Semantic Based Collaborative P2P in Ubiquitous Computing

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Abstract

We propose a collaborative environment for semantic-enabled mobile devices (e.g. PDAs, cell phones, laptops) in peer to peer scenarios. Within the environment, resource discovery is performed exploiting technologies and techniques for knowledge representation developed for the Semantic Web, which have been adapted to cope with the highly flexible structure of ad-hoc networks in ubiquitous computing. The approach exploits the standard Bluetooth stack, using the original UUID payload, to carry semantically annotated data. The environment is motivated and presented in a museum case study.

1. Introduction

The growth in the diffusion of wireless-enabled handheld devices provides the necessary infrastructure for creating ad-hoc environments for ubiquitous computing. They are based on short range, low power technologies like Bluetooth [4], which grant the peer to peer interaction among hosts. In such a mobile infrastructure there is one or more devices providing and using services. As an ad-hoc network is a very unpredictable environment, Service Discovery (SD) becomes an essential feature. In an ubiquitous context, information and descriptions about services are often unavailable because the location of mobile devices could change continuously [5]. A flexible service search system is desirable, based on wireless network infrastructure and able to overcome difficulties due to the host mobility. Existing service discovery methods use a syntactic matching, which is largely inefficient in ad-hoc environments where there is not a common service interface. Here we need to submit articulate requests and to receive adequate answers [6]. In this paper we present a collaborative ontology based environment where a semantic service search mechanism is used to obtain advanced discovery features, providing automated services to users participating to the ad-hoc network. To achieve this goal, we borrow from the Semantic Web vision, both ideas and technologies, and export them in small ad-hoc networks based on the Bluetooth technology. In a semantic-enabled Web, each resource is annotated using OWL [1], an XML-based language, whose formal semantics is mapped to a formal logic language. There is a close relation between OWL and Description Logics (DLs) [3] semantics, which allows the use of DLs reasoners in order to infer new information from the one stated in the annotation itself. We use some results and approaches we experienced both in semantic-enabled marketplaces [7], and semantic web services orchestration [10], to extend the Bluetooth Service Discovery Protocol (SDP) in order to provide semantic-based services to the users within the piconet. The original Bluetooth standard uses SDP at the application layer. It is based on a 128 bit Universally Unique Identifier (UUID), where each UUID is associated to a single service class. Therefore in a Service Discovery Request the device specifies the requested service UUID and any host in the piconet, holding the service identified by the same UUID replies to the requester. Then a communication can be established. Obviously a code-based SDP can handle only exact matches. Yet, if we want to search and retrieve resources whose description cannot be classified within a rigid schema (e.g. the description of paintings in a museum or goods in a shopping mall [2]) a more flexible SDP is needed. Such a SDP must be able also to cope with non-exact matches, and provide a ranked list of discovered resources, computing a distance between each retrieved resource and the requested one after a matchmaking process. Actually, a set-value based approach could satisfy, at a first glance, similar SDP requirements, but imagine the following simple example related to a museum. Suppose you are looking for paintings whose subject is a portrait, $R = \{portrait\}$, and in the museum there is a collection of selfportraits as offered resources, $O = \{selfportrait\}$, the two values do not match and nothing is known about their relations. Hence, no resource will be retrieved to answer your request. To overcome similar, and more complex, problems we need to model the meaning of the terms and their relations. That is, a representation of their semantics is needed. The SDP efficiency and flexibility can then be increased by exploiting knowledge representation techniques. The rest of the paper is structured as follows: next section presents the framework and our approach; in section 3 we introduce our system and present its features and behavior. In section 4 we comment on related works, and finally we present our conclusions in section 5.

2. Framework and approach

As pointed out in [2], Bluetooth SDP is largely inefficient when it comes to complex requests. In fact SD on Bluetooth only allows exact match discovery of uniquely identified services. This is a restriction in view of the transmission capabilities increase, devised in new drafts of the standard. A more advanced usage of service discovery protocol is desirable, associating semantic descriptions to the services rather than simple numeric identifiers. For such purpose knowledge representation (KR) technologies and techniques can be exploited and adapted to the ubiquitous environments. In the framework we present, after the wireless client has been identified within the piconet, it is able to share and retrieve information from other hosts. In a typical configuration, a user contacts the zone service provider (hotspot) and submits a query about his/her interests. The server identifies clients able to share services and replies with found services, possibly ranked in a list according to their degree of correspondence to the request. The zone server classifies services contents by means of an ontology. In addition users submit requests in a DL language [1]. Then the hotspot collects the descriptions of the offered resources (modeled using DLs) and computes the matchmaking rank between the request and available resources. The provided result is a ranked list of offered resources potentially matching the user request. It should be noticed that DL-based systems usually only provide two basic reasoning services:
Concept Satisfiability: given a ontology $\mathcal{T}$ and a concept C, does there exist at least one model of $\mathcal{T}$ assigning a non-empty extension to C?
Subsumption: given a ontology $\mathcal{T}$ and two concepts C and D, is C more general than D in any model of $\mathcal{T}$?

In a semantically-enabled resource retrieval scenario, where a matchmaking process between a request C and each of the available resources D is needed, using subsumption it is possible to establish if D is more specific than the request C, $D \sqsubseteq C$. If the previous relation holds, then the retrieved resource completely satisfies the request, *i.e.*, an *exact match* occurs. With Concept Satisfiability the discovery of incompatible resources with respect to the request can be performed. If $C \sqcap D$ is not satisfiable w.r.t. the ontology $\mathcal{T}$, the D is not compatible with the request. Although subsumption and concept satisfiability are very useful in several scenarios for resource discovery, *exact matches* are usually rare in a semantically-enabled matchmaking process, and the above services result inadequate. Typically, both $C \sqcap D$ is satisfiable and $D \not\sqsubseteq C$, that is D is compatible with C but it does not completely satisfy it. Then there is the need to go beyond subsumption and concept satisfiability to manage these frequent situations. A metric is needed to establish "how much" the resource D is compatible with the request C or, equivalently, "how much" it is not specified in D in order to completely satisfy C, that is to make the subsumption relation $D \sqsubseteq C$ true. In [9] the *rankPotential* algorithm was presented, such that, given a set of $\mathcal{ALN}$ axioms, $\mathcal{T}$ and two $\mathcal{ALN}$ concepts C and D both satisfiable in $\mathcal{T}$, it computes a *semantic distance* of C from D with respect to the ontology $\mathcal{T}$. Notice that we write *the distance of D from C* rather then *the distance between C and D* because of the non-symmetric behavior of *rankPotential* (see [9] for further details). In fact the relation we wish to reach here is $D \sqsubseteq C$ rather then $D \equiv C$. With the aid of *rankPotential* it is also possible to compute a complex concept depth with respect to the taxonomy represented by the axioms set $\mathcal{T}$. In fact, if $C \equiv \top$ then *rankPotential(C,D)* = *rankPotential($\top$,D)* represents the distance of D from $\top$, *i.e.*, the most generic concept in the ontology. Notice that such distance is not trivially the depth of a node in a tree for at least two main reasons:
1. An $\mathcal{ALN}$ ontology, typically, is not a simple terms taxonomy tree, *i.e.*, it does not contain only IS-A relations between two atomic concepts, and can be better represented as a labeled oriented graph.
2. An $\mathcal{ALN}$ complex concept is the conjunction of atomic concepts and role expressions. The value returned by *rankPotential($\top$,D)* here represents how specific is a *complex concept expression* D with respect to an ontology $\mathcal{T}$.

Notice that since the proposed approach is fully-compliant with Semantic Web technologies, the user exploits the same semantic enabled descriptions s/he may use in other Semantic Web compliant systems. That is, there is no need for different customized resource descriptions and modeling if the user uses different applications either on the web, or in mobile systems. The syntax and formal semantics of the descriptions is unique with respect to the reference ontology and can be shared among different systems. In what follows we detail the discovery and matchmaking process with respect to a case study deployed in a museum. Suppose you are in a mu-

1 We assume the reader be familiar with basics of DLs; see [3] for a thorough introduction to the topic.

seum, which uses ontologies shared on the web to describe its resources. Such resources and related descriptions are also available on the museum web site. We associate the 128 bit UUID [2] to each specific ontology and we call this identifier OUUID (Ontology Universally Unique Identifier). In this way, a generic client request can be done by means of OUUID both by *hotspot* and by other invisible ubiquitous hosts in the environment. With respect to the implementation of matchmaking and ontology support features, we have inserted *Semantic Service Discovery* function into the stack with some small modifications of the discovery protocol. SDP uses a simple request/response method for data exchange between SDP client and SDP server [11]. Since the communication is referred to the peer layers of the protocol stack, each transaction is represented by one request Protocol Data Unit (PDU) and another PDU as response. In every SDP PDU, we have a header like in Figure1 containing the identifier of the PDU, the identifier of the transaction and the length of the next PDU parameters field. If the

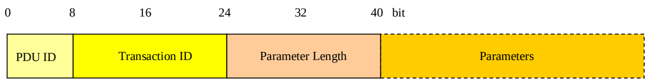

Figure 1. The Service Discovery Protocol elementary PDU structure

SDP request needs more than a single PDU (this case is frequent enough if we use semantic service discovery) SDP server generates a partial response and SDP client waits for next part of the complete response. By adding to the original SDP_SERVICESEARCHPDU (request and response) and SDP_SERVICEATTRIBUTEPDU (request and response) the new SDP_SEMANTICSERVICESEARCHPDU, we insert into SDP the further semantic service search function. No modifications are made to the original structure of transactions, but simply we differently use the SDP framework.

Hence our approach allows to reuse UUID function within Bluetooth, without troubling the original standard, and furthermore it implements an advanced P2P exchange information mechanism, where users are peer clients in the piconet, which can be both service requesters and possible service suppliers.

3. The System

The system we describe here is being deployed as part of the CNOSSO project, which is aimed at developing in-

2 Used in the standard Bluetooth devices service class

novative ways to benefit from cultural sites and heritage in Apulia region. For the sake of simplicity we refer to a scenario such as the one pictured in Figure 2, in order to explain the approach and the rationale behind it. The purpose of such piconet is to find, within the ad-hoc network, services and resources requested by users (with a generic Bluetooth compatible device) searching among on-line available ones. Each resource in the environment owns an URI and exposes its OWL description. The *hotspot* is endowed with

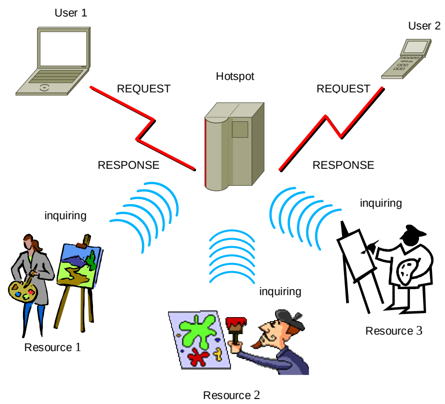

Figure 2. Semantic based P2P piconet infrastructure

a *MatchMaker* (in our system we adapt the MAMAS reasoner [9]), which carries out the matchmaking process between each offered service in the piconet and the requested one measuring a ”semantic distance”. The transaction between service requester and discovery service starts with ad-hoc network creation. [3] When a user becomes a member of the ad-hoc network, s/he is able to ask for a specific service/resource (by submitting a semantic-based description). After a user request, the system collects resources available in the area and performs the matchmaking process between their OWL-based descriptions and the user request. The matchmaking results are then ranked and returned to the user. The generic steps from piconet establishment to response providing for a service request are detailed in the following:

1. Hotspot inquiring and piconet establishment.
2. The user sends a service request (R) to the hotspot. This step can be performed either interactively between the user and the hotspot, or automatically between the user client and the hotspot (see below for further details).
3. The hotspot broadcasts the OUUID provided by the user together with the request ($OUUID_R$) to the piconet clients and selects the ones matching $OUUID_R$.

3 The Bluetooth piconet is a network continuously in evolution. It changes according to on-line subjects in range of hotspot which are ready to communicate.

4. The hotspot sends a service request to the piconet clients with $OUUID_R$.
5. Each client replies with the corresponding OWL description of each resource it shares, which is classified with the previously selected $OUUID_R$.
6. The hotspot performs the matchmaking process between R and both each received OWL descriptions and the ones related to the resources cached within the hotspot itself. Taking into account the matchmaking results, all the resources are ranked with respect to R.
7. The hotspot replies to the user.

Each resource retrieval session starts after the submission from master to slaves of the ontology identifier (OUUID) in order to select possible hosts, suitable for requested services. Notice that steps 3-5 are based on the original SDP in Bluetooth. Each host processes the incoming request at SDP layer and it provides the *hotspot* with OWL descriptions of its shared resource. During step 6 the *hotspot* calls the semantic-based service MAMAS and computes the ranked list of the retrieved resource descriptions with respect to the request. A simple use case will explain system behavior. Let us suppose we are visiting an art gallery, which classifies its work of art in a local knowledge base with an ontology (with OUUID=3217) represented in Figure 3.

For the sake of simplicity, in the example ontology in Figure 3 only subclass and disjoint relations are represented. Let us also suppose that a generic visitor (`user2`) is visiting the same museum and in particular the same room we are in. `user2` is interested in dadaist style. S/He has previously downloaded on his/her mobile device a document file with more information concerning dadaist oils on canvas from the knowledge base of the consortium the art gallery is associated with. This KB classifies its contents by means of the previous OUUID=3217 ontology. Let us imagine that the *hotspot* KB is populated with the following individuals:

LN *League of nations* classified as:
$\texttt{Painting} \sqcap \forall \texttt{hasStyle}.\texttt{Dadaism} \sqcap \forall \texttt{hasTechnique}.\texttt{Pastel}$

FU *Forme uniche nella continuità di spazio* classified as:
$\texttt{Sculpture} \sqcap \forall \texttt{hasStyle}.\texttt{Futurism}$

MSV *Mont Saint Victor* classified as:
$\texttt{Painting} \sqcap \forall \texttt{hasTechnique}.\texttt{Oil}$

SP *Self-portrait* classified as:
$\texttt{WorkOfArt} \sqcap \forall \texttt{hasSubject}.\texttt{SelfPortrait} \sqcap \forall \texttt{hasStyle}.\texttt{Symbolism}$

WCH *Woman combing her hair* classified as:
$\texttt{Statue} \sqcap \forall \texttt{hasSubject}.\texttt{Naked}$

Moreover the document file on the `user2` PDA is a specific document on painting *Broyeuse de chocolat no.2* classified as: $\texttt{Painting} \sqcap \forall \texttt{hasStyle}.\texttt{Dadaism} \sqcap \forall \texttt{hasTechnique}.\texttt{Oil}$ (we will indicate such resource with **BC**).

Hence we can submit to the *hotspot* a semantic request for more info on *oil dadaist paintings with landscape as subject*. The request will be formulated in DLs format as $D = \texttt{Painting} \sqcap \forall \texttt{hasStyle}.\texttt{Dadaism} \sqcap \forall \texttt{hasTechnique}.\texttt{Oil} \sqcap \forall \texttt{hasSubject}.\texttt{Landscape}$ with respect to the ontology identified by the OUUID=3217.

Painting $\sqsubseteq$ WorkOfArt
Sculpture $\sqsubseteq$ WorkOfArt
Dadaism $\sqsubseteq$ Style
Futurism $\sqsubseteq$ Style
Symbolism $\sqsubseteq$ Style
Abstraction $\sqsubseteq$ Subject
Nature $\sqsubseteq$ Subject
Portrait $\sqsubseteq$ Subject
Religious $\sqsubseteq$ Subject
Scenery $\sqsubseteq$ Subject
PaintingTechnique $\sqsubseteq$ Technique
SculptureTechnique $\sqsubseteq$ Technique
Bust $\sqsubseteq$ Sculpture
Statue $\sqsubseteq$ Sculpture
Landscape $\sqsubseteq$ Nature
Seascape $\sqsubseteq$ Nature
StillLife $\sqsubseteq$ Nature
Icon $\sqsubseteq$ Portrait
Naked $\sqsubseteq$ Portrait
SelfPortrait $\sqsubseteq$ Portrait
Icon $\sqsubseteq$ Religious
Cityscape $\sqsubseteq$ Scenery
Landscape $\sqsubseteq$ Scenery
Seascape $\sqsubseteq$ Scenery
Distemper $\sqsubseteq$ PaintingTechnique
Oil $\sqsubseteq$ PaintingTechnique
Pastel $\sqsubseteq$ PaintingTechnique
Watercolors $\sqsubseteq$ PaintingTechnique
Carving $\sqsubseteq$ SculptureTechnique
LowRelief $\sqsubseteq$ SculptureTechnique
Mold $\sqsubseteq$ SculptureTechnique
Sculpture $\sqsubseteq$ $\neg$Painting
PaintingTechnique $\sqsubseteq$ $\neg$SculptureTechnique
Style $\sqsubseteq$ $\neg$Subject
Statue $\sqsubseteq$ $\neg$Bust
Watercolors $\sqsubseteq$ $\neg$Oil
Watercolors $\sqsubseteq$ $\neg$Pastel
Watercolors $\sqsubseteq$ $\neg$Distemper
Oil $\sqsubseteq$ $\neg$Pastel
Oil $\sqsubseteq$ $\neg$Distemper
Pastel $\sqsubseteq$ $\neg$Distemper
Mold $\sqsubseteq$ $\neg$Carving
Mold $\sqsubseteq$ $\neg$LowRelief
Carving $\sqsubseteq$ $\neg$LowRelief

Figure 3. A simple art gallery ontology used as reference in the example

The *hotspot* will search for OUUID=3217 and will find the `user2` client plus the others hosts already known. In fact `user2` is in the range of the *hotspot* and s/he exposes a service classified by the same ontology managed by the matchmaker. Then `user2` sends the OWL description of his resource to the *hotspot* which calls the matchmaker module for rank computation. In table 1 matchmaking results are presented. The second column shows whether the resource is compatible or not with D and, in case, the *rankPotential* computed result.

After having shared his resource file, `user2` will receive a connection request from our PDA with our connection parameters and he can decide to establish a communication session with us. In such a way a small community is created.

resource	compatible (Y/N)	score
BC	Y	3
LN	Y	4
MSV	Y	4
SP	Y	9
WCH	N	-
FU	N	-

Table 1. Matchmaking results

3.1. Resource Based Services for the User

In order to promote resources sharing, additional user-oriented services are provided. First of all the sharing of a resource is the *wild card* to set up a virtual community of mobile users. In fact, if we share resources, the system will communicate each choice attempt for services we expose. Then we can decide to establish a private session of communication among these users by exchanging short messages with them. The prototype allows to implement an elementary recommendation system. In fact if a user enters the hotspot range and decides to share her resources by providing the system with a description of her offered services, the system will return a list with best proposals for her interests. In fact MAMAS on the *hotspot* will match the semantic description of shared resources with all other available ones in the entire area. Hence the zone server will suggest to the user the resources that better match ones she owns. For instance, `user2` can receive a proposal for specific services by the system according to his/her preferences. In particular the hotspot will match the semantic description of `user2` offered resources with all the ones both available in the art gallery and stored in its database. For each resource it will compute the rank value and will suggest to `user2` only best results.

Notice that such basic recommendation system service can be used also to suggest, for instance, possible visiting paths within the museum, if they are described and stored in the *hotspot*. In order to explain further features of the system, available when a user decides to share her resources, we suppose `user2` shares her **BC** document file. Immediately the hotspot starts a recommendation process for `user2`. In particular the zone server will match the semantic description of **BC** with all the descriptions of resources in its database (**LN**, **MSV**, **SP**, **WCH**, **FU**). With respect to our example, table 2 ensues.

resource	compatible (Y/N)	score	location
LN	Y	1	room A - floor 2
MSV	Y	1	room B - floor 2
SP	Y	6	room A - floor 1
WCH	N	-	-
FU	N	-	-

Table 2. Static recommendation results

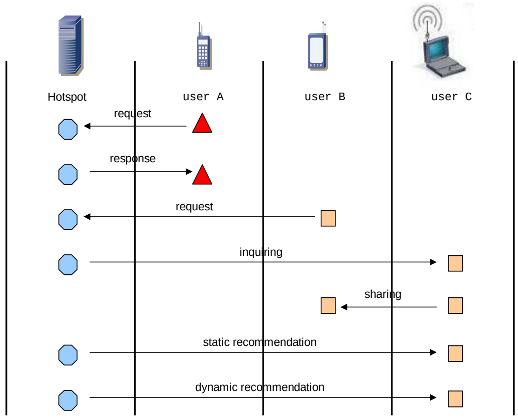

Figure 4. Static and dynamic recommendation feature

The best matched resources are available in the museum. Then the system will suggest to `user2` to visit rooms where they are located. The recommendation feature also works in a dynamic way. The hotspot is able to suggest to `user2` possible requests to be submitted to the system. It will match the `Painting` ⊓ ∀`hasStyle.Dadaism` ⊓ ∀`hasTechnique.Oil` description with semantic descriptions of other shared resources. Hence it will compute the best rank and will extract corresponding requests submitted by the users which shared them. Let us suppose that in the museum room `user3` and `user4` have just come in. `user3` shares two resources:

r1.3 *Resource n.1 by user3* classified as:
`Bust` ⊓ ∀`hasSubject.Religious`

r2.3 *Resource n.2 by user3* classified as:
`WorkOfArt`⊓∀`hasStyle.Symbolism`⊓∀`hasSubject.Icon`

and submitted the following request to the system:

d1.3 *Demand n.1 by user3* classified as:
`WorkOfArt` ⊓ ∀`hasSubject.Religious`

`user4` shared the resource:

r1.4 *Resource n.1 by user4* classified as:
`Painting` ⊓ ∀`hasStyle.Dadaism`⊓ ∀`hasSubject.StillLife`

and submitted the following requests to the system:

d1.4 *Demand n.1 by user4* classified as:
`Painting`⊓∀`hasStyle.Dadaism`⊓∀`hasSubject.Nature`

d2.4 *Demand n.2 by user4* classified as:
`Painting` ⊓ ∀`hasStyle.Dadaism`⊓ ∀`hasTechnique.Distemper`

The system will match the **BC** resource of `user2` with **r1.3**, **r2.3** and **r1.4**. Then it will determine the ranked list in table 3.

Hence the system recommends to `user2` requests **d1.4** and **d2.4** submitted to the hotspot by `user4`. In fact **r1.4** resource shared by `user4` best matches **BC** resource managed by `user2`. Hence, even if `user2` does not submit

resource	compatible (Y/N)	score
r1.4	Y	1
r2.3	Y	6
r1.3	N	-

Table 3. Dynamic recommendation results

any explicit profile description to the *hotspot*, the system tries to identify her preferences. Notice that static and dynamic recommendation features allow an elementary and implicit user profiling implementation. In fact without inserting any profile, the user exposes to the system her interests by means of resources she owns and wishes to share in the ad-hoc virtual community. Then the system proposes to the user a collection of most specific services based on preferences. The system does not force the user to insert her profile for selecting suitable contents but equally succeeds to extract possible services in her interests.

4. Related Work

There is a widespread request for an increase of discovery features in wireless contexts like Bluetooth piconets. In [2] the need for discovery mechanisms more powerful than those of the original standard, inadequate for modern ubiquitous scenarios, was clearly pointed out for the first time. In recent years dynamic distributed systems have been developed adopting various technologies and for different purposes. In [6] a Jini-based distributed agent framework is used in a hybrid agent oriented-service oriented approach, whereas in [14] semantic user profiles are introduced to increase matching level of services. In [12] an example of collaborative environment is presented, where ontologies are used to infer new information about mobile users profile. We believe that existing semantic service discovery architectures have some limitations which make them unsuitable for a widespread use in ad-hoc networks. In a mobile environment, where subjects on-line are continuously in evolution, modeling really peer to peer interaction calls for a common vocabulary to classify semantic descriptions of services. In fact two or more clients in the piconet who want to share information must have a common way for describing them. Existing service discovery systems do not support a well defined common ontology infrastructure. In fact architectures like Jini allow to ”capture” the ontology among services by means of mechanisms like Java classes which are difficult to be widely adapted. This limitation, as admitted in [6] and in [5], is due to the lack of shared ontology support. In [5] it is assumed that a client request is described by means of the same ontology a service uses for describing itself. This assumption is fundamental because it restricts the discovery only to services classified in the same manner. In [5] there is no mention of the technique to obtain this objective. Here we proposed a simple method for ontology matching prior to service discovery. The preliminary ontology matching grants a quick restriction of the available services only to those semantically suitable. Semantic service discovery via matchmaking in the Bluetooth framework was investigated in [2]. Also in this paper the issue of somehow ranking and proposing approximate matches in the absence of exact matches was discussed, but as in the previous papers no formal framework was given. Instead, a logical formulation is expected to allow devising correct algorithms to classify and rank matches.

In [14] a mobile environment is presented where semantic services are matched against semantic user profiles. In it, if there is no intersection between user interests and service offers, we conclude the user is not interested in the service. A complete and integrated solution for matching degree determination is absent. In [13] home appliances are divided into three classes according to their computational capabilities. Such classification imposes to distinguish service discovery protocol functions. Furthermore several assumptions are done about services identification. A catalogue service is employed for available services classifications and scope of the search is limited to discovery device type, service type or attributes. No semantic approaches are presented to solve limitations of syntactic device discovery. With respect to SDP on Bluetooth, knowledge representations techniques allow to obtain the same features of communication framework which are presented in SDP@HA. In fact we use an hybrid client/server architecture in sessions establishment but also peer to peer in contents sharing among hosts. Therefore in [13] peer to peer communication occurs in a hardware mode and there is no references to the high level user mode knowledge sharing. Chen et al. in [6] present an hybrid approach, agent/service oriented, to perform dynamic service discovery in mobile environments based on Bluetooth-like devices. For such purpose they use Jini platform and enrich it with a distributed agent layer. In fact Jini Lookup Service does not solve some important service discovery problems. Therefore the provided framework may require too large computational resources to be easily adapted to a really mobile scenario. The agent software layer should perform semantic level service discovery or inexact matching, which is computationally heavy to run on a mobile device. Hence, as admitted by the authors, a proxy agent which resides in a computer on the wired side is needed. The handheld devices are responsible only for rendering GUI display. Furthermore there is no mention to the solution of inexact matching problem. No formal methods to determine approximate matches are outlined. The system is strictly client server. It does not allow to implement a real P2P scenario. The sharing of resources managed by a network client with other mobile hosts is not expected, then it can be obtained only by loading shared services into a local database and by registering them into Jini Lookup Service. This is a big restriction as it makes not possible a direct communication among two or more peers in the ad-hoc network by-passing Jini Lookup or any broker agent. The spontaneous and occasional collaboration among mobile users is investigated in [12]. Here a collaborative context is described where a matchmaking service communicates with a localization service, which discovers all the MAC addresses of the mobile devices in the environment. Matchmaking service compares the user profiles associated to those MAC. Thus we do not have a close integration between discovery phase and matching phase. A merging of the proposed matchmaking system in a complex semantic service discovery architecture is still lacking. As investigated in [15] a significant application of semantic ad-hoc networks can be made just for tourism, where a more efficient system is desirable for searching, delivering and sharing of information. After U-commerce, where the use of ubiquitous computing supports personalized transactions between an organization and its buyers, U-tourism has become the new perspective of tourism. In spite of lack of information technology to support tourists especially when they are making a visit, there is a widespread interest for personalized virtual guides. In [15] there is an articulated proposal for such a system, but it is exclusively addressed to tourist purposes. Hence the proposed architecture is not suitable in different scenarios like U-commerce contexts or home wireless networks.

5. Conclusion and Future Work

In this paper we have exploited KR techniques and technologies to enrich the capabilities of the SDP in Bluetooth. Adding information modeled using languages with a well-defined formal semantics, we have made the SDP able to manage also non-exact matches between the requested service (resource) and the offered ones. In such a way a semantic layer has been integrated in the existing standard SDP for Bluetooth allowing a semantic-based matchmaking process.

The approach extends the basic SDP to discover and rank both resources and advanced peer services (as for the recommendation and community), by adding reasoning mechanisms to the discovery process. Notice that the proposed framework also allows to use pure Bluetooth services without any troubling of the original standard.

The system, developed within the CNOSSO project, adopts these enhanced features and uses them to provide various user-oriented services, which benefit of the KR approach. In particular, beyond the classical P2P semantically-enabled resource sharing, here semantic-based recommendation system and community formation have been presented.

Under development is a Natural Language based querying process facilitator [8] involving both the hotspot and the mobile clients.

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