# RFID Meets Bluetooth in a Semantic Based U–commerce Environment

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## ABSTRACT

We present a novel resource discovery framework for u-commerce. Both the original RFID data exchange protocol and the Bluetooth Service Discovery Protocol have been extended in order to enable support for the semantic annotation of products and goods. Given a request, the approach we propose allows an enhanced discovery process exploiting the semantics of resource descriptions available in a u-marketplace. The enhancement is backward compatible with both the original discovery protocols, thus allowing the smooth coexistence of the resource discovery and/or identification approaches. We present and motivate our approach in an innovative u-commerce framework, and show its benefits.

## Categories and Subject Descriptors

H.3 [**Information Storage and Retrieval**]: Miscellaneous; E.2 [**Data Storage Representations**]: [object representation]

## General Terms

Algorithms, Standardization

## Keywords

RFID, Bluetooth, Semantic Web, Matchmaking

## 1. INTRODUCTION

A growing number of people make use of information resources for business and leisure purposes on mobile systems. The ICT paradigm "anytime and anywhere for anyone" is nowadays close to reality. The next major step in ubiquitous computing is to enable information processing and communication for "anything", by embedding short-range mobile transceivers into a wide array of products and everyday items [16].

Information technology can assist users in a marketplace –both buyers and sellers– in discovering more alternatives and analyzing choices, thus giving to people more elements to make rational decisions [30]. From both user and industry standpoints, *u-commerce* (ubiquitous commerce) is the third evolutionary stage following e-commerce and *m-commerce* [17]. E-commerce (*i.e.*, Web-based commerce) allows transactions "at any time". In m-commerce (mobile commerce) transactions can also take place from "anywhere", since they are conducted over mobile telecommunication networks. Finally, in u-commerce the digital and physical worlds converge. Ubiquitous computing technologies allow novel interactions with products (the "anything" dimension) supporting personalized services (*i.e.*, for "anyone"). In [30] the impact of ubiquitous computing on the evolution of e-commerce was analyzed and a more detailed definition of u-commerce was given, based on the *ubiquity*, *universality*, *uniqueness* and *unison* network properties.

Radio-Frequency IDentification (RFID) technologies have been identified as a key element to bridge the gap between the digital networked world and the physical world [29]. Basically an RFID system consists of two main components: **(1)** a transponder to carry data (*tag*) which is located on the object to be identified –this normally consists of a coupling element (such as a coil, or a microwave antenna) and an electronic microchip; **(2)** an interrogator (or *reader*) to receive the transmitted data (generally integrated on a handheld device). Low-cost tags can be attached to objects unobtrusively, preserving their normal appearance and functions. They usually contain an unique item identification code, which can be read by RFID readers. Traditional RFID applications have been focused on supply chain management and asset tracking [31]. Industry standards for RFID technologies emerged in latest years, due to efforts of organizations like the EPCglobal consortium [12].

Ad-hoc networks composed by mobile devices and objects monitored through RFID have inherently high volatility. Hence, in ubiquitous contexts, information and descriptions about services/resources are often unavailable because the location of nodes could change continuously and unpredictably [6]. Therefore dynamic and flexible Service Discovery (SD) techniques become highly desirable.

Establishing common vocabularies for describing available


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resources is also important for an effective contextual service provisioning in ubiquitous computing [28]. Existing service discovery methods for mobile scenarios use string matching, which is largely inefficient in ad-hoc environments. Users need to submit articulate requests and to receive adequate answers [8]. In order to achieve this goal, we adapt ideas and technologies from the Semantic Web for a u–marketplace, where objects endowed with RFID tags have been dipped into Bluetooth mobile ad-hoc networks (MANET). Building on previous works that enhanced the basic discovery features of Bluetooth with semantic-based discovery capabilities [24], in this paper we focus on an extension of EPCglobal specifications for RFID tag data standards, providing semantic-based value-added services, and present its deployment in an advanced u–commerce setting.

The remaining of the paper is structured as follows. In Section 2 the approach to semantic-based u–commerce is presented. Next, in Section 3 basics of reasoning in Description Logics is introduced. Furthermore Section 4 refers to the enhanced Bluetooth SDP proposed in [24] whereas Section 5 outlines proposed modifications to the RFID data exchange protocol. In Section 6 a case study clarifies the proposed framework. Discussion on related work in Section 7 and conclusion in Section 8 close the paper.

## 2. FRAMEWORK AND APPROACH

In [1] it was observed that Bluetooth SDP is largely inefficient when it comes to complex requests. This is a strong limitation in view of the incoming transmission capabilities increase, devised in new drafts of the standard. A more advanced service discovery protocol is then desirable, able to cope with rich descriptions associated to resources. To this aim, in [24] a backward-compatible enhanced Bluetooth semantic-based discovery protocol was introduced.

On the other hand, currently RFID technology [27] is used merely as a link between physical objects and a "virtual counterpart" [23] in the digital world. Tags only store an identification code, which is used as a key to retrieve relevant properties of the object from an information server, through a networked infrastructure. Several techniques have been proposed for advanced exploitations of the identification and monitoring capabilities provided by RFID systems. No formal frameworks, however, have been devised yet for those contexts based on mobile ad-hoc networks involving resources equipped with RFID technologies.

Here we propose an extension of EPCglobal standards [27] enabling semantic-based services in a u–commerce framework. Nevertheless, protocols to read/write tags have been preserved maintaining original code-based access keeping a backward compatibility with legacy applications practically without any modification.

In the proposed solution a middleware "interconnects" the enhanced Bluetooth service discovery in [24] and RFID-based infrastructures at the application layer, allowing to provide high level services to the user in a u–environment. The approach is conceived to create a unified framework, as depicted in Figure 1.

In what follows, ideas behind the proposed system are briefly sketched. In a generic u–marketplace a good can describe itself by means of a semantic annotation stored in the RFID tag it is associated with. When a good is picked up, the user implicitly makes a choice, interacting with the marketplace. That is the user selection is an implicit request to

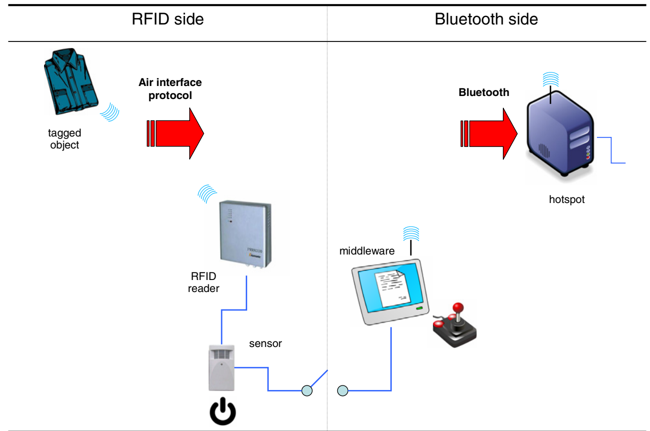


**Figure 1: Proposed framework components**

the system for resources similar to the picked one or to be combined with. The RFID reader scanning characteristics of the selected good enables a further discovery phase. It exploits the semantic based Bluetooth SDP in order to discover and return to the user best matching resources within the u–marketplace whose semantically annotated descriptions are stored in the shopping mall server.

A semantic-based approach would provide several benefits w.r.t. traditional ones, justifying higher complexity. As shown in Figure 2, different information fragments –related both to product properties and processes it is subjected to– could be added or updated in real time at each stage of product life cycle. That information would then be immediately available in later stages, without resorting to a particular support infrastructure. Such an approach would improve traceability during production and distribution, facilitate sales and post-sale services, and finally provide means for more efficient recycling and disposal [32]. Similarly to the original vision of the Semantic Web as proposed by Tim Berners Lee *et al.*, in order to enable automated knowledge management and integration for such a wide array of activities, we use formal ontologies and describe items w.r.t. them.

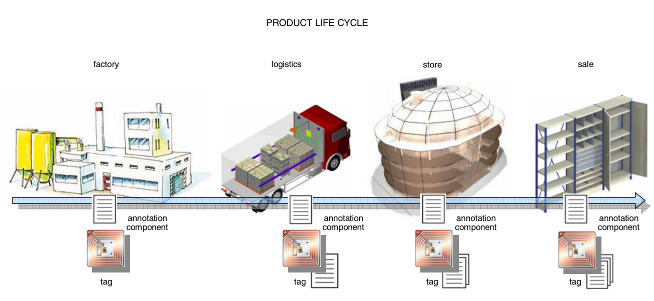


**Figure 2: Progressive semantic annotation in a generic product life cycle**

## 3. REASONING IN DESCRIPTION LOGICS

In the rest of the paper we will assume the reader be familiar with basic syntax and semantics of Semantic Web languages –in particular OWL [22]– and of Description Logics (DLs) [2]. Here we formalize examples by adopting DL syntax instead of OWL for the sake of compactness. Nevertheless all the semantically annotated resources, as well as the ontology employed to model them, can be easily rewritten using OWL-DL or DIG [3] formalisms (see later on for further details). In particular in our prototype we refer to DIG syntax instead of OWL-DL because it is less verbose and more compact.

It should be noticed that DL-based systems usually only provide two basic reasoning services:

**Concept Satisfiability** $\mathcal{T} \models C \not\sqsubseteq \bot$: given a domain ontology $\mathcal{T}$ (for Terminology) and a description $C$ (for concept), is the information represented by $C$ consistent with the one in $\mathcal{T}$?

**Subsumption** $\mathcal{T} \models C_1 \sqsubseteq C_2$: given a ontology $\mathcal{T}$ and two descriptions $C_1$ and $C_2$, is the information in $C_1$ more specific than the one represented by $C_2$ with respect to what is modeled in $\mathcal{T}$?

In a semantically-enabled resource retrieval scenario, where a matchmaking process between a request –described by $D$– and each of the available resources –represented by $C$– is needed, using subsumption it is possible to establish if $C$ is more specific than $D$, $\mathcal{T} \models C \sqsubseteq D$. If the previous relation holds, then the information $C$ associated to the retrieved resource completely satisfies the one requested by $D$, *i.e.*, an *exact match* occurs. With Concept Satisfiability the discovery of incompatible resources with respect to the request can be performed. If $D \sqcap C$ is not satisfiable w.r.t. the ontology $\mathcal{T}$, then $C$ is not compatible with the request.

Unfortunately *exact matches* cannot be deemed the only useful, as they will be probably rare. Given a request and a set of resources, usually $C \not\sqsubseteq D$ and $D \sqcap C$ w.r.t. $\mathcal{T}$ . That is, the resource does not completely satisfy the request but it is compatible with it. Hence, a metric is needed to establish "how much" the resource $C$ is compatible with the request $D$ or, equivalently, "how much" it is not specified in $C$ to completely satisfy $D$, in order to make the subsumption relation $C \sqsubseteq D$ true. In [11] ***rankPotential*** algorithm was proposed, for the $\mathcal{ALN}$ subset of DLs, able to evaluate this measure. Given an $\mathcal{ALN}$ ontology $\mathcal{T}$ and two $\mathcal{ALN}$ concepts $C$ and $D$ both satisfiable in $\mathcal{T}$, *rankPotential* $(C,D,\mathcal{T})$ computes a *semantic distance* of $C$ from $D$ w.r.t. the ontology $\mathcal{T}$.

If some requirements in the request $D$ are in conflict with the resource $C$, the *rankPotential* cannot be applied. Nevertheless, in looking for least unsatisfactory proposals when recovering from an initial "no potential match", a partial match could be "not so bad"! In [11] the ***rankPartial*** algorithm was proposed for ranking incoherent pairs of supplies and requests. Given an ontology $\mathcal{T}$and two concept expressions $D$ and $C$, both satisfiable with respect to $\mathcal{T}$, if $D$ is not compatible with $C$ *i.e.*, their conjunction is not satisfiable with respect to $\mathcal{T}$, then *rankPartial* returns a score measuring the semantic incompatibility of $D$ and $C$.

The communication with state of the art DL reasoners is performed using an HTTP interface developed by the Description logics Implementation Group (DIG)[3]. DIG prescribes the use of POST method for HTTP requests/responses allowing to identify the reasoner, to manage the Knowledge Bases (KBs), to add information to a KB and to retrieve information from it via the classical TELL/ASK mechanism. The language to be used for communication is an XML-based language tailored to represent all DL constructs and all possible queries (ASKs) to be posed to a DL KB.

| PDU name | ID | Parameters |
|---|---|---|
| *SDP_OntologySearchRequest* | 0x08 | *OntologySearchPattern*<br>ContinuationState |
| *SDP_OntologySearchResponse* | 0x09 | *TotalOntologyCount*<br>*OntologyRetrievedPattern*<br>ContinuationState |
| *SDP_SemanticServiceSearchRequest* | 0x0A | *SemanticResourceDescription*<br>*ContextAwareParam1*<br>*ContextAwareParam2*<br>MaximumResourceRecordCount<br>ContinuationState |
| *SDP_SemanticServiceSearchResponse* | 0x0B | TotalResourceRecordCount<br>CurrentResourceRecordCount<br>*SemanticResourceRecordHandleList*<br>ContinuationState |

**Table 1: PDUs and respective parameters**

# 4. SEMANTICS ENHANCES BLUETOOTH SERVICE DISCOVERY PROTOCOL

The framework proposed in [24] allowed the management of both syntactic and semantic discovery of resources, by integrating a semantic layer within the OSI Bluetooth stack at application level. The Bluetooth standard was enriched by new functionalities which permitted to maintain a backward compatibility (handheld device connectivity), adding the support to matchmaking of semantically annotated resources.

We associated unused classes of 128 bit UUIDs in the original Bluetooth standard to mark each specific ontology and we called this identifier *OUUID* (Ontology Universally Unique IDentifier). By means of the OUUID matching, the context was identified and a preliminary selection of resource referring to the same request's ontology was performed.

Within the marketplace, we assume each good is semantically annotated and a description of the resource is stored within a shop server (hotspot) as a database record labeled with a unique 32-bit identifier. Each record contains general information about a single semantic enabled resource and it entirely consists of a list of resource attributes. In addition to the OUUID attribute, there are *ResourceName* (a human–readable name for the resource), *ResourceDescription* (the resource description expressed using DIG syntax) and a variable number of *ResourceUtilityAttr_i* attributes, *i.e.*, numerical values used according to specific applications. In general, they are associated to context-aware attributes of a resource [20]; in the current implementation we adopt, for instance, the price of the good.

In [24], by adding four SDP PDUs *SDP_OntologySearch* (request and response) and *SDP_SemanticServiceSearch* (request and response) to the original standard (exploiting not used PDU ID), together with the original SDP capabilities, further semantic enabled discovery functionalities had been introduced. The overall interaction was based on the original SDP in Bluetooth. No modifications were made to the original structure of transactions. There was just a different use of the SDP framework. Their parameters are shown in Table 1.

# 5. SEMANTICS ENHANCES EPC RFID STANDARD

Similarly to the Bluetooth SDP enhancement, we add semantic based functionalities to a RFID application infrastructure. For simplicity, in our initial prototype we use a single RFID reader. Hence we do not take into account interferences among readers and the arbitration process needed to assign the scan of a tag detected by more devices.

In our framework we refer to RFID transponders conforming to the EPC standard for class I - second generation UHF tags [27]. Memory of a EPC class I Generation-2 UHF RFID tag is divided in four logical banks [13]:

**1. Reserved**. It is optional; if present, it stores 32-bit kill and access passwords.

**2. Electronic Product Code (EPC)**. It stores, starting from address 0: **(a)** 16 bits for a Cyclic Redundancy Check (CRC) code; **(b)** a 16-bit Protocol Control (PC) field, composed of *(I)* 5 bits for identification code length, *(II)* 2 bits reserved for future use and *(III)* 9 bits of numbering system identification; **(c)** an EPC field for the identification code.

**3. Tag identification (TID)**. It stores at least: **(a)** 8 bits having fixed binary value $11100010_2$; **(b)** 12 bits for tag manufacturer identification; **(c)** 12 bits for tag model identification. This bank may be enlarged to store other manufacturer or model-specific data (*e.g.*, a tag serial number) that could allow to recognize the support for optional characteristics and protocol commands.

**4. User**. An optional bank that stores data defined by the user application. Memory organization is user-defined.

EPCglobal Generation-2 UHF RFID air interface protocol is an *Interrogator-Talks-First* (ITF) protocol: tags only reply to reader commands. Here we briefly outline the protocol features required to better understand our work.

A RFID reader can preselect a subset of the tag population currently in range, on the basis of user-defined criteria, by means of a sequence of *Select* commands.

**Select** command sends a bit string to all tags in range. Each tag will compare it to a memory area specified by the reader, then it will set/reset one of its status flags according to the comparison result (match/no-match). Parameters are as follows: **(1)** *Target* determines which tag status flag will be modified by the Select command; **(2)** *Action* tells how a tag is required to modify the flag (set, reset, do nothing) for either positive or negative match outcome (a three-bit field is thus required to encode the six cases); **(3)** *MemBank* indicates what memory bank must be compared; **(4)** *Pointer* is the address of the first bit of MemBank tag memory area that must be compared; **(5)** *Length* is the length of the bit string to be compared; **(6)** *Mask* is the bit string to be compared with the content of the memory area selected by MemBank, Pointer and Length values; **(7)** *Truncate* tells the tag to send only part of its EPC code in the following protocol step; **(8)** *CRC* used for command data integrity protection.

After this phase, the inventory loop begins. In each iteration the reader isolates one tag in range, reads its EPC code and has the opportunity to access its memory content. Among available commands, only *Read* and *Write* are relevant for our purposes.

**Read** command allows to read from one of the four tag memory banks. Parameters are: **(1)** *MemBank* indicates the bank data must be read from; **(2)** *WordPtr* points to the first 16-bit memory word to be read; **(3)** *WordCount* is the number of consecutive 16-bit memory words that must be read (if it is 0, then the tag will send data stored up to the end of the memory bank); **(4)** *RN*, random number used as access transaction identifier between reader and tag; **(5)** *CRC*

**Write** command allows a reader to write a 16-bit word to one of the four tag memory banks. Its structure is similar to READ.

## 5.1 Protocol evolution

In the proposed approach, we use two reserved bits in the EPC area within each tag memory. The first bit –at $15_{hex}$ ($10101_2$) address– is exploited to indicate if the tag has a user memory (bit set) or not (bit reset). The second one –at $16_{hex}$ address– is set to mark semantic enabled tags. In this manner, by means of a SELECT command (see Table 2), a reader can easily distinguish semantic based tags.

The EPC standard for UHF - class I tags imposes the content of TID memory up to $1F_{hex}$ bit is fixed. Optional information could be stored in the further additional TID memory. Generally these information are serial numbers or manufacturer data. Hence we use the TID memory area starting from $100000_2$ address. In that area we store the identifier of the ontology w.r.t. the description contained within the tag is expressed. Making the ontology support system proposed for the semantic based SDP in Bluetooth [24] compliant with RFID systems, we set a bidirectional correspondence among OUUIDs stored in RFID transponders and those managed by Bluetooth devices. Hence we adopt a 128 bit structure for the RFID OUUIDs analogous to the one used by the Bluetooth SDP in its semantic enabled version. Finally, in order to retrieve the OUUID value stored within a tag, a reader will exploit a READ command by adopting parameters shown in the following Table 3.

Contextual parameters (whose meaning depends on the specific application), will be stored within the user memory banks of the tag together with the semantically annotated description of the good the tag is clung to. Due to the strict amount of memory available, the resource description has to be coded. We use a simple compression technique in order to reduce the memory occupancy. Recall that semantically annotated descriptions are expressed in DIG syntax –which is an XML formalism [3]– hence because of verbosity of that format, the use of a compression algorithm is needed. For the sake of brevity, here we omit characteristics of the adopted DIG encoding tool. By exploiting it, to store a semantically annotated description with a medium complexity (up to 50 concept and roles) we estimate a memory occupancy which does not exceed 8 kbit.

The extraction and the storing of a description carried out on a tag, can be performed by a reader by means of one or more READ or WRITE commands. Both commands are obviously compliant with the RFID air interface protocol. In the Table 4, parameters of the READ command for extracting a compressed description are reported.

Together with previous features, the EPCglobal standard provides a support infrastructure for RFID applications: the *Object Naming Service (ONS)* [14]. It allows to locate metadata and services associated to a specified EPC. They are provided by the authority managing the object family the tag belongs to. The ONS is based on the Domain Name System adopted to solve symbolic Internet addresses. In particular, ONS format for requests and replies must adhere to DNS standards. Basically the system performs the translation of the EPC code into a domain name and results of this interrogation correspond to valid records of DNS resources.

In our approach the ONS mechanism is considered as a supplementary system able to grant the so called ontology support. Recall that the whole proposed system is basically structured as a MANET. Hence, in case the reader does not manage the ontology w.r.t. which is expressed the description within the tag, it needs an Internet connection in order

| PARAMETER | Target | Action | MemBank | Pointer | Length | Mask |
|---|---|---|---|---|---|---|
| VALUE | $100_2$ | $000_2$ | $01_2$ | $00010101_2$ | $00000010_2$ | $11_2$ |
| DESCRIPTION | SL flag | set in case of match, reset otherwise | EPC memory bank | initial address | number of bit to compare | bit mask |

**Table 2: SELECT command able to detect only semantic enabled tags**

| PARAMETER | MemBank | WordPtr | WordCount |
|---|---|---|---|
| VALUE | $10_2$ | $000000010_2$ | $00001000_2$ |
| DESCRIPTION | TID memory bank | starting address | read up to 8 words (128 bit) |

**Table 3: READ command able to extract OUUID from the TID memory bank**

to retrieve the related DIG file. For this purpose we use the ONS service and we hypothesize to register within the *EPCglobal Network Protocol Parameter Registry* the new service suffix *dig*. Recall that the registry maintains all the registered service suffixes (*ws* for a Web Service, *epcis* for a EPCglobal Information Service (providing authoritative information about objects associated with a EPC code), *html* for a Web Page of the manufacturer). The new *dig* suffix will indicate a service able to retrieve ontologies with a specified OUUID value. Of course the same could be done for OWL or any other ontological language.

In case of EPC derived from the GS1 standard[1], we assume that the pair of fields used for ONS requests and referred to the manufacturer and to the merchandise class of the good, will correspond to a specific ontology. In fact that pair identifies exactly the product category. Two goods with the same values for that field parameters will be surely homogeneous or even equal. Nevertheless the vice versa is not verified. Products belonging to the same category, described by means of the same ontology, could have different values for parameters. This is the case of similar goods with different manufacturer or manufactured by the same producer but belonging to different merchandise classes.

## 5.2 The role of semantics in the proposed approach

The *rankPartial* and *rankPotential* algorithms cited above are used in matchmaking scenarios to retrieve resources interesting for the user by means of the semantic enabled extension of SDP in Bluetooth. In order to provide a general framework suitable for various applications, we support both potential and partial matches.

In our RFID scenario a user request is already built starting from the initial interest in a specific resource; furthermore it is possible the system suggests most similar goods but also goods to be used in combination with the picked up ones. Best association among resources can be retrieved by means of a rank partial approach. Nevertheless note that two resources in a partial correspondence do not satisfy criteria of a good match in an automatic fashion: some verifications have to be performed about specific features which make them not completely compatible. The system performs a preliminary control about the class determining the incompatibility. If it is possible a combination with the request, the hotspot will provide two different lists of resource records (by means of two different *SDP_SemanticService SearchResponse* PDU) respectively for resources in a potential correspondence with the request and in a partial one.

[1]GS1 (originally EAN.UCC) is an international organization interested in design and distribution of industrial standards for increasing the quality of good and service exchanges. It introduced the bar code identification of products and services.

In advanced mobile scenarios, the match between a request and a provided resource involves not only the description of the resource itself but also data-oriented properties. It would be quite strange to have an interaction among mobile hosts in a u–commerce context without taking into account first of all price and quantity, but also remaining device battery power, among others. Hence, the overall match value should depend not only on the semantic distance between the description of the demand and of the resource, but also on those subsidiary values. An overall utility function has to combine all these parameters to give a global value representing the match degree [24].

The utility function allows to perform a post filtering process of matchmaking results. In the proposed case study (see the next section for further details) where a virtual dressing room is modeled and used, the utility function is based on two contextual parameters: the first one is the price of the good (in US dollars) whereas the second one is the so called "body area". This parameter is referred to a specific part of the body, as shown in Table 5.

The adopted utility function has a double expression:

$$f(s\_match, p_R, p_O, a_R, a_O) = \begin{cases} 1: f_{POT}(pot\_match, p_R, p_O, a_R, a_O) \\ 2: f_{PAR}(par\_match, p_R, p_O, a_R, a_O) \end{cases}$$

(1): if the demand is compatible with the supply
(2): if the demand is incompatible with the supply
where *pot_match* and *par_match* respectively are the potential and partial match values, $p$ is the price, $a$ the body area. The index $R$ is referred to the request whereas $O$ to the supply.

Adopted formulas for the utility function are reported in what follows:

$$f_{POT} = \frac{pot\_match}{2} + \frac{p_O - (1+\alpha)p_R}{\gamma p_R} + tanh\frac{|a_R - a_O|}{\beta}$$

$$f_{PAR} = \frac{par\_match}{2} + \frac{p_O - (1+\alpha)p_R}{\gamma p_R} + \beta\left|\frac{1-|a_O - a_R|}{\delta + |a_O - a_R|}\right|$$

After simulation and experiments with human users, in this scenario we set these parameters respectively $\alpha = 0.1$, $\beta = 2$, $\gamma = 5$, $\delta = 0.5$. Smaller values of the utility function indicates better responses to the user request, *i.e.*, shorter distances between demand and supply. In both formulas the leading term is represented by the semantic match. The second component (common to both expressions) is related to the price of the good. The price imposed by the requester is increased with an $\alpha$ factor because, usually, the demander is willing to pay up to some more than what she originally specified on condition that she finds the requested item, or something very similar. The last addend depends on the body area and it is differently used in the proposed formulas. In that one for potential matches (discovery of resources similar w.r.t. the request) will be penalized offers of clothing related to body areas different w.r.t. the one specified with the request. Differently, in the second formula will be penalized resources covering the same body area of the request and will be favored that ones referred to adjacent areas.

| PARAMETER | MemBank | WordPtr | WordCount |
|---|---|---|---|
| VALUE | $11_2$ | $000000000_2$ | $00000000_2$ |
| DESCRIPTION | user memory bank | starting address | read up to the end |

**Table 4: READ command able to extract the semantically annotated description from the user memory bank**

| Value | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Body area | hands | head | chest (outer layer) | chest (inner layer) | legs | feet |

**Table 5: Mapping of human body to values of context-aware resource attribute**

# 6. CASE STUDY

Figure 1 shows the main logical elements of the proposed architecture. A central role is covered by the interface component equipped with an integrated RFID reader as well as provided by Bluetooth connectivity. A middleware at the application layer is responsible of a joined cooperation between RFID and Bluetooth environments.

A zone resource provider (*hotspot*) keeps track of semantic-based services/resources within the u–marketplace; it interacts with a reader replying to its requests. In particular the hotspot is equipped with a DL reasoner. In our approach we adopt *MAMAS-tng* [11] which exploits *rankPotential* and *rankPartial* algorithms cited above.

The above logical framework can be adapted to different real scenarios with various physical devices involved. Figure 3 shows the implementation of a smart dressing room case study: the middleware runs in that case over a tablet computer within the dressing room which also integrates a Bluetooth client.

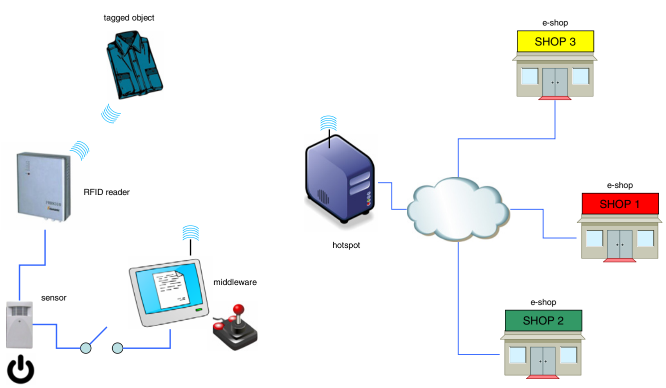


**Figure 3: Main components of the proposed case study architecture**

The proposed architectural framework and approach will be now illustrated and motivated with a prototype developed for our example scenario; as said before it refers to an apparel store. A typical interaction sequence is described in the following.

A customer enters a dressing room to try on an item she is willing to purchase. The system is able to assist her in discovering additional available items, either similar or suitable for combination with the selected one. Shop items are tagged with RFID transponders containing EPC, OUUID, encoded semantic description and contextual attributes, according to the enhanced RFID tag data standard described in Section 5. Ontologies shared on the web are used to describe tagged shop items, whose related descriptions are also available on the store web site. For our case study, we adopted a simplified apparel ontology (marked with a specific identifier we indicate $OUUID_A$). As explained in Section 5.2, price and body area are used as contextual attributes for shop items in our scenario.

After a request, the hotspot selects resource descriptions it stores referred to the specified ontology and performs the matchmaking process. Semantic description and context-aware attributes of available items can be collected by the enterprise back-end database, already deployed for supply chain and inventory management. Notice that each resource retrieval session starts after submission from client to server of the ontology identifier ($OUUID_A$), in order to agree on the resource category to be adopted in upcoming requests. Server host will process the incoming request at SDP layer whereas the smart dressing room acts as client. It is equipped with a sensor for user detection, an RFID reader and a tablet computer. The latter provides user interface and is endowed with Bluetooth communication capabilities for server interaction, through the enhanced Bluetooth SDP protocol described in Section 4.

Cooperation of RFID readers, sensors and Bluetooth devices is achieved through an agent-based, message-oriented middleware infrastructure. It has been built upon *IBM WebSphere RFID Tracking Kit* [7], which provides a basic framework for the orchestration of multiple heterogeneous devices in mobile applications. A semantic-based layer has been integrated in order to support features introduced by our approach. Sequence diagram in Figure 4 shows a typical use case for the proposed application.

Let us suppose the following scenario: *a young man has just got his first job as a bank clerk. He enters the apparel store to buy some elegant clothing. He notices a fine dark green jacket and decides to try it on.* Sensors detect the customer entering the dressing room. The RFID reader is triggered and reads data stored within the tag attached to the jacket, then it is deactivated again. Tagged description corresponds to an elegant, large-sized, dark green jacket, in mostly linen cloth, suitable for young adult men and fall climate, with buttons and five pockets. It can be expressed in DL formalism w.r.t. a reference ontology (not reported here for the sake of conciseness) as:

- $Jacket \sqcap = 1\ hasColors \sqcap \exists\ hasFastenings \sqcap \forall\ hasFastenings.Buttons \sqcap \forall\ hasMainColor.DarkGreen \sqcap \exists\ hasMaterials \sqcap \forall\ hasMainMaterial.Linen \sqcap \forall\ hasPattern.Plain \sqcap = 5\ hasPockets \sqcap \forall\ hasSize.Large \sqcap \forall\ hasSleeves.LongSleeves \sqcap \forall\ hasStyle.Elegant \sqcap \forall\ suitableForAge.YoungAdult \sqcap \forall\ suitableForGender.Male \sqcap \forall\ suitableForSeason.Fall$

Its equivalent DIG representation is stored on the RFID tag in a compressed encoding, along with the item EPC, ontology identifier $OUUID_A$ and its contextual parameters. In this case price is \$195 and body area value is 3.

*The customer is trying on the jacket, as usual in a dressing room. Meanwhile, the tablet touchscreen is activated and item details are shown* (see Figure 5) . *Those elements will*

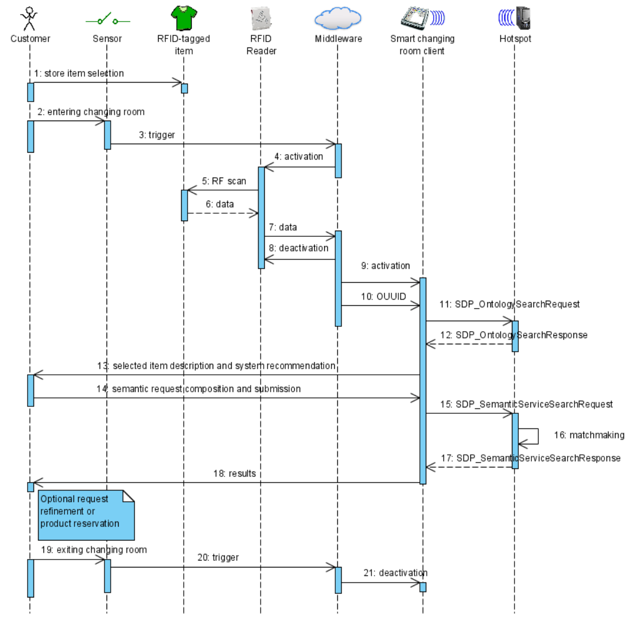


**Figure 4: Sequence diagram of a basic use case in our application**

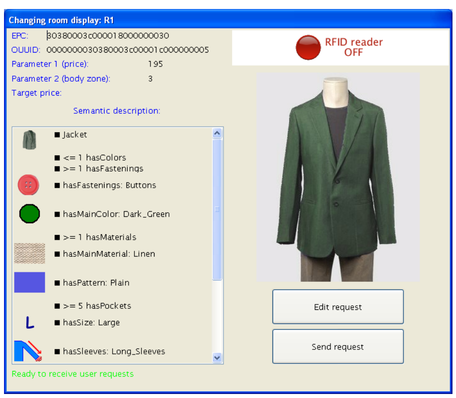


**Figure 5: Product details are read via RFID and shown to the user**

*be used by the customer for building his semantic request.* Let us note that it consists in a DL conjunctive query, where conjoined concepts represent the desired features. User can customize it through a graphical user interface that allows to add or remove features, as well as to set target values for contextual attributes.

Feature selection is performed by an intensional navigation of the reference ontology represented as a hierarchy of elements. A tabbed panel allows an easy navigation even in large ontologies. Users can concentrate on their current focus and at the same time can freely change the entry point through the upper tabs which record navigation history [9]. Pop-up menus and drag-and-drop are supported to further simplify user interaction.

*Customer substantially likes his jacket but he would like to search for similar ones. At the same time, he would like a pair of trousers fitting with that jacket. Therefore he sets a target price of \$200 and only removes the constraint on season from the system recommendation* (see Figure 6). The DL expression for user request thus becomes:

- **D:** $Jacket \sqcap = 1\ hasColors \sqcap \exists\ hasFastenings \sqcap \forall\ hasFastenings.Buttons \sqcap \forall\ hasMainColor.DarkGreen \sqcap \exists\ hasMaterials \sqcap \forall\ hasMainMaterial.Linen \sqcap \forall\ hasPattern.Plain \sqcap = 5\ hasPockets \sqcap \forall\ hasSize.Large \sqcap \forall\ hasSleeves.LongSleeves \sqcap \forall\ hasStyle.Elegant \sqcap \forall\ suitableForAge.YoungAdult \sqcap \forall\ suitableForGender.Male$

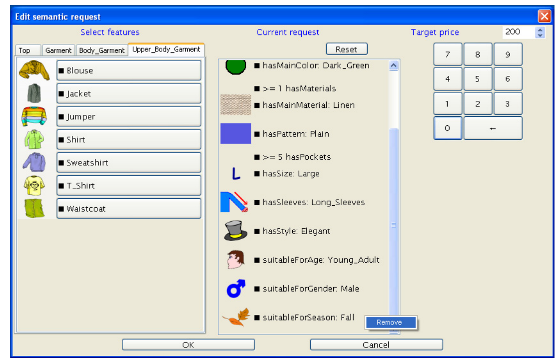


**Figure 6: GUI for semantic request composition**

*Customer confirms his request.* It is so translated into an encoded DIG description, w.r.t. the ontology marked as $OUUID_A$, and associated with user-supplied target values for contextual attributes. The request is encapsulated in a Bluetooth *SDP_SemantictServiceSearchRequest* PDU and submitted from the tablet computer in the smart dressing room to the shop hotspot.

Let us suppose the following products are available in the apparel store knowledge base:

- **S1:** an elegant, large-sized, gray suit, in mostly linen cloth, suitable for adult men and spring climate, with two button fastenings and ten pockets. Price is \$678; body area is 3:
$Suit \sqcap \forall\ hasMainColor.LightGray \sqcap \forall\ hasMainMaterial.Cotton \sqcap = 10\ hasPockets \sqcap \geq 2\ hasFastenings \sqcap \forall\ hasFastenings.Buttons \sqcap \forall\ hasPattern.Plain \sqcap \forall\ hasSize.Large \sqcap = 2\ hasLegs \sqcap \forall\ hasLegs.PipeLegs \sqcap \forall\ suitableForAge.Adult \sqcap \forall\ suitableForGender.Male \sqcap \forall\ suitableForSeason.Spring \sqcap = 2\ hasMaterials \sqcap \exists\ hasColors \sqcap \leq 1\ hasColors$

- **S2:** medium-sized blue jeans, suitable for casual young adult men and spring climate, with pipe legs and five pockets . Price is \$38; body area is 5:
$Trousers \sqcap = 1\ hasColors \sqcap \forall\ hasMainColor.MediumBlue \sqcap \geq 2\ hasFastenings \sqcap \leq 2\ hasFastenings \sqcap \forall\ hasLegs.PipeLegs \sqcap \forall\ hasMainMaterial.Jeans \sqcap = 1\ hasMaterials \sqcap \forall\ hasPattern.Plain \sqcap = 5\ hasPockets \sqcap \forall\ hasSize.Medium \sqcap \forall\ hasStyle.Casual \sqcap \forall\ suitableForAge.YoungAdult \sqcap \forall\ suitableForGender.Male \sqcap \forall\ suitableForSeason.Spring$

- **S3:** an elegant, large-sized, midnight blue jacket, in mostly linen cloth, suitable for young adult men and fall climate, with buttons and five pockets. . Price is \$190; body area is 3:
$Jacket \sqcap = 1\ hasColors \sqcap \exists\ hasFastenings \sqcap \forall\ hasFastenings.Buttons \sqcap \forall\ hasMainColor.MidnightBlue \sqcap \exists\ hasMaterials \sqcap \forall\ hasMainMaterial.Linen \sqcap \forall\ hasPattern.Plain \sqcap = 5\ hasPockets \sqcap \forall\ hasSize.Large \sqcap \forall\ hasSleeves.LongSleeves \sqcap \forall\ hasStyle.Elegant \sqcap \forall\ suitableForAge.YoungAdult \sqcap \forall\ suitableForGender.Male \sqcap \forall\ suitableForSeason.Fall$

- **S4:** an elegant, medium-sized striped lavender jacket, in mostly synthetic material, suitable for adult women and spring climate, with buttons and two pockets. Price is \$194; body area is 3:
$Jacket \sqcap = 3\ hasColors \sqcap \exists\ hasFacings \sqcap = 1\ hasFastenings \sqcap \forall\ hasFastenings.Buttons \sqcap \forall\ hasMainColor.Lavender \sqcap = 3\ hasMaterials \sqcap \forall\ hasMainMaterial.Synthetic \sqcap \forall\ hasPattern.Striped \sqcap = 2\ hasPockets \sqcap \forall\ hasSize.Medium \sqcap \forall\ hasSleeves.LongSleeves \sqcap \forall\ hasStyle.Elegant \sqcap \forall\ suitableForAge.Adult \sqcap \forall\ suitableForGender.Female \sqcap \forall\ suitableForSeason.Spring$

- **S5:** a pair of pure-cotton maroon trousers, suitable for elegant adult men and fall climate, with buttons and four pockets. Price is \$124; body area is 5:
$Trousers \sqcap \forall\ hasFastenings.Buttons \sqcap \forall\ hasMainColor.Maroon \sqcap = 4\ hasPockets \sqcap \forall\ hasSize.Medium \sqcap \forall\ hasStyle.Elegant \sqcap \forall\ suitableForAge.Adult \sqcap \forall\ suitableForGender.Male \sqcap \forall\ suitableForSeason.Fall \sqcap \forall\ hasMainMaterial.Cotton \sqcap \forall\ hasPattern.Plain \sqcap \forall\ hasLegs.PipeLegs \sqcap = 1\ hasColors \sqcap = 1\ hasMaterials$

- **S6:** an extra-large multi-colored striped shirt, in pure cotton cloth, suitable for casual adult men and summer climate, with short sleeves, buttons and no pockets.Price is \$40; body area is 4: $Shirt \sqcap \geq 4\ hasColors \sqcap = 1\ hasFastenings \sqcap \forall\ hasFastenings.Buttons \sqcap = 1\ hasMaterials \sqcap \forall\ hasMainMaterial.Cotton \sqcap \forall\ hasPattern.Striped \sqcap \leq 0\ hasPockets \sqcap \forall\ hasSize.ExtraLarge \sqcap \forall\ hasSleeves.ShortSleeves \sqcap \forall\ hasStyle.Casual \sqcap \forall\ suitableForAge.Adult \sqcap \forall\ suitableForSeason.Summer$

The hotspot performs the matchmaking as described in Section 5.2. Results are presented in Table 6. The second column shows the similarity match result computed via the *rankPotential* algorithm exploiting the ontology designed for finding similar goods, whereas the third one presents combination matches computed via the *rankPartial* exploiting the ontology designed for finding associations of goods. Finally, results of the overall utility function application are shown in the last column. Being a distance measure, a lower value means a better match.

Note that $S3$ is by far the best supply for similarity match. Among others, $S4$ is incompatible with $D$, as they both represent jackets but $S4$ is a women garment. Body area proximity and price, on the contrary, favor $S6$ over $S5$ and $S2$, despite a slightly higher semantic distance from $D$. Also note that, among combinations, the women jacket has the better *rankPartial* value: it is quite sane a female jacket is semantically better than a trouser w.r.t. the request. Nevertheless the utility function degrades this item to the last position in the whole ranking.

Ranked resource list is returned to the customer by means of a *SDP_SemantictServiceSearchResponse* PDU. For each retrieved resource a picture is displayed along with matchmaking score, price and description, as shown in Figure 7.

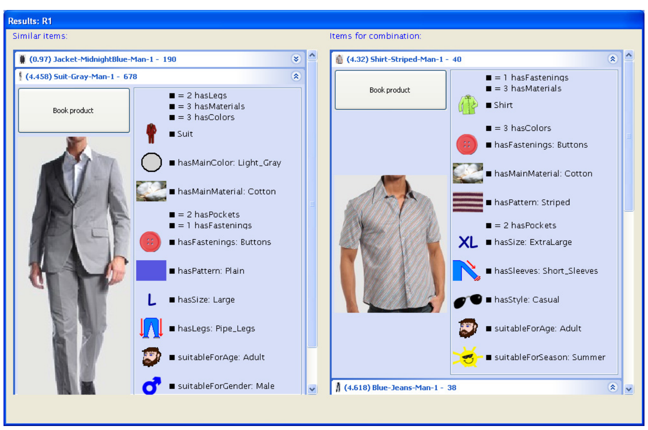


**Figure 7: Retrieved resources are shown to the user**

*Customer can reserve one or more items.* Reservation request will then be sent to the hotspot, so that items could be prepared in advance[2]. *Otherwise, if customer is not satisfied with the results, he can refine his request and issue it again. Eventually our customer exits the dressing room to finalize his purchase.* Sensor detects the exit event and touchscreen is turned off. The dressing room is now ready for another customer.

A thorough experimental evaluation of system performance in our approach requires a complete implementation onto a testbed with real semantic-enabled RFID devices. That would only be possible through partnership agreements with device manufacturers/integrators. Tests are ongoing with our software-simulated RFID platform. In early experiments of reading and decoding compressed semantic resource annotations from simulated RFID tags, a read rate of nearly 500 tags/s was obtained. Whereas independent sources estimated read rates ranging from 7 to approximately 100 tags/s with Class 1 Generation 2 UHF RFID systems in typical conditions [18]. This is a preliminary evidence that our approach does not impair performance of semantic-based RFID applications w.r.t. traditional ones. The latter, in turn, will not suffer any direct performance degradation from the newly introduced features, as they will read the EPC only.

[2]This part of the application has not been implemented yet, but it is trivially achievable exploiting the above infrastructure.

# 7. RELATED WORK

A decentralized approach is fundamental for applications aiming to be really ubiquitous. A support infrastructure built upon powerful devices and expensive large-scale network links should not be a mandatory prerequisite, even though it may be exploited when available. Vasudevan envisions such a flexible and context-aware ubiquitous service infrastructure in [28]. The biggest obstacle toward decentralized approaches is seen in the too high cost of RFID tags with sufficient memory. Notwithstanding, the growing demand of RFID solutions and the constant progress in micro devices (Moore's law) allow to expect that passive RFID tags with higher memory capacity will be available at low cost in the next few years [5].

In [10] is presented a pervasive architecture for tracking mobile objects in real-time for supply chain and B2B transaction management. A global and persistent IT infrastructure is necessary in order to interface RFID system within partner organizations through the Internet. These requirements make the approach less suitable for mobile B2C and C2C scenarios. An XML formalism named Physical Markup Language (PML) is used to describe objects and processes. While creating expressions and extending the basic language, it does not exploit any semantics of resource descriptions. Conceptual domain knowledge is embedded in the PML specification itself. It only allows string matching resource discovery.

Such an approach is followed in [4] to enhance a 3D scene visual analysis system. RFID tags attached to objects in the environment are used to identify items and to retrieve their geometrical models, stored in a database as XML documents. Models describe geometrically invariant configurations that help the system in recognizing location and orientation of objects in the observed space.

Römer *et al.* [23] present two frameworks for ubiquitous computing applications using smart identification technologies. Core design abstractions such as object location, neighborhood, composition, history and context make them flexible, and they were indeed adapted to several applications. Nevertheless, as admitted by the authors, scalability issues are present. They may be related to the virtual counterpart approach, which seems to be unsuitable to real mobile applications. A further limitation is that semantics of object properties and capabilities is not explicit, but it is encapsulated in either Java classes or Web Services. Jini and UDDI are used as service discovery protocols.

Several efforts have been put on exploiting RF technolo-

| Supply | Compatibility (Y/N) | *rankPotential* score | *rankPartial* score | $f(\cdot)$ |
|---|---|---|---|---|
| S1: Men gray suit | Y | 8 | - | 4.458 |
| S2: Men blue jeans | N | - | 9 | 4.618 |
| S3: Men midnight blue jacket | Y | 2 | - | 0.97 |
| S4: Women lavender jacket | N | - | 7 | 8.974 |
| S5: Men classic trousers | N | - | 9 | 5.204 |
| S6: Men striped shirt | N | - | 10 | 4.32 |

**Table 6: Matchmaking results**

gies to enhance *Human-Computer Interaction* (HCI) in wearable computer architectures. Hum [15] early introduced an OSI-like protocol stack he called *Fabric Area Network* (FAN), supporting a dynamic data routing between RFID tags deployed on garments and a single wearable base station. Different clothing layers can be associated to different applications, such as health monitoring (through sensors embedded in RFID tags) and personal security (by letting the FAN interact with RFID tags attached to user wallet and keys).

The paper of Schmidt *et al.* focuses on implicit HCI in pervasive computing, taking user activity in the real world as input to computers. In [25] the authors introduce a wearable RFID solution enabling operations on an information system simply by picking up or using an operation-related tagged object. The proposed system has been also integrated with SAP R/3 in a case study. Since no semantic information are associated to RFID tags themselves, a virtual counterpart is always needed. Interaction patterns are quite unnatural in some cases, because real-world objects are used to start even those tasks that need explicit HCI (*e.g.*, editing a document in a word processor).

In [26], interaction patterns between users endowed with GSM phones and everyday objects are investigated. Exploited objects are augmented through so-called *BTnodes*, active RFID transponders equipped with on-board sensors, modest computing capabilities and Bluetooth connectivity. An infrastructure enabling a hybrid implicit-explicit HCI model is implemented. In order to minimize user involvement, an "invisible" pre–selection, based on contextual conditions, is performed. Elected objects send *interaction stubs* to the GSM terminal of the user (basically stubs are SMS templates to issue commands to objects or to ask their status). Authors claim proposed interaction patterns are perceived as natural, but to send SMS to special objects requires too much user attention so altering normal relationships between people and things. The need for a costly communication link such as GSM is an open issue.

User intention detection is a relevant question for context–aware ubiquitous applications. Proper techniques must be devised to recognize user tasks in order to assist her in timely and unobtrusive ways, without either being inappropriate or altering her habits. Nakauchi *et al.* present a prototypical activity detection and support system in [21]. It consists in a room where all furniture elements are equipped with sensors connected to a machine learning system exploiting RFID tags. Although limited to a small set of possible tasks, experimental tests showed learning algorithms may improve system accuracy in recognizing human activities.

In [19] a support system aimed at enhancing information exchange within a conference room is presented. RFID–enabled badges are given to the meeting attendants having a remotely stored profile. Each room has a RFID reader. A middleware tracks participants while entering or exiting meetings. Location–keyed and user–keyed databases are populated in order to verify user attendance at the events. Upon this basic infrastructure, two support services are implemented. An instant messaging tool running on the laptops of users attending the same room, automatically invites them to a shared chat session. Furthermore a remote file system folder is associated to each meeting event and the access to it is dynamically granted to users as long as they stay in the room. The applicability of a such proposal is limited by the preliminary explicit profiling of both users and events of interest. Nevertheless, it is a good example of implicit HCI in ubiquitous computing, because it enhances user experience without modifying people habits or their interactions with the environment.

## 8. CONCLUSION

We proposed a general framework and an implementation of a middleware infrastructure able to integrate RFID technologies with enhanced Bluetooth SDP presented in [24] which integrates the support to formal semantics. The approach we have presented provides semantic-based context-aware features especially useful in u-commerce scenarios. Objects tagged with RFID transponders carry their semantically annotated description so permitting to implement a resource-oriented Decision Support System which assists the customer in discovering u-marketplace goods best matching her preferences.

The approach and the rationale behind it have been presented and motivated w.r.t. a smart dressing room case study. Some slight modifications of the EPCglobal standards have allowed the support to ontology-based data, while keeping backward compatibility. The framework has been implemented within a commercial middleware in order to test the usability and the utility of the proposed solution.

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