Design, Modeling, and Performance Analysis of Web-based Multi-purpose Discovery Middleware in Ubiquitous Environments

Ho-Jin Shin[1], Min-Goo Kang[1] and Kee-Hyun Choi[2]

[1]*Dept. of Information Science and Telecommunication HanShin University*
[2]*College of Information and Communication Engineering Sungkyunkwan University*
{hjshin, kangmg}@hs.ac.kr, gyunee@ece.skku.ac.kr
**Corresponding author: KeeHyun Choi*

Abstract

Service discovery has become more complicated than it was just a few years ago, because lots of service discovery platforms are introduced for their own purpose. As a result, the devices concurrently existed in such platforms must be equipped with corresponding modules which enable the devices to communicate with other devices. A great deal of papers dealing with service discovery has recently been published, and many efficient and fast searching schemes are proposed, they, however, do not consider the problem of interoperability between discovery protocols, and scalability as well as user's accommodation needs. Therefore, we propose a Web-based multi-purpose discovery middleware to support discovering in heterogeneous ubiquitous environments, and show that proposed system outperforms in terms of path length and hitting probability.

Keywords: *Service discovery, Middleware, P2P*

1. Introduction

In the last few years, service discovery has become increasingly important in heterogeneous ubiquitous environments as a key element. Service discovery is the process of locating available nearby services, which enables users to discover information about matched services automatically. A great deal of papers dealing with service discovery has recently been published. The ReMMoC [16] adopts the reflection and component technology to resolve the heterogeneity problem especially in the mobile environment, and supports small-scaled service discovery protocols such as UPnP [3] and SLP [2]. Although many efficient and fast searching schemes for service discovery are proposed in these papers, they do not consider the problem of interoperability between discovery protocols, and scalability at the same time. In order to overcome the problems of heterogeneous middleware technology, system must be able to adapt to the dynamic situations. Therefore, we propose Web-based Multi-purpose Discovery Middleware (WMDM) which supports most widely-used discovery protocols such as UPnP and SLP, and LSD [13]. The unique features of WMDM are that communicate with agent platforms such as JADE and FIPA-OS [21], and can be extended into hierarchical peer-to-peer network. The rest of the paper is organized as follows. Section 2 describes the related backgrounds and Section 3 presents the system architecture of proposed system. Modeling and mathematical analysis for evaluating the proposed system is presented in Section 4. Finally, we conclude this paper with some remarks in Section 5.

2. Background

In this section, we present a short overview of background technologies we used. At first, we introduce agent-based discovery facilitator run with CALM [14], and then show the web-based discovery. The CALM is designed to support context-awareness by providing sufficient flexibility to enable active service deployment and reconfiguration in response of rapidly changing contexts. The most fundamental processes of the CALM usually occur in the internal layers [18]. However, these fundamental processes cannot efficiently work without service directory, called directory facilitator (DF). It must be noted the fact that service discovery is one of the most important topics in ubiquitous environments because there will be many different services available in the future Internet and users want to find services which perform actions to accomplish an user's goal [19, 20]. Web-based discovery systems are fundamental mechanism to provide consumer with the contents which are the information of interest to consumers and may be static Web data [1]. It works on the Web infrastructure in which various users such as system administrator, employees of the organization, and the persons outside of the company may concurrently exist. We adopt Web infrastructure to provide basic services, since Web infrastructure is needed to deploy the hierarchical P2P system and basically provides user with availability, stability, and scalability. If we can find a web-server which provides user-specific services by using a structured method, then we can easily utilize the services using well-defined protocol such as HTTP.

3. Web-based Multi-purpose Discovery Middleware

3.1. Message Monitor

Service discovery protocol (SDP) usually uses a multicast group address to send discovery messages (e.g. advertisement, request, and response). In a similar way, communication of agent and P2P communication may use unique port number. The port number may be interpreted as a permanent SDP identification tag so that we could detect such message just after listening to these messages. Since we must continually monitor such messages to detect changes as fast as possible in dynamic network, passive monitoring mechanism which listens to the well-known SDP multicast groups is efficient way with respect to bandwidth consumption as well as computation resources. To achieve this feature, the Message Monitor (MM) subscribes itself to several SDP multicast groups. We can imagine that three multicast groups (i.e. UPnP, SLP, and LSD) are connected to WMDM through the MM. After the MM listens to the messages from multicast groups, it forwards the message to Discovery Adapter (DA) to classify the messages as depicted in Figure 1.

3.2. Discovery Adapter

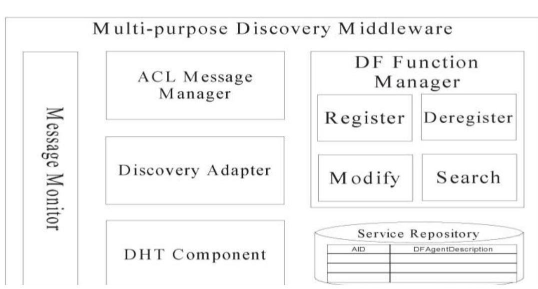


Figure 1. Multi-purpose Discovery Middleware

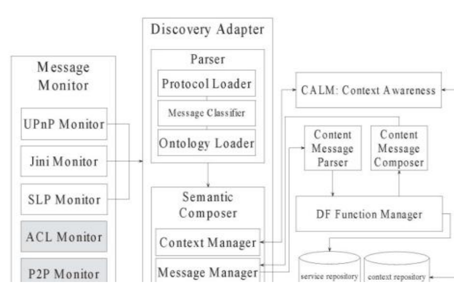


Figure 2. Discovery Adapter

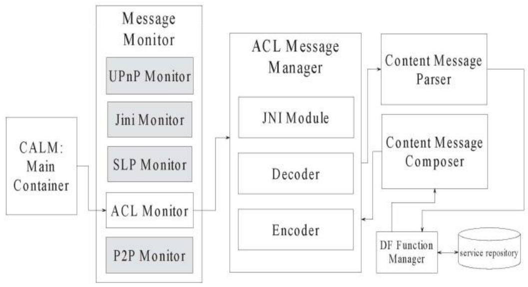


Figure 3. ACL Message Manager

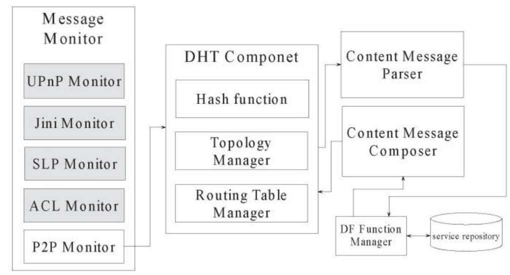


Figure 4. DHT component

The DA analyzes the messages sent from the MM and then loads appropriate parser and semantic composer. The parser interprets the messages encoded in syntactic structure and the semantic composer generates common messages for DF. Protocol Loader loads a corresponding protocol according to the SDPs, and then message classifier interprets the message if it needs a semantic processing in the case of advertisement message. The ontology Loader only passes the request message to the Message Manager in the semantic composer. Context Manager sends the context information in the SDP messages to the CALM as depicted in Figure 2. It is important to note that DA does not provide direct interoperability between two SDPs since it is impossible to perfectly change the each messages. However, we provide indirect interoperability which registers common message at first and then uses it. Thus, Semantic Composer expunges the some elements of original messages and appends dummy messages into common message. In fact, we may use a fixed set of common events which are defined for all SDPs.

3.3. ACL Message Manager

Both Agent platform (CALM) and WMDM must be connected in order that WMDM works as an agent. After both systems are connected, the ACL Message Manager (AMM) receives the ACL messages sent from an agent and the main container in the CALM. FIPA ACL is an outer language that specifies message format and includes descriptions of their pragmatics, and its agent can communicate with each other using the semantic languages; every agent has common semantics that is based on shared ontology for communication [8-12]. Thus, we need to decode the ACL messages and then parse the content messages to get the agent descriptions. Content Message Parser (CMP) can support not only FIPA-SL for agent ontology but also other semantic languages such as RDF, OWL, and DAML+OIL. It is important to call attention to the fact that each agent can have different semantic languages, so that the conventional agent platform could not inter-communicate with each other due to its contents language even though they use the same semantic languages. Therefore, AMM has two elements; Content Message Parser can interpret the semantics which generated in different semantic languages, and Content Message Composer generates the contents message according to the agent's needs as shown in Figure 3.

3.4 DHT Component

WMDM is organized into two-layered hierarchy, where the lower layer consists of several discovery domains and the higher layer consists of P2P overlay network. DHT component (DC) comprises of hash function, topology manager, and routing table manager. The hash function is the main module which provides abstract key space such as the set of 160-bit strings. Topology manager is responsible for producing the topology of overlay network (e.g. circle, butterfly, and de Brujin). To join the high-layer overlay network, Routing Table Manager registers hash key from local peer (i.e. every nodes in local groups) with repository and then generates new hash key using address of WMDM itself. Thus, Routing Table Manager is responsible for registration of local service and publication of newly-generated key. Figure 4 illustrates DHT component.

4. Modeling and Performance Analysis

4.1 Modeling of Structured P2P System

In flat P2P system, look-up process depends on its particular algorithms. We analyze the performance of structured P2P networks including Chord [4], CAN [5], Tapestry [6], and Pastry [7] through a Markov process for their query method. Most of DHT-based P2P systems use routing table by which peer selects a neighbor in random or non-random, and then forwards message sent from arbitrary peer. In Chord, for example, routing mechanism is similar to binary search, where the searching space will be reduced to half after a search/routing-hop. Thus, the number of nodes that must be contacted to resolve a query in a N-node network, and the table size is *O(logN)*. In paper [15], the authors model the flat P2P system using a discrete absorbing Markov process. However, they use static failure probability for node dynamics. Therefore, we re-model the flat P2P system using the failure probability distribution (FPD) based on lifetime model [17]. This distribution is well agreed with our flat and hierarchical model. An example of a discrete absorbing Markov process with transition probability is depicted in Figure 5 (a), where *Q*, *U*, and *V* are expressed as follows:

$$Q=\begin{pmatrix} 0 & 0 & 0 & 0 \\ p_{2,1} & 0 & 0 & 0 \\ p_{3,1} & p_{3,1} & 0 & 0 \\ p_{4,1} & p_{4,1} & p_{4,1} & 0 \end{pmatrix},\ U=\begin{pmatrix} p_{1,0} \\ p_{2,0} \\ p_{3,0} \\ p_{4,0} \end{pmatrix},\ V=\begin{pmatrix} p_{1,4} \\ p_{2,4} \\ p_{3,4} \\ p_{4,4} \end{pmatrix} \tag{1}$$

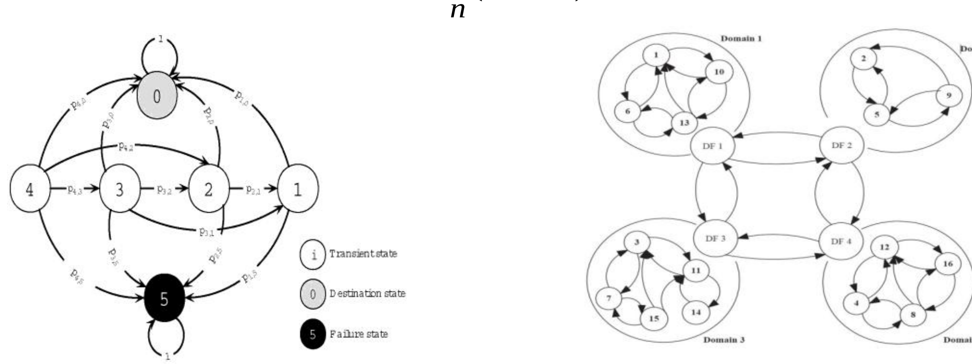
We use the following equations to compute the hitting probability and expected steps to absorbing state:

$$A=(I-Q)^{-1}U \tag{2}$$

$$S=((I-Q)^{-1}A) \tag{3}$$

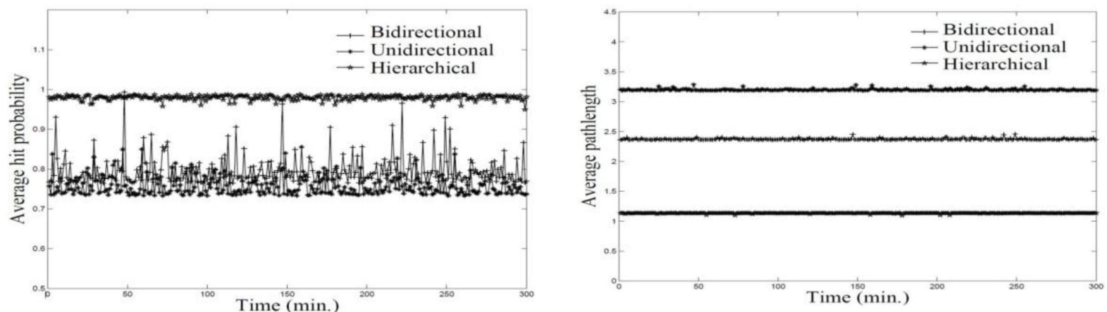
Thus, the average hitting probability and average hopping count as followings:

$$\overline{a}=\frac{1}{n}(\pi^{0}A+1) \tag{4}$$



(a) Flat P2P **(b) Hierarchical P2P**

Figure 5. The Transition Model of P2P Systems



(a) Average hitting probability **(b) Average path length**

Figure 6. Comparison of Bidirectional, Unidirectional and Hierarchical Chord

$$\bar{m} = \frac{1}{n}\pi^0 S \tag{5}$$

Where $\pi^0 = (1, 1, \cdots, 1)$.

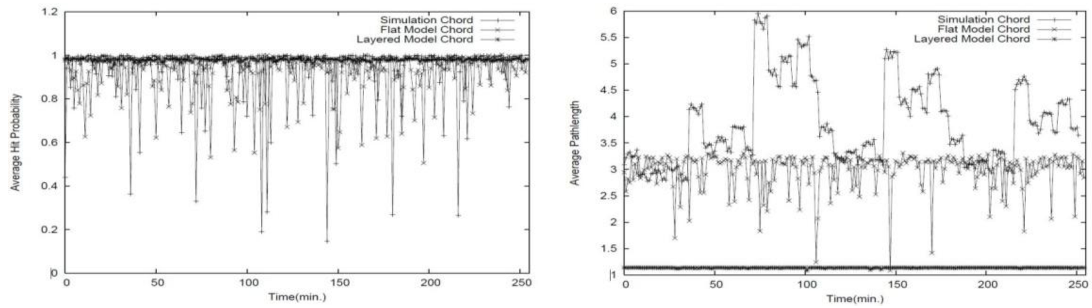
4.2 Modeling of Hierarchical P2P System

In this subsection, we introduce Layered Absorbing Markov Process (LAMP) based on conventional theory of absorbing Markov chain (AMP). Figure 5 (b) shows a transition model of layered Markov chain. We compose the model of 16 sub-states and 4 domains, which are depicted by small and big circles respectively. Transition process among domains at the upper layer is independent of sub-layer transition process between the sub-states. We adopt the same routing mechanism used in Chord for top-level routing, and routing mechanism among sub-states in a domain is various according to its size of participant peers. Although we can use directory service of DF in most cases, other routing mechanism such as broadcasting, mesh routing, and other P2P mechanisms (i.e. Chord, Pastry and so on) can be used. We used the former case in our model, hence routing path takes one hop to reach the other node in the same domain. Whole transition model should be a function of both the transitions among domain and sub-states. We used the index of a domain or sub-state to designate the domain or sub-state. For example, the second domain is D_2 and the third sub-state of O^2 is o_3^2. An overall system state is also called a global system state in contrast to a local sub-state. The LAMP is a 6-tuple $LAMP$ = (D, G, v_G, O, S, v_S). We compute domain hitting probability using matrix H, and its probability used in matrix h denoted τ'^j:

$$H = \left[\begin{array}{c|c} Q & V \\ \hline 0 & 1 \end{array}\right], \qquad h = \left[\begin{array}{c|c} Q' & \dfrac{(1-\sigma)e}{\tau'^j \times s_{\ddot{S}_j}^J} \\ \hline 0 & 1 \end{array}\right] \tag{6}$$

$$\tau'^1 = \begin{pmatrix} 0.973 \\ 0.963 \\ 0.998 \\ 0.963 \end{pmatrix}, \ \tau'^2 = \begin{pmatrix} 0.943 \\ 0.997 \\ 0.998 \end{pmatrix}, \ \tau'^3 = \begin{pmatrix} 0.983 \\ 0.996 \\ 0.953 \\ 0.963 \end{pmatrix}, \ \tau'^4 = \begin{pmatrix} 0.978 \\ 0.986 \\ 0.973 \\ 0.953 \\ 0.975 \end{pmatrix} \tag{7}$$

τ'^j is result of computing the upper-layer hitting probability. Thus, τ'^1 is, for example, hitting probability from a state of domain 1 to the absorbing domain. We consider four domains and the number of state in each sub-domain is the same as denoted in matrix (6) and (7). The right-top column vector of h denotes the transition probability from a sub-state to absorbing sub-state. Here, σ is failure probability and **e** is column vector (**e** = [1, 1,⋯, n_t]). The transition in the intra-domain takes one hop to reach the destination because



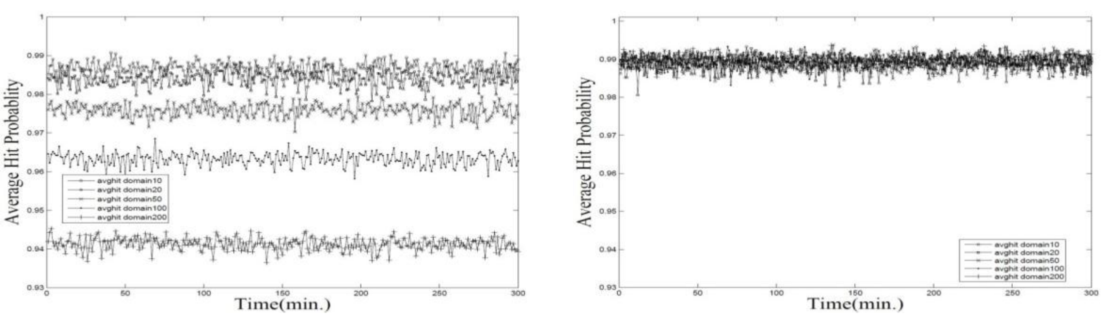
(a) Average hitting probability **(b) Average path length**

Figure 7. Comparison of Simulation Results using MATLAB and P2Psim

we assume that *superpeer* (denoted $\ddot{S}$) has routing information and thus the matrix Q' has zero as their elements. As a result, we can compute hitting probability using Eq. (2). The fundamental matrix is just equal to the *identity matrix* because matrix Q' has no value. Thus hitting probability can be computed as follows:

$$A = I \times \left[\tau'^{j} \times s^{J}_{\ddot{S}j} \,|\, (1-\sigma)\mathbf{e} \right] \tag{8}$$

4.3 Performance Analysis



(a) Unstable DF **(b) Stable DF**

Figure 8. Comparisons of Hierarchical P2PMATLAB and P2Psim

We simulate the structured P2P system including flat and hierarchical using two simulation tools: MATLAB and P2Psim [22]. We use MATLAB to perform mathematical simulation and obtain the path length using the Eq. 8, and the simulation result depicted in Figure. 6. The mathematical simulation results are comprised of three P2P routing mechanisms of Chord: Unidirectional, Bidirectional, and Hierarchical. In Hierarchical model, the average hitting probability almost approaches to 1 and has the same value over time, which means that churn ratio does not affect the hitting probability even if all nodes in other domain leave at the same time. Furthermore, average path length of global system is just one-hop length. Thus the simulation results give us clear and convincing evidence that hierarchical approach for P2P system is reasonable solution in terms of network dynamism. We use the P2Psim to simulate for considering real network environments. It is difficult to simulate all P2P algorithms using this simulator due to particular characteristics of these algorithms. We compared the simulation results using P2Psim with the mathematical simulation results. Figure 7 shows that hierarchical mathematical model provides the better performance than both mathematical results and simulation results using P2Psim. Figure 8 shows simulation result of hierarchical P2P where domain number varies range from 10 to 200. The number of node has range from 10,000 to 200000 because we set number of intra-domain nodes to 1000. Hit probability downgrades according to the number of domain in the case that inter-domain transition probability is not fixed value as shown in Figure 8 (a). We can increase the hit ratio if we consider more stable WMDM, and expect that average hit probability reaches almost 1 in real P2P systems as shown Figure 8 (b).

5. Conclusions

In ubiquitous environments, we must consider the heterogeneity of devices and applications. In addition to this, it is important to consider whether we can find distributed services in large-scaled network and access the services we need at any time. In this paper, we have proposed a novel architecture, namely WMDM, to provide various services in the network using three methodologies; the first is *brokering mechanism* that acts as a transient node between the conventional SDPs. The second is *ACL converting mechanism* by which an agent can be communicated across the different platform. We believe that these two mechanisms successfully resolve the heterogeneity problem even though there are many systems have to be accounted for. The WMDM adopts *peer-to-peer discovery mechanism* to provide various services in the large-scaled network based on the Web infrastructure, which is the third mechanism used in WMDM. Although WMDM may seem like a little heavy system compared to conventional systems that are supported by WMDM, in fact WMDM is rather lightweight systems because it mainly focuses on the interpretation and conversion of messages sent from conventional systems. The key roles of discovery systems such as advertisement, invocation, and event handling are left in conventional systems. We have presented experimental results of hierarchical P2P based on our proposed system. It shows that WMDM outperforms in terms of path length and hitting probability. Formulating a rigorous mechanism for applying the meta-semantics is to be studied as future work.

References

[1] M. Becker and R. Booker, “EC Infrastructure Investments: Will You Get What You Pay For (and Need)?”, Messaging Magazine, **(1999)** March/April.

[2] Service Location Protocol Version 2, Internet Engineering Task Force (IETF), RFC 2608, **(1999)** June.

[3] Universal Plug and Play Device Architecture Reference Specification Version 1.0, Microsoft Corporation, **(2000)** June.

[4] I. Stoica, R. Morris, D. Karger, M. F. Kaashoek and H. Balakrishnan, “Chord: A scalable peer-to-peer lookup service for internet applications”, In Proceedings of the ACM SIGCOMM'01 Conference, **(2001)** August, pp. 149-160, San Diego, California.

[5] S. Ratnasamy, P. Francis, M. Handley, R. Karp and S. Schenker, “A scalable content-addressable network”, in Proc. SIGCOMM, San Diego, CA, **(2001)** August, pp. 161-172.

[6] B. Y. Zhao, L. Huang, J. Stribling, S. C. Rhea, A. D. Joseph and J. D. Kubiatowicz, “Tapestry: A Resilient Global-Scale Overlay for Service Deployment”, IEEE Journal on Selected Areas in Communications, vol. 22, no. 1, **(2004)** January.

[7] A. Rowstron and P. Druschel, "Pastry: Scalable, distributed object location and routing for large-scale peer-to-peer systems", in Proceedings of Middleware, Heidelberg, Germany, **(2001)** November, pp. 329-350.
[8] FIPA: Abstract Architecture Specification, **(2002)** December.
[9] FIPA: Agent Message Transport Service Specification, **(2002)** December.
[10] FIPA: Agent Message Transport Envelope Representation in Bit Efficient Specification, **(2002)** December.
[11] FIPA: Agent Management Specification, **(2002)** December.
[12] FIPA: Agent Discovery Service Specification, **(2003)** October.
[13] B. -I. Lim, K. -H. Choi and D. -R. Shin, "An Architecture for Lightweight Service Discovery Protocol in MANET",, ICCS 2005, LNCS 3516, **(2005)**, pp. 963-966.
[14] Y. K. You, S. Han, S. K. Song and H. Y. Youn, "CALM: An Intelligent Agent based Middleware Architecture for Community Computing", the 4th Workshop on Adaptive and Reflective Middleware, **(2005)**.
[15] S. Wang, D. Xuan, and W. Zhao, "Analyzing and Enhancing the Resilience of Structured Peer-to-Peer Systems", Journal of Parallel and Distributed Computing (JPDC), vol. 65, no. 2, **(2005)** February, pp. 207-219.
[16] P. Grace, G. S. Blair and S. Samuel, "A Reflective Framework for Discovery and Interaction in Heterogeneous Mobile Environments", ACM SIGMOBILE Mobile Computing and Communications Review, **(2005)** January, pp. 2-14, special section on Discovery and Interaction of Mobile Services.
[17] D. Leonard, V. Rai, and D. Loguinov, "On LifetimeBased Node Failure and Stochastic Resilience of Decentralized Peer toPeer Networks", ACM SIGMETRICS, **(2005)** June.
[18] J. Paik, H. Y. Youn and U. M. Kim, "Extraction of Implicit Context Information in Ubiquitous Computing Environments", ICCSA 2006, LNCS 3983, **(2006)**, pp. 456-465.
[19] H. -J. Kim, K. M. Lee, K. -H. Choi and D. R. Shin, "Agent-Based Service Discovery Middleware in Ubiquitous Environments", ICCS 2006, LNCS 3993, **(2006)**, pp. 895-898.
[20] K. M. Lee, H. -J. Kim, K. -H. Choi and D. -R. Shin, "An Intelligent Middleware Architecture for Context-Aware Service Discovery", ICCS 2006, LNCS 3993, **(2006)**, pp. 899-902.
[21] http://sourceforge.net/projects/fipa-os, **(2006)** June.
[22] http://pdos.csail.mit.edu/p2psim/

Authors

Ho-Jin Shin

1999.03-2006.02 Ph. D. in Electrical, Electronics and Computer Engineering, Sungkyunkwan Univ., Korea

1996.03-1999.02 M.S. in Electrical Engineering, Sungkyunkwan Univ., Korea

1987.03-1994.02 B.S. in Electrical Engineering, Sungkyunkwan Univ., Korea

2009-Now Assistance Professor, Dept. of Information and Telecommunication, Hanshin Univ., Korea

Min-Goo Kang

1989.09-1994.02 Ph. D. in Electronics Engineering, Yonsei Univ., Korea

1987.03-1989.02 M.S. in Electronics Engineering, Yonsei Univ., Korea

1982.03-1986.02 B.S. in Electronics Engineering, Yonsei Univ., Korea

2000-Now Professor, Dept. of Information and Telecommunication, Hanshin Univ., Korea

Kee-Hyun Choi

2002.03-2006.08 Ph.D. in Electrical, Electronics and Computer Engineering, Sungkyunkwan Univ., Korea

2000.03-2002.02 M.S. in Electrical, Electronics and Computer Engineering, Sungkyunkwan Univ., Korea

1996.03-2000.02 B.S. Electrical, Electronics and Computer Engineering, Sungkyunkwan Univ., Korea

2007.09-Now Research Professor, College of Information & Communications Engineering, Sungkyunkwan Univ., Korea