-based and keyword-based discovery system.

As shown in Figure.11 and Figure.12, the precision and the recall have been improved in the semantic-based method compared with that in the keyword-based approach. This is due to the effect of the thesaurus ontology and the domain ontology.

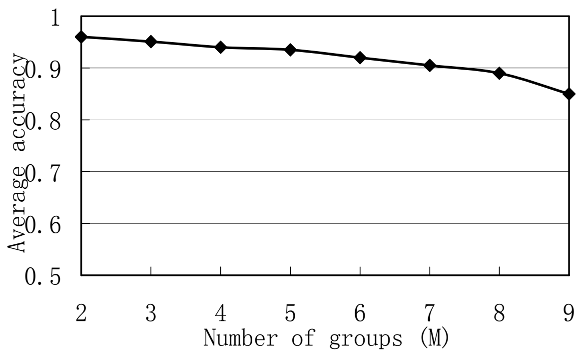


Figure 13. Evaluating the effect of semantic group numbers on accuracy.

We plot the accuracy over different group numbers in Figure.13, where R=20 and S=20. If R=S, the values of recall and precision are the same by definition. Therefore, the term accuracy is used here to mean both recall and precision when R=S=20. As there are more related services in one group with smaller group number, the number of correct returned services is greater. Thus, the accuracy decreases with respect to M. From Figure.7 and Figure.12, we can see that the setting of 6 groups provides a good tradeoff between searching efficiency and accuracy.

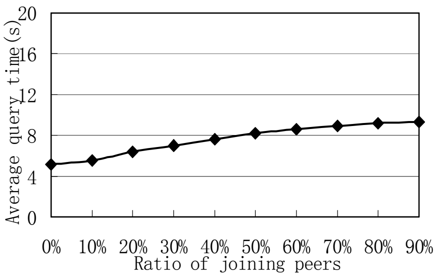


Figure 14(a). Join effect on efficiency.

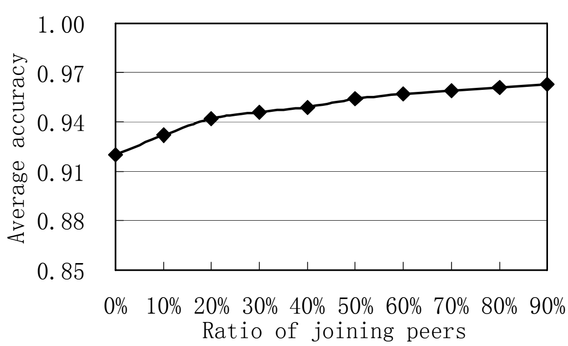


Figure 14(b). Join effect on accuracy.

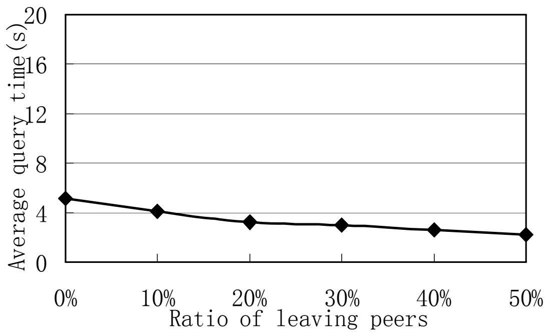


Figure 15(a). Leave effect on efficiency.

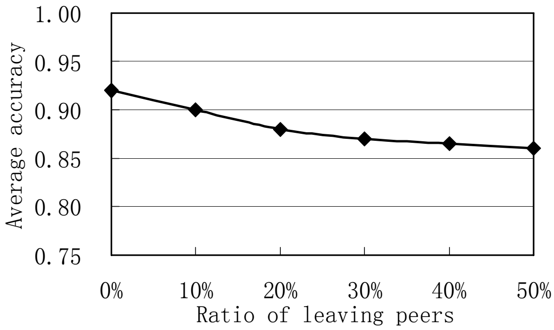


Figure 15(b). Leave effect on accuracy.

### *D. Evaluation for Peer Joining and Leaving*

In this experiment, we examine the updating issue on our discovery system. We have studied the changes of efficiency and accuracy when new peers join the network or registered peers leave the network. Using the 15 queries, we simulated the performance when peers join the network incrementally with M=6, R=20, and S=20, and recorded the average changes of efficiency and accuracy. We define the ratio of joining/leaving peers as the percentage of the number of joining/leaving peers to the total number of existing peers. As Figure.14(a) and Figure.14(b) show, both efficiency and accuracy increase with the growth of the ratio of peer joining, because the larger number of peers can provide more related services, but cost more time for matching process. Likewise, the efficiency and the accuracy decrease when the ratio of peer leaving grows as Figure.15(a) and Figure.15(b) illustrate.

## V. DISCUSSIONS

Recently, many efforts have been made to address service discovery, and a number of distributed service discovery systems have been proposed in the literature. Maedche & Staab[27] specified that service-driven architectures promise a new paradigm providing an extremely flexible approach for building complex information systems; they also presented technologies for building next-generation service-driven systems such as Peer-to-Peer and Semantic Web.

METEOR-S WSDI [28] is a scalable environment for service publication and discovery among multiple registries. It uses an ontology-based approach to organize registries, and takes JXTA as its infrastructure. When a client peer sends a query to the peer group, it will receive the registry ontologies and need to choose the most relevant domain specific ontology. This approach demands a high performance of the client peer. To bring down the requirement for the client peer, we make the peer group leader select the relevant domain for the client. This method can also reduce the time to transmit the ontologies between the client and the peer group leader.

Oden (Ontology-based discovery enabled network) [16] is an ontology-based distributed service discovery system. It assumes a global namespace of services, which is very difficult to achieve in that different people may give different descriptions even for the same service. This problem is alleviated by using "*" in Oden at the expense of efficiency. We adopt the thesaurus ontology to address this problem.

GloServ [18-19] is a hybrid hierarchical and ontology-based global service discovery system. It makes use of the service classification ontology to locate services in a specific domain; however, it didn't discuss the case where queries or registries may have very close relations with several domains. We solve this problem by calculating the similarity between the query or registry and different domains, and then choosing those whose similarity degrees are above the threshold value.

UbiSearch [29] is another service discovery system used for a large-scale ubiquitous computing environment. It puts forward a semantic service discovery in the semantic vector space (SVS), and also assigns each service a coordinate value, so that the Euclidean distance between two coordinates approximates the semantic distance between two services. This scheme makes services that are semantically close to each other map to nearby positions in SVS. UbiSearch utilizes a set of properties to indicate a service. However, it doesn't consider IOPE of the specified service.

The most related research work to this paper is reference [30], which puts the non-semantic QoS information into UDDI. In contrast, we add the QoS information to the service description ontology and establish a special ontology for QoS.

In this work, we combine the semantic web technology with a P2P infrastructure, and bring QoS measurements to increase the success rate of service discovery. We have verified that this combined approach for service discovery in the Universal Network is more efficient and makes searching results more accurate.

## VI. Conclusions and Future Work

Services are classified and have various qualities in the Universal Network, so the service discovery of the Universal Network is different from that of the current Network. This paper contributes to this challenge by describing pervasive services with OWL-QoS and proposing a matching algorithm based on it. It allows the matching of advertisements and requests not only on the basis of the capabilities that they describe, but also on the QoS requirements which they specify. Moreover, we also bring a P2P infrastructure—JXTA, which is a suitable foundation to build the future computer systems on, to avoid the single point of failures caused by the centralized approach. Experiments demonstrate the high performance of the P2P based semantic service discovery with QoS measurements.

As future work, the presented model can be used in the next generation network, where various services coexist with different QoS. Besides, we take advantage of JXTA as a distributed infrastructure in this work. However, as the number of services grows very fast, we will extend our work by taking Hadoop as a foundation structure. Hadoop is an open-source software framework for storage and large scale processing of data-sets on clusters of commodity hardware. Compare with JXTA, Hadoop processes large amounts of data much more quickly. In addition, our discovery work will focus on not only services but also data. We plan to do unified discovery for both service and data. The unified approach will provide a convenient system for people and decrease wastes created by two separate systems.

## Acknowledgment

This work was jointly supported by the National Natural Science Foundation of China (No.61305056, No.61300132), Beijing Higher Education Young Elite Teacher Project (No.YETP0702, No.YETP0706), and the Fundamental Research Funds for the Central Universities.

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