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Towards New Generation of Mobile Communications: Discovery of Ubiquitous Resources

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Abstract. Continual advances in wireless telecommunications together with the rapid proliferation of various types of portable devices are paving the road towards new generation of mobile communications. Next-generation mobile networks will create environments crowded with diverse types of ubiquitous semantic-aware communication-enabled devices which will provide a remarkable selection of resources (information and services). Consequently, such an environment will require efficient mechanisms which can match supplies (available resources) to demands (requested resources), anywhere and anytime. In this paper, we propose an economic approach to solving this problem combined with AI (Artificial Intelligence) concepts. We implemented a multi-agent system for enabling autonomous inter-device coordination in the heterogeneous environment of pervasive next-generation mobile networks. The efficiency of our model is realized by applying a resource discovery process which uses two-level filtration of available resources before a final ranked set of eligible resources is recommended to requesters in response to their needs. The filtration processes do not only consider the semantic information associated with available resources, but also ratings regarding the actual performance of resource providers (with respect to both price and quality) and the prices paid by providers for advertising their resources.

Keywords: pervasive computing, intelligent software agents, semantic Web Services, resource discovery

Naproti novi generaciji mobilnih komunikacij: iskanje povsodnih virov

Povzetek. Nenehen razvoj brezžičnih komunikacij in razmah različnih tipov mobilnih naprav tlakujeta pot novi generaciji mobilnih komunikacij. Naslednja generacija mobilnih omrežij bo omogočila pomensko-zaznavna okolja, ki bodo prenapolnjena z raznolikimi povsodnimi komunikacijskimi napravami. Te bodo nudile izredno izbiro različnih virov (informacije in storitve). Posledično bodo takšna okolja potrebovala učinkovite mehanizme za zagotavljanje ponudbe (razpoložljivi viri) glede na povpraševanje (željeni viri) – kjerkoli in kadarkoli. V prispevku predlagamo ekonomski pristop k reševanju tega problema z uporabo konceptov umetne inteligence. Implementirali smo sistem z več agenti, ki omogoča neodvisno in avtonomno koordinacijo med napravami v heterogenem in pomensko-zaznavnem okolju naslednje generacije mobilnih omrežij. Učinkovitost našega modela določa proces za iskanje virov. Ob povpraševanju se opravi dvostopenjsko filtriranje razpoložljivih virov. Postopek izbire urejene množice primernih virov ne upošteva zgolj pomen, ki je pridružen posameznemu viru, temveč tudi oceno dejanske storitve ponudnika (glede na ceno in kvaliteto) in zneska, ki ga je plačal ponudnik za oglaševanje svoje ponudbe.

Ključne besede: prodorno računalništvo, inteligentni programski agenti, semantične spletne storitve, iskanje virov

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1 Introduction

When in 1991 Mark Weiser introduced a concept of *ubiquitous computing* (now also called *pervasive computing*), it was just a vision for the 21st century. "The most profound technologies are those that disappear", he wrote. "They weave themselves into the fabric of everyday life until they are indistinguishable from it" [1]. With these words Weiser envisions computers as invisible tools that are quickly forgotten but always with us, while effortlessly used throughout our lives [2]. It is important to note that computers are not physically invisible, but as a part of the context of use. At that time Weiser also identified three main eras of computing [3]:

- First era is the era of mainframes, each shared by lots of people;
- Second era is characterized by personal computing, in which person and machine stare uneasily at each other across the desktop;
- Third era is the era of ubiquitous computing, or the age of calm technology, when technology recedes into background of our lives.

Today we are witnessing the advent of the third era.

Although Weiser tried to make his vision a reality, 15 years ago there were too many technological constraints. Meanwhile, continual advances in wireless technologies and mobile telecommunication systems together with the rapid proliferation of various types of portable devices have advanced the Weiser's vision towards technical and economic viability [4]. The Weiser's ideas are becoming reality as the new generation of mobile communication systems [5][6]. Next-generation mobile networks will create heterogeneous environments crowded with diverse types of ubiquitous semantic-aware communication-enabled devices which will provide a remarkable selection of ubiquitous resources (information, and services). Consequently, such an environment will require efficient mechanisms which can match supplies (available resources) to demands (requested resources), anywhere and anytime.

This paper presents an agent-mediated environment developed from the multi-agent system described in [7][8] by upgrading and adapting its mechanisms for application in real world ubiquitous computing scenarios characteristic for next-generation mobile network environments. The proposed resource discovery model is not only interesting from a scientific point of view, but is also very amenable to real world applications. Organization of our paper is as follows. In Section 2, we present the next-generation mobile networks. A multi-agent system implementing the resource discovery in heterogeneous environment of the next-generation mobile networks is presented in Section 3. Section 4 proposes directions for future work and concludes the paper.

2 Next-Generation Mobile Networks

Emergence of the next-generation mobile networks is a result of fusion of the pervasive computing and Semantic Web concepts. This fusion is grounded on the existing Internet infrastructure and emerging 3G mobile networks, enabled by wide-accepted technologies such as Web Services and supported by AI (*Artificial Intelligence*) mechanisms.

The initial architecture of the Internet was geared towards delivering information visually to humans, while the initial purpose of mobile telecommunication systems was enabling people to communicate while they are in the motion. Currently, we are witnessing a convergence of the telecommunications and the Internet into one system whose architecture is directed towards enabling goal-directed applications to intelligibly and adaptively coordinate information exchanges and actions [9]. At the same time, computers physically "disappear" while being embedded into the environment and they logically evolve from single isolated devices to entry points into a worldwide network of information exchange [10].

2.1 Pervasive computing

In the proposed multi-agent system, pervasive computing concept is applied while creating such an environment which aims to minimize distractions on a user's attention and that adapts to the user's context and needs [11]. In such an environment, diverse types of ubiquitous communication-enabled devices are used as user's quiet and invisible servants, the enablers of *calm technology*. Calm technology is that which informs, but does not demand our focus or attention [3]. Two computing paradigms which nowadays make the Weiser's vision of pervasive computing possible are *distributed systems* and *mobile computing*.

At the moment when the networking became technically possible and cost-acceptable, personal computing evolved to distributed computing. This paved the road towards pervasive computing by introducing a seamless access to remote resources from ubiquitous attachment points. Although the Internet was not conceived to be a distributed computing infrastructure, its network ubiquity has made it an attractive environment for implementation of pervasive computing concepts [4].

Mobile computing emerged from the integration of 3G network technology with the Internet infrastructure as the effect of cellular network transformation to the IP-grounded network. Everyday-falling size and price of portable devices and the concept which separates the device (e.g., the 3G mobile phone) and the device owner (e.g., the SIM - *Subscriber Identity Module*) support the Weiser's vision of inch-scale computing devices readily available to users in any human environment [4].

2.2 Semantic Web Services

In the proposed multi-agent system, semantic Web Service technology is used to unambiguously represent resources in the heterogeneous environment of the next-generation mobile networks.

The Tim Berners-Lee's vision of the Semantic Web [12] provides a foundation for the semantic architecture of Web Services. By applying the Semantic Web concepts realized through OWL-S[1] (*Web Ontology Language for Services*), every Web Service can be described with a set of ontologies. Each OWL-S ontology utilizes one or more domain ontologies which define the concepts important for a particular domain of interest. Concepts in domain ontologies, as well as the relations between the concepts themselves, are specified with OWL[2] (*Web Ontology Language*), a semantic mark-up language for publishing and sharing ontologies on the Internet. As a result, intelligent software agents can interpret and exchange semantically enriched knowledge for their principals [13].

2.3 Intelligent Software Agents

In the proposed multi-agent system, intelligent software agents, supported by AI mechanisms, are used to

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1 http://www.w3.org/Submission/OWL-S
2 http://www.w3.org/TR/owl-features

impersonate providers, consumers and mediators in the volatile and heterogeneous environment of the next-generation mobile networks in order to enable automated interaction and coordination.

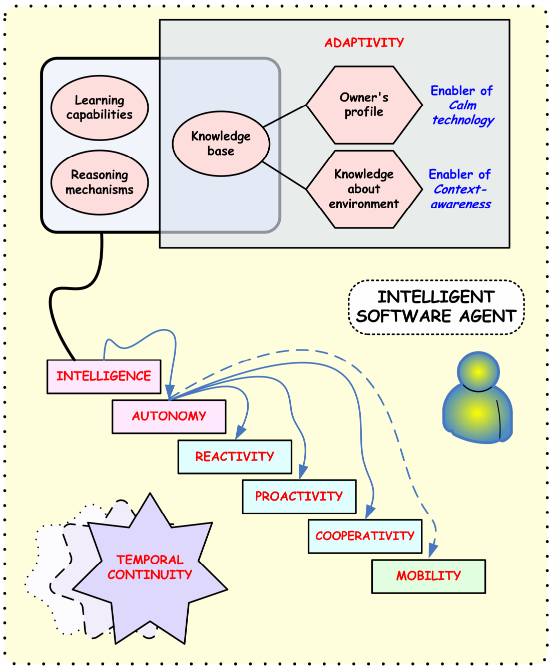

Figure 1. Model of an intelligent software agent
Slika 2. Model inteligentnega programskega agenta

The dynamic and distributed nature of both data and applications in the next-generation mobile networks requires computer programs to not only respond to requests for resources but to intelligently anticipate and adapt to their environment while actively seeking ways to support their principals. In addition to assisting in the coordination of tasks between humans/organizations, these systems should also manage cooperation among distributed software [14]. Therefore, an intelligent software agent is an autonomous program which acts on behalf of its principal while conducting complex information and communication actions over the Internet. The technology of intelligent software agents enables automated process execution and coordination, thus creating added value for its principal. Fig. 1 presents the relations between the main features of intelligent software agents [15][16][17][18][19]: *intelligence, adaptivity, autonomy, reactivity, proactivity, cooperativity, mobility,* and *temporal continuity*.

The next-generation mobile networks will be shaped by open, heterogeneous and complex structures, consisting of diverse types of ubiquitous semantic-aware communication-enabled devices. Intelligent software agents embedded in such devices will interact and negotiate on behalf of their principals [20], but OWL is not sufficient in providing software agents with semantic abilities. Software agents must implement adequate knowledge-based mechanisms which can extract knowledge from OWL documents and understand the corresponding semantic information. A matching algorithm is a mechanism which assists in the discovery of eligible resources for given owner's preferences. In this work, we use an existing matching algorithm from [21] based on the available semantic information encoded in OWL-S.

2.4 Automation of resource discovery

Representation of ubiquitous resources in the next-generation mobile networks and automation of discovery processes are facilitated through semantic Web Services and enabled by applying AI concepts realized through intelligent software agent technology (Fig. 2). We introduce three types of agents into the classical architecture of Web Services. They are *Requester Agents (RAs)*, *Provider Agents (PAs)* and *Intermediary Agents (IAs)*. An RA acts on behalf of its owner (consumer) in the discovery process of suitable resources and subsequently negotiates utilization of these resources. A PA acts on behalf of a resource provider. An IA enables PAs to advertise their resource descriptions and recommends ranked sets of eligible resources to RAs in response to their requests. These agents extend the classical architecture of Web Services by adding to it the capabilities of automated resource discovery and autonomous negotiation regarding the utilization of chosen resources [7]. Thus, there is no need for Web Service providers to change their Web Service providing entities, but simply to upgrade their architecture with an agent (the PA in Fig. 2). This agent's role is to serve as a gateway between the software agent environment and the Web Services environment. A Web Service architecture modelled in such a manner has the capability to simultaneously function in the "classical" and "agent" mode.

3 Discovery of Ubiquitous Resources

Discovery is the process of searching for possible matches between supplies and demands. However, the objective of this process is not simply to find all the available resources which match a requester's demand. Efficient discovery processes should identify all the supplies that can fulfill a given demand to some extent, and then propose just the most promising ones [22].

Traditional discovery solutions, which are essentially based on the exact matching of syntactic patterns (e.g. keyword matching) cannot be flexible enough to effectively deal with the heterogeneity typical of mobile and pervasive environments [23]. Therefore, recent approaches to the discovery processes are increasingly grounded on mechanisms which exploit the semantics of resource descriptions ("intelligent discovery") [24][25][26][27]. Nevertheless, none of these solutions exploit implicit semantics, i.e., patterns and/or relative frequencies of resource descriptions computed by techniques such as data mining, linguistics, or content-based information retrieval (IR). In order to exploit these techniques, we used OWLS-MX [21] for semantic matchmaking, which represents a hybrid semantic Web Service matching tool that combines description logic-based reasoning with approximate matching based on syntactic IR similarity computations.

All of the above mentioned mechanisms facilitate the discovery of adequate resources solely through semantic matchmaking between descriptions of available and requested resources. Thus, they either lack a mechanism for ranking matches or they rank potentially suitable resources only according to their semantic similarity. Such an approach to the discovery process can yield a large number of irrelevant search results since there is no assurance that information advertised by resource providers is accurate [28]. Furthermore, providers of resources with identical descriptions may differ dramatically in performance levels [29]. Therefore, we suggest automated resource discovery based, not only on semantic resource descriptions, but also on information regarding the actual performance of the resource providers and the prices these providers paid for advertising.

The discovery model proposed in this paper combines an economic approach to resource discovery with AI concepts. Two-level filtration of advertised resources is used for efficient discovery of the eligible ones. First-level filtration is based on semantic matchmaking between descriptions of resources requested by consumers and those advertised by providers. Resources which pass the first level of filtration are then considered in the second filtration step. Second-level filtration combines information regarding the actual performance of resource providers and the prices bid by PAs. The performance of resource providers is calculated from requester agent's feedback ratings. Following filtration, a final ranked set of available resources is chosen and recommended to RAs as an answer to their request.

The architecture of a discovery mediator is depicted in Fig. 2. It can be noticed that the IA serves as an interface agent between PAs/RAs and the discovery mediator. The *SPPCA Auction Agent (SAA)*, the *Matching Agent (MA)* and the *Discovery Agent (DA)* enable the necessary functionalities of the discovery mediator. The SAA is in charge of conducting the SPPCA auction. *Interaction 1.1* is used for registering/deregistering PAs in the auction, while the SAA uses *interaction 1.2* to announce a new auction round. The MA facilitates semantic matchmaking which corresponds to the first level of filtration in the resource discovery process. It receives OWL-S descriptions of the requested resources through *interaction 2.1* and forwards a list of semantically eligible resources through *interaction 2.2* to the DA which carries out second-level filtration and recommends top-ranked advertised resources (*interaction 2.3*). Sometime later,

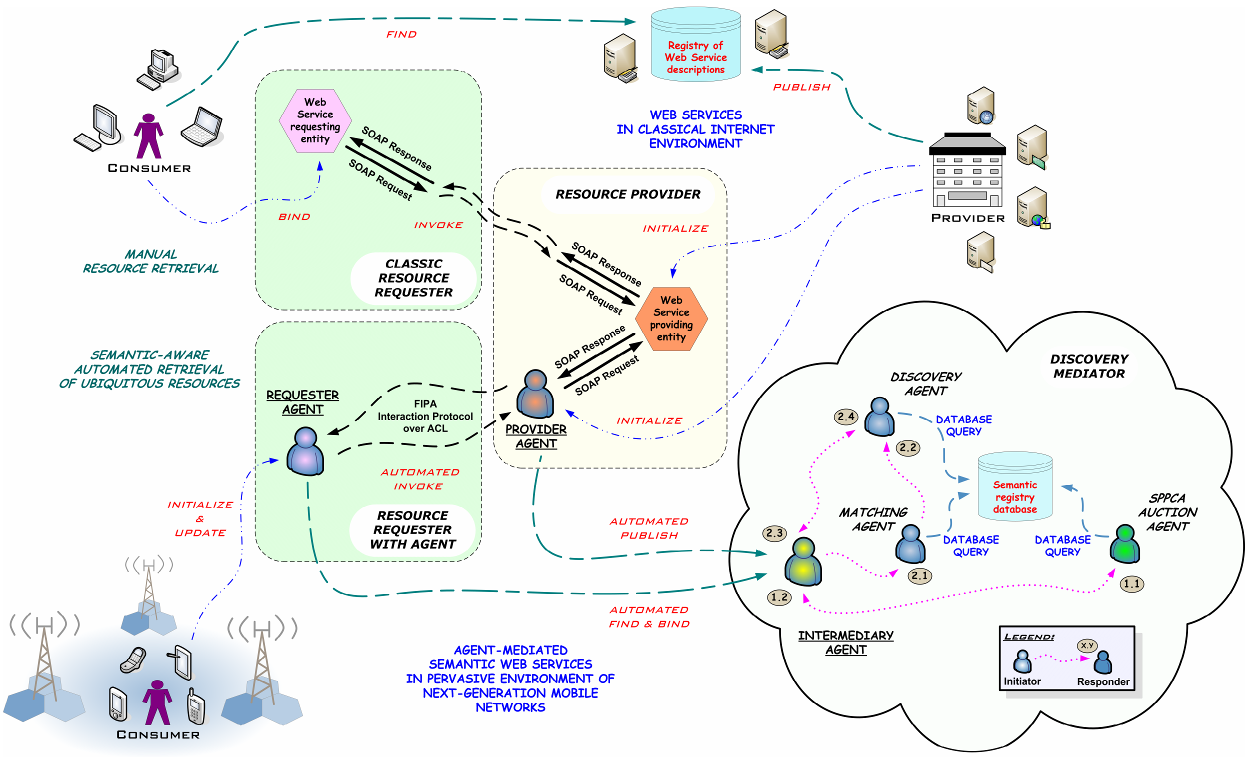

Figure 2. Manual vs. automated resource discovery
Slika 2. Ročno proti avtomatiziranemu iskanju virov

the DA receives feedback information from RA regarding the performance of the proposed resource providers *(interaction 2.4*).

PAs put up bids for advertising their resources in the SPPCA auction. The SPPCA [7] auction is based on Pay-Per-Click (PPC) advertising auctions which are currently used by Google and Overture (a search engine which provides sponsored search results for Yahoo, MSN, Lycos, AltaVista, etc.) as a new mechanism for placing and paying for advertisements. We adapted PPC auction for the agent environment and enhanced it with a semantic dimension. A PPC advertising auction [30][31] is an auction for sponsored positions in search engines. For instance, if a user types in a search for “Croatian hotels” on Google, he/she will get back a set of listings. These include sponsored sites which have paid on a PPC auction to have their companies shown. PPC auctions are an indispensable part of the business model of modern web search engines and are responsible for a significant share of its revenue [32].

A resource-provider performance model tracks a provider’s past performance which can be used to estimate its performance with respect to future requests [29]. Our model monitors two aspects of the resource provider's performance – the resource quality and the price of utilizing the resource [33][34][35]. The rating value (both for quality and price) is a real number $r \in [0, 1.0]$. A rating of 0.0 is the worst (i.e., the provider could not provide the resource at all and/or utilizing the resource is very expensive) while a rating of 1.0 is the best (i.e., the provided resource perfectly corresponds to the consumer’s needs and/or utilizing the resource is very cheap). The overall rating can be calculated a number of ways, but we use the EWMA (*Exponentially Weighted Moving Average*) method.

4 Conclusions and Future Work

In this paper, we present the next-generation mobile networks – dynamic and heterogeneous crowded with diverse types of ubiquitous semantic-aware communication-enabled devices which provide a remarkable selection of resources (information and services). As resource discovery represents a crucial activity within such an environment, we propose a new auction-based mechanism for semantic-aware resource discovery. The designed discovery mechanism also takes into account the performance of resource providers. Implementation of the proof-of-concept prototype is grounded on a pervasive computing concept, enabled by technologies of semantic Web Services and intelligent software agents, and supported by the existing Internet infrastructure and emerging 3G mobile networks.

Our future work will be towards enhancing the existing practical solutions for incorporation of intelligent software agent technology into portable devices and testing the proposed discovery model in real-life scenarios, foremost to determine its behaviour with respect to scalability and time performance.

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5 References

[1] Weiser, M. The Computer for the 21st Century. *Scientific American*, 265, 3 (1991), 94-104.

[2] Weiser, M. The World is not a Desktop. *ACM Interactions*, 1, 1 (1994), 7-8.

[3] Weiser, M.; and Brown, J.S. The Coming Age of Calm Technology. In *Beyond Calculation: The Next Fifty Years of Computing*. Dening, P.J.; Metcalfe, R.M.; and Burke, J. (Eds.), 75-86. New York: Springer-Verlag, 1997.

[4] Saha, D; and Mukherjee, A. Pervasive Computing: A Paradigm for the 21st Century. *IEEE Computer*, 36, 3 (2003), 25-31.

[5] Dumic, G.; Podobnik, V.; Jezic, G.; Trzec, K.; and Petric, A. An Agent-Based Optimization of Service Fulfillment in Next-Generation Telecommunication Systems. In *Proc. of the 9th Int. Conf. on Telecommunications (ConTEL’07)*, Zagreb, 2007, 57-63.

[6] Ljubi, I.; Podobnik, V.; and Jezic, G. Cooperative Mobile Agents for Automation of Service Provisioning: A Telecom Innovation. *In Proc. of the 2nd IEEE Int. Conf. on Digital Information Management (ICDIM’07)*, Lyon, 2007, 817-822.

[7] Podobnik, V.; Trzec, K.; and Jezic, G. An Auction-Based Semantic Service Discovery Model for E-Commerce Applications. *Lecture Notes in Computer Science*, 4277 (2006), 97-106.

[8] Podobnik, V.; Trzec, K.; and Jezic, G. Context-Aware Service Provisioning in Next-Generation Networks: An Agent Approach. *International Journal of Information Technology and Web Engineering*, 2, 4 (2007), 41-62.

[9] Podobnik, V.; Petric, A.; and Jezic, G. The CrocodileAgent: Research for Efficient Agent-Based Cross-Enterprise Processes. *Lecture Notes in Computer Science*, 4277 (2006), 752-762.

[10] Fensel, D. *Ontologies: A Silver Bullet for Knowledge Management and Electronic Commerce*. Berlin: Springer-Verlag, 2004.

[11] Garlan, D.; Siewiorek, D.; Smailagic, A.; and Steenkiste, P. Project Aura: Toward Distraction-Free Pervasive Computing. *IEEE Pervasive Computing*, 1, 2 (2002), 22-31.

[12] Berners-Lee, T.; Hendler, J.; and Lassila, O. The Semantic Web. *Scientific American*, 284, 5 (2001), 34-43.

[13] Hendler, J. Agents and the Semantic Web. *IEEE Intelligent Systems*, 16, 2 (2001), 30-37.

[14] Bradshaw, J.M. *Software Agents*. Cambridge: MIT Press, 1997.
[15] Chorafas, D.N. *Agent Technology Handbook*. New York: McGraw-Hill, 1998.
[16] Cockayne, W.T.; and Zyda, M. *Mobile Agents*. Greenwich: Manning Publications, 1998.
[17] Fasli, M. *Agent Technology for E-Commerce*. Chichester: Wiley & Sons, 2007.
[18] Jurasovic, K.; and Kusek., M. Verification of Mobile Agent Network Simulator. *Lecture Notes in Computer Science*, 4496 (2007), 520-529.
[19] Matijasevic, M.; and Jezic, G. Monitoring Data Visualization and Agent-based Software Management for the Grid. *Electrotechnical Review*, 72, 1 (2005), 52-57.
[20] Trzec, K.; Lovrek, I.; and Mikac, B. Agent Behaviour in Double Auction Electronic Market for Communication Resources. *Lecture Notes in Computer Science*, 4251 (2006), 318-325.
[21] Klusch, M.; Fries, B.; and Sycara, K. Automated Semantic Web Service Discovery with OWLS-MX. In *Proc. of the 5th Int. Joint Conf. on Autonomous Agents and Multiagent Systems (AAMAS'06)*, Hakodate, 2006, 915-922.
[22] Di Noia, T.; Di Sciascio, E.; Donini, F.M.; and Mongiello, M. A System for Principled Matchmaking in an Electronic Marketplace. *International Journal of Electronic Commerce*, 8, 4 (2004), 9-37.
[23] Bellavista, P.; Corradi, A.; Montanari, R.; and Toninelli, A. Context-Aware Semantic Discovery for Next Generation Mobile Systems. *IEEE Communications*, 44, 9 (2006), 62-71.
[24] Sycara, K.; Paolucci, M.; Anolekar, A.; and Srinivasan, N. Automated Discovery, Interaction and Composition of Semantic Web Services. *Journal of Web Semantics*, 1, 1 (2004), 27-46.
[25] Colucci, S.; Noia, T.D.; Sciascio, E.D.; Donini, F.; and Mongiello, M. Concept Abduction and Contraction for Semantic-based Discovery of Matches and Negotiation Spaces in an E-Marketplace. *Electronic Commerce Research and Applications*, 4, 3 (2005), 345-361.
[26] Klein, M.; and Bernstein, A. Toward High-Precision Service Retrieval. *IEEE Internet Computing*, 8, 1 (2004), 30-36.
[27] Keller, U.; Lara, R.; Lausen, H.; Polleres, A.; and Fensel, D. Automatic Location of Services. *Lecture Notes in Computer Science*, 3532 (2005), 1-16.
[28] Lim, W.S.; and Tang, C.S. An Auction Model Arising from an Internet Search Service Provider. *European Journal of Operational Research*, 172, 3 (2006), 956-970.
[29] Luan, X. Adaptive Middle Agent for Service Matching in the Semantic Web – A Quantitive Approach. *Thesis*, University of Maryland, Baltimore County, USA, 2004.
[30] Jansen, B.J. Paid Search. *IEEE Computer*, 39, 7 (2006), 88-90.
[31] Kitts, B.; and LeBlanc, B. Optimal Bidding on Keyword Auctions. *Electronic Markets*, 14, 3 (2004), 186-201.
[32] Aggarwal, G.; Goel, A.; and Motwani, R. Truthful Auctions for Pricing Search Keywords. In *Proc. of the 7th ACM Conf. on Electronic Commerce (EC'06)*, Ann Arbor, 2006, 1-7.
[33] Fan, M.; Tan, Y.; and Whinston, A.B. Evaluation and Design of Online Cooperative Feedback Mechanisms for Reputation Management. *IEEE Transactions on Knowledge and Data Engineering*, 17, 2 (2005), 244-254.
[34] Padovan, B.; Sackmann, S.; Eymann, T.; and Pippow, I. A Prototype for an Agent-Based Secure Electronic Marketplace Including Reputation-Tracking Mechanisms. *International Journal of Electronic Commerce*, 6, 4 (2002), 93-113.
[35] Wishart, R.; Robinson, R.; Indulska, J.; and Jøsang, A. SuperstringRep: Reputation-Enhanced Service Discovery. In *Proc. of the 28th Australasian Conf. on Computer Science (ACSC'05)*, Newcastle, 2005, 49-57.

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