Integrating Radio Frequency Object Discovery and Bluetooth for Semantic-based M–commerce

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Abstract

RFID and current ubiquitous protocols and technologies call for an integration, to provide innovative and advanced wireless services, with semantics being a candidate glue for such an integration. To this aim, in this paper we study an enhancement to the original RFID data exchange protocol and its integration in a semantic-based Bluetooth resource discovery framework. The semantic annotation of products and goods can then be exploited to allow an effective retrieval process. The proposed approach is presented and motivated in a novel m-commerce context.

1 Introduction

Ubiquitous computing envisions information and communication technologies permeate everyday life in a pervasive and unobtrusive way [15]. Today, the availability of powerful handheld devices and wireless protocols provide the necessary infrastructure to devise innovative and effective ubiquitous applications. Short-range, low-power technologies like Bluetooth [2] grant peer-to-peer interaction among hosts. In such a mobile context, devices may find and use services/resources. We believe the next step in ubiquitous computing is to enable communication toward and from "anything" especially in mobile commerce contexts, by embedding transceivers into a wide array of everyday products [8]. In this paper we present a semantic-based environment where pervasive tagged objects expose their semantic-annotated descriptions, thus being able to be discovered/purchased/used in a pervasive scenario.

It is well-known that Radio-Frequency IDentification (RFID) technologies are seen as a key element to bridge the gap between the digital networked world and the physical world [14]. 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; **(2)** an interrogator (or *reader*) to receive the transmitted data (generally integrated into a handheld device).

Low-cost RFID tags usually contain an unique identification code, which can be read by RFID readers. RFID exploits a string matching identification method for object discovery, which is largely inefficient in ad-hoc environments. Users need to submit articulate requests and to receive adequate answers [4], to really interact with available resources. In order to reach such goal we adapt ideas and technologies borrowed from the Semantic Web. Objects endowed with adapted RFID tags are dipped into a semantic-enhanced Bluetooth context [11].

This paper focuses on an extension of EPCglobal specifications for RFID [9], allowing semantically-annotated descriptions be properly stored within the tag memory, so letting the tagged object self-describe in a variety of mobile contexts. No external fixed data repositories are needed to obtain information, as well as semantic-based services such as discovery/retrieval and matchmaking are enabled. The proposal is motivated in the framework of an innovative m-commerce setting and illustrated by means of a prototypical system implementation.

The remaining of the paper is structured as follows. In Section 2 the proposed infrastructure is outlined. Section 3 illustrates modifications to the RFID data exchange protocol and in Section 4 the proposed object discovery approach is explained. Our evaluation test-bed is introduced in Section 5, while Section 6 further clarifies our framework with an illustrative working example. Conclusions close the paper.

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2 Basic Infrastructure

In the rest of the paper we will assume the reader be familiar with basics of Description Logics (DLs) [1] and of Semantic Web languages (in particular OWL [10]).

We believe that RFID tagging should be fully exploited, extending the current usage of available storage area, to let the tag contain structured self-describing information about the tagged good. Such information could then be used in several contexts, starting at the manufacturer's site and again used in all stages of product lifecycle.

To completely use such information in ubiquitous settings, integration is needed among various technologies. In particular here we show how to make interoperable RFID EPCglobal standard [9] with an enhanced Bluetooth Service Discovery Protocol (SDP) [11]. A good may hence "describe itself" by means of an ontology-based semantic annotation stored in the RFID tag it is associated with [13]. When the product is picked up and its tag is scanned by a reader, the system is triggered to discover resources similar to the chosen one or to be combined with it. Semantically annotated descriptions of resources within the m-marketplace are stored in the shopping mall server (from now on *hotspot*). Hotspot is also equipped with a DL reasoner able to return to the user resources best matching her request.

Figure 1. Proposed framework components

The connection between readers and hotspot is performed via a semantic based Bluetooth SDP. In the proposed solution a middleware "interconnects" the enhanced Bluetooth service discovery and RFID-based infrastructures at the application layer, making possible to provide high level services to a buyer in the m–marketplace. In spite of a higher complexity w.r.t. traditional identification applications, a semantic-based approach may provide several benefits. Different information fragments could be added or updated in real time at each stage of product life cycle. This improves traceability during production and distribution, facilitates sales and post-sale services, and finally provides means for more efficient recycling and disposal [16].

Bluetooth side. The backward-compatible semantic-based Bluetooth SDP proposed in [11] allowed the management of both syntactic and semantic discovery of resources, by integrating a semantic layer within the protocol stack at application level. Unused classes of 128 bit service identifiers in the original Bluetooth (UUIDs) were exploited to label specific ontologies naming this value *OUUID* (Ontology Universally Unique IDentifier). By means of the OUUID matching between request and supplies the context was determined and a preliminary selection of resources referring to the same ontology of the request was performed. A general description of each resource of the marketplace is stored within a shop server as a database record labeled with a unique 32-bit handle. Each record entirely consists of an attribute list containing the OUUID, a human-readable name for the resource, a resource description expressed in OWL syntax and a variable number of utility attributes (*i.e.*, numerical values used according to specific applications). By adding four SDP PDUs to the original standard (exploiting not used PDU IDs), further semantic enabled discovery functionalities had been introduced together with the original SDP capabilities. The overall interaction was based on the original application layer in Bluetooth. No modifications were made to the original structure of transactions.

RFID side. In the vast majority of its applications, Radio Frequency technology is merely used as a code-based identification system. Basically, tags store an identifier which is used as a key to retrieve generic properties of the object from an information server, through a networked infrastructure. We propose an extension of EPCglobal standard enabling semantic-based discovery services for m-commerce scenarios. Original read/write features have been preserved maintaining the compatibility with legacy applications, but also advanced peculiarities have been enabled by exploiting Knowledge Representation techniques and technologies.

3 Semantic-enhanced EPC RFID

We refer to the EPC standard for second generation UHF RFID systems [9]. Memory of those tags is divided in four logical banks [6]:

1. *Reserved.* An optional bank storing access and kill passwords.

2. *Electronic Product Code (EPC).* It contains: a 16-bit Protocol Control (PC) field with two subfields related to protocol version and two reserved bits;

Table 1. SELECT command to detect only semantic enabled tags

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

an EPC field for the unique item identification code.

3. *Tag identification (TID)*. It stores tag manufacturer and model identification codes. This bank may be enlarged to store other manufacturer or model-specific data (*e.g.*, a tag serial number) allowing to enable the support for optional features and protocol commands.

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

EPCglobal RFID air interface protocol is an *Interrogator-Talks-First* (ITF) protocol: tags only reply to reader commands. For the sake of clarity, here we briefly recall main protocol features. Among available commands, *Select*, *Read* and *Write* are relevant for our purposes.

Select command sends a bit string to all the tags in radio range. Each tag will compare it with the content of a memory area specified by the reader, setting/resetting a status flag according to (match/no-match) result. A RFID reader can preselect a subset of the tags currently in its radio range, according to user-defined criteria, by means of a sequence of *Select* commands. Furthermore the inventory loop begins. In each iteration the reader isolates one of the preselected tags, reads its EPC code and can access its memory contents. In particular, **Read** command allows to read one or more 16-bit words from one of the four tag memory banks. Similarly, **Write** command allows a reader to write a single 16-bit word.

Together with previous features, the EPCglobal standard provides a support infrastructure for RFID applications: the *Object Naming Service (ONS)* [7]. It allows to locate metadata and services associated to a specified EPC. The ONS is based on the Domain Name System infrastructure. Basically the system translates the EPC code into a domain name corresponding to valid DNS resource records. The *EPCglobal Network Protocol Parameter Registry* maintains service suffixes that identify every allowed service class (*e.g.*, *ws* for a Web Service, *epcis* for a EPCglobal Information Service [7], and *html* for a Web Page of the manufacturer).

Table 2. READ command to extract OUUID from the TID memory bank

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

3.1 Protocol evolution

In the proposed approach, we use two reserved bits in the EPC memory area. The first one –at 15_h address– is exploited to indicate if the tag has a user memory (bit set) or not (bit reset). The second one –at 16_h address– is set to mark semantic enabled tags. Hence by means of a *Select* command (see Table 1), a reader can easily distinguish semantic based tags.

The EPC standard for UHF-class I tags imposes the content of TID memory up to $1F_h$ bit is fixed. Optional information could be stored in additional TID memory. There we store the identifier of the ontology (OUUID) w.r.t. the description contained within the tag is expressed. In order to make RFID systems compliant with the ontology support system developed for semantic-based Bluetooth SDP [11] we adopt a 128 bit structure for the RFID OUUIDs analogous to the one used by the semantic enabled Bluetooth SDP. In order to retrieve the OUUID value stored within a tag, a reader will issue a *Read* command as shown in Table 2.

Contextual parameters such as price or expected delivery time will be stored within the user memory bank together with the semantic annotation of the good the tag is clung to. Recall that annotations are expressed in a XML format, *i.e.*, OWL. It is evident that storing verbose ontological descriptions requires some compression tools; in a companion paper presented at this same venue, an efficient compression scheme, specifically devised for such purpose, is presented [12]. We estimate a memory occupancy which does not exceed 8 kbit to store a description up to 50 OWL classes and properties. The extraction or the storage of a description within a tag can be performed by means of one or more *Read* (see Table 3) or *Write* commands.

The ONS mechanism is considered as a supplementary system able to grant the *ontology support*. In case the reader does not manage the ontology w.r.t. the description within the tag is expressed, it needs an In-

Table 3. READ command to extract semantic annotations from the User memory bank

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

ternet connection in order to retrieve the related OWL file. For this purpose we use the ONS service and we hypothesize to register within the *EPCglobal Network Protocol Parameter Registry* a new service suffix, the *owl* one. It will indicate a service able to retrieve the ontologies with a specified OUUID value.

4 Semantic-based object discovery

In order to make the paper self-contained, here we briefly recall features of *rankPartial* and *rankPotential* algorithms devised in [5] and adapted to a mobile scenario in [11]. Both algorithms rank available resources w.r.t. a given request based on their semantically annotated description according to the degree of correspondence. The *rankPotential* is exploited when descriptions themselves are logically compatible while *rankPartial* allows to obtain a ranking also when they are logically disjoint.

In our RFID scenario the system can suggest most similar goods but also goods to be used in combination with the picked up one. To this aim, a two-step discovery is performed, exploiting two different ontologies. In the first step *rankPotential* algorithm is exploited to retrieve correspondences with the request. Resources analogous to the one selected by the user are identified, but –at the same time– semantically incompatible goods are recognized. Their descriptions are submitted to the second matchmaking step. It exploits *rankPartial* over a differently modeled ontology so allowing to discover products to be associated with the chosen one. The hotspot will thus return two different lists of resource records, respectively for objects in a potential correspondence with the request and in a partial one.

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 contextual properties. An overall utility function has to combine these subsidiary values with semantic matchmaking results, in order to give a global match measure [11]. In the proposed case study –referred to a m-commerce electronic product store– the utility is based on three contextual parameters: price (in US dollars), estimated delivery time (in days), and product category, as shown in Table 4.

Table 4. Good category contextual parameter

Value	phones	computers	photo	audio/video	hobbies
Product category	1	2	3	4	5

The utility function has two expressions, for potential and partial matches respectively:

$$f_{POT}(\cdot) = \frac{pot\_match}{2} + \frac{\tanh(\frac{t_R - t_O}{\beta})}{3} u(t_R - t_O) + (\frac{p_O}{p_R} - 0.5)\frac{(1+\alpha)p_R - p_O}{3(1+\alpha)p_R}$$

$$f_{PAR}(\cdot) = \frac{par\_match}{2} + \frac{\tanh(\frac{t_R - t_O}{\beta})}{6} u(t_R - t_O) + \frac{1-\gamma|c_R - c_O|}{3(2+|c_R - c_O|)}$$

where *pot_match* and *par_match* respectively are the potential and partial match values, p is price, t is delivery time and c is product category. The index R is referred to the request whereas the O one is referred to the supply and $u(\cdot)$ is Heaviside step function. Values we experienced for parameters are $\alpha = 0.1$, $\beta = 10$, $\gamma = 0.2$. A higher utility function value corresponds to a better match. In both formulas the leading term is represented by the semantic match. The second term depends on the estimated delivery time and it is differently weighted in proposed formulas. In the first one (discovery of goods similar to the request) a late delivery is more penalized, because in our m-commerce scenario, user is already interested in a similar product available for purchase. On the other hand, partial matches refer to items that can be used together with the selected one (such as accessories or complements), therefore a delay is less of a concern. The last term is different in the two formulas. For potential matches, it is related to product price. The price imposed by the requester is increased with a factor α 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. Supplies with a much lower price than request (less than 50%) are penalized since they likely represent items in a different market segment. In the formula for partial matches, the last addend considers product category. Products in the same category are favored, because they are presumably more suitable to be used together with the one selected by the user.

5 Testbed

A prototypical system was developed to validate the above theoretical framework, integrating RFID and Bluetooth environments at the application layer. It is based upon *IBM WebSphere RFID Tracking Kit* [3], an agent-based message-oriented middleware for the integration of mobile and embedded technologies in enterprise applications. Simulations and experiments with such platform show that proposed semantic-enhanced solutions can coexist with traditional radio-frequency identification and tracking applications.

In the m-commerce reference environment, a zone resource provider (*hotspot*) keeps track of resources within the marketplace. It interacts with a reader equipped with Bluetooth connectivity, replying to its requests at SDP layer. In particular the hotspot is equipped with a reasoner implementing *rankPotential* and *rankPartial* algorithms cited above. In our current implementation *MAMAS-tng* [5] is adopted. WebSphere software module implementing EPCglobal RFID tag standards has been extended with support to semantic-based product descriptions.

Currently, RFID tags and reader are software-simulated, as EPCglobal standards are substantially closed. To the best of our knowledge, no development kits are publicly available to customize the memory organization of EPCglobal-compliant transponders. Consequently, a thorough and significant quantitative evaluation of system performances could be allowed only thanks to a partnership with RFID device manufacturers/integrators.

Middleware agents are designed as loosely coupled modules that interact through event-based asynchronous message exchange. Agents were developed to connect semantic-enhanced Bluetooth and RFID subsystems. System architecture comprises further agents aiming to make the system independent from device peculiarities so making it more easily adaptable to the variety of scenarios supported by our framework.

6 Illustrative example

Our approach will be now illustrated and motivated in a virtual consumer electronics store case study. A "smart shopping cart" is equipped with a sensor and a tablet computer, which integrates a RFID reader and a Bluetooth interface. When a customer picks up an item she is interested in, the system can assist her in discovering additional items, either similar or usable in combination with the selected one. For our case study, we adopted a consumer electronics ontology, marked with a specific identifier we indicate $OUUID_E$. Let us suppose a woman is looking for a new laptop computer. She notices a quite cheap notebook model, bundled with an office productivity suite. She puts it into the smart shopping cart. Sensor detects the customer took a product. The RFID reader is triggered and reads data stored within the tag attached to the laptop package, then it is deactivated again. Tagged description corresponds to a notebook with Intel Centrino Core Duo CPU, 1 GB RAM, 80 GB hard disk drive, DVD writer and wireless LAN connectivity; it has Windows XP Home Edition OS and an office software suite. This can be expressed in DL formalism as:

- $notebook \sqcap \forall\, has\_CPU.Intel\_centrino\_core\_duo \sqcap \forall\, has\_HDD. = 80\ GB \sqcap \forall\, has\_disc\_recorder.DVD\_rec\_16X\_6X \sqcap \forall\, has\_ram. = 1\ GB \sqcap \forall\, has\_cards.wireless\_802\_11\_card \sqcap \forall\, has\_OS.Windows\_XP\_Home\_edition \sqcap \forall\, has\_software.suite\_office$

w.r.t. $OUUID_E$ reference ontology. Its equivalent OWL expression is stored on the RFID tag in a compressed encoding, along with the item EPC, ontology identifier $OUUID_E$ and contextual parameters. Price is $550, delivery time is 0 days and product category is 3. The tablet touchscreen shows product details for building further semantic based requests. A request consists in a DL conjunctive query, whose conjunct concepts represent the desired features. Let us suppose the customer likes her choice. Now she would like to find some basic accessories. She therefore confirms the system-recommended request. It is submitted from the virtual shop assistant on the shopping cart to the hotspot.

Let us assume the following products are available in the consumer electronics store knowledge base:

- **S1:** notebook with AMD Athlon XP-M CPU, 1 GB RAM, 80 GB hard disk drive, DVD writer and wireless LAN connectivity. It is bundled with Windows XP Professional and antivirus software. Price is $599; delivery time is 0 days; product category is 2:
$notebook \sqcap \forall\, has\_CPU.AMD\_Athlon\_XP\_M \sqcap \forall\, has\_HDD. = 80\ GB \sqcap \forall\, has\_disc\_recorder.DVD\_rec\_16X\_6X \sqcap \forall\, has\_ram. = 1\ GB \sqcap \forall\, has\_cards.wireless\_802\_11\_card \sqcap \forall\, has\_OS.Windows\_XP\_Professional \sqcap \forall\, has\_software.antivirus$

- **S2:** notebook with Intel Centrino Core Duo CPU, 1 GB RAM, 80 GB hard disk drive, DVD writer and wireless LAN connectivity. It is bundled with Linux and an office suite. Price is $529; estimated delivery time is 1 day; product category is 2:
$notebook \sqcap \forall\, has\_CPU.Intel\_centrino\_core\_duo \sqcap \forall\, has\_HDD. = 80\ GB \sqcap \forall\, has\_disc\_recorder.DVD\_rec\_16X\_6X \sqcap \forall\, has\_ram. = 1\ GB \sqcap \forall\, has\_cards.wireless\_802\_11\_card \sqcap \forall\, has\_OS.Linux \sqcap \forall\, has\_software.suite\_office$

- **S3:** a desktop computer with Intel Pentium 4 CPU, 1 GB RAM, 250 GB hard disk drive, DVD writer, wireless LAN connectivity and an LCD display. It is bundled with Windows XP Home Edition and an office suite. Price is $499; delivery time is 0 days; product category is 2:
$desktop\_computer \sqcap \forall\, has\_CPU.Intel\_Pentium\_4 \sqcap \forall\, has\_HDD. = 250\ GB \sqcap \forall\, has\_display.LCD\_display \sqcap \forall\, has\_disc\_recorder.DVD\_rec\_16X\_6X \sqcap \forall\, has\_ram. = 1\ GB \sqcap \forall\, has\_cards.wireless\_802\_11\_card \sqcap \forall\, has\_OS.Windows\_XP\_Home\_edition \sqcap \forall\, has\_software.suite\_office$

- **S4:** a blue notebook bag. Price is $19; delivery time is 0 days; product category is 2:
$notebook\_bag \sqcap \forall\, has\_color.blue$

- **S5:** a UMTS mobile phone with dual display and miniSD memory card support. Price is $169; delivery time is 0 days; product category is 1:
$mobile\_phone \sqcap \forall\, has\_connectivity.UMTS \sqcap = 2\ has\_display \sqcap \forall\, has\_display.LCD\_display \sqcap \forall\, has\_memory\_card.mini\_sd$

The hotspot performs the matchmaking as described above: outcomes are presented in Table 5. The second column shows whether each retrieved resource is compatible or not with request R. If yes, the *rankPotential* computed result is shown, otherwise the *rankPartial* result value is presented. In the last column results of the overall utility function are reported. Note that $S2$ is ranked as the best supply for similarity match, despite a longer delivery time than $S1$. This is due to a

Table 5. Matchmaking results

Supply	Compatibility (Y/N)	*rankPotential* score	*rankPartial* score	$f(\cdot)$
S1: notebook with antivirus	Y	6	-	0.001
S2: notebook with office suite	Y	3	-	0.236
S3: desktop computer	N	-	79	0.166
S4: notebook bag	N	-	26	0.502
S5: UMTS phone	N	-	23	0.443

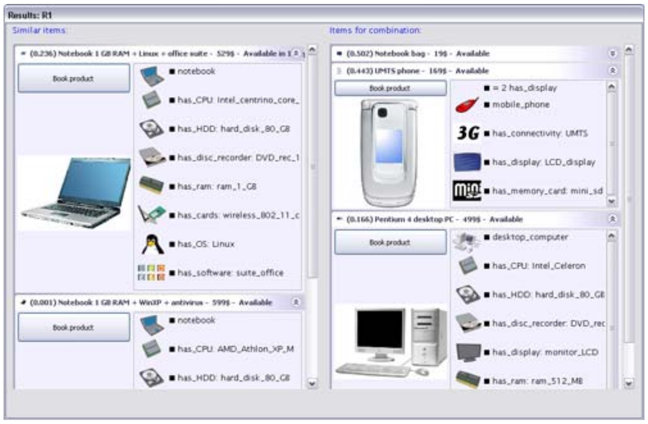

Figure 2. Results window

better *rankPotential* outcome. Among candidate resources for combination, product category affinity favors $S4$ over $S5$, while $S3$ has a poorer match. For each retrieved resource a picture is displayed along with matchmaking score, price and description (Figure 2).

7 Conclusion

We proposed a unified framework integrating RFID technologies with enhanced Bluetooth SDP supporting formal semantics. The framework provides semantic-based features, devised and implemented for m-commerce scenarios. Objects tagged with RFID transponders carry semantic annotations so permitting to implement a resource-oriented Decision Support System which assists customers in a mobile marketplace. Some slight modifications of the EPCglobal standard have allowed the support to ontology-based data, while keeping backward compatibility. Currently, the approach has been implemented within a message-oriented commercial middleware in order to test the feasibility and the usability of the proposed solution.

References

[1] F. Baader, D. Calvanese, D. Mc Guinness, D. Nardi, and P. Patel-Schneider. *The Description Logic Handbook*. Cambridge University Press, 2002.

[2] Bluetooth. http://www.bluetooth.com.

[3] J. Chamberlain, C. Blanchard, S. Burlingame, S. Chandramohan, E. Forestier, G. Griffith, M. Mazzara, S. Musti, S. Son, G. Stump, and C. Weiss. *IBM WebSphere RFID Handbook: A Solution Guide*. IBM International Technical Support Organization, May 2006.

[4] H. Chen, A. Joshi, and T. Finin. Dynamic Service Discovery for Mobile Computing: Intelligent Agents Meet Jini in the Aether. *Cluster Computing*, 4(4):343–354, 2001.

[5] T. Di Noia, E. Di Sciascio, F. Donini, and M. Mongiello. A System for Principled Matchmaking in an Electronic Marketplace. *International Journal of Electronic Commerce*, 8(4):9–37, 2004.

[6] EPCglobal Inc. EPC Radio-Frequency Identity Protocols Class-1 Generation-2 UHF RFID Protocol for Communications at 860 MHz–960 MHz. Technical report, EPCglobal, January 2005.

[7] EPCglobal Ratified Specification. Object Naming Service (ONS - ver. 1.0). http://www.epcglobalinc.org, October, 4, 2005.

[8] ITU. Ubiquitous Network Societies: The Case of Radio Frequency Identification. In *ITU Workshop on Ubiquitous Network Societies*, April 2005.

[9] K. Traub et al. EPCglobal Architecture Framework. Technical report, EPCglobal, July 2005.

[10] OWL. www.w3.org/TR/owl-features/.

[11] M. Ruta, T. Di Noia, E. Di Sciascio, and F. M. Donini. Semantic-Enhanced Bluetooth Discovery Protocol for M-Commerce Applications. *International Journal of Web and Grid Services*, 2(4):424–452, 2006.

[12] M. Ruta, T. Di Noia, E. Di Sciascio, and F. Scioscia. An efficient data compression algorithm for semantic-based ubiquitous computing applications. In *International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies (UBICOMM 2007)*, 2007. To appear.

[13] M. Ruta, T. D. Noia, E. D. Sciascio, and F. Scioscia. If Objects Could Talk: Semantic-enhanced Radio-Frequency IDentification. In *The First International Workshop on RFID Technology Concepts, Applications, Challenges (IWRT 2007)*, pages 25–34. INSTICC Press, 2007.

[14] R. Want. Enabling ubiquitous sensing with RFID. *Computer*, 37(4):84–86, April 2004.

[15] M. Weiser. The computer for the 21st century. *SIGMOBILE Mob. Comput. Commun. Rev.*, 3(3):3–11, 1999.

[16] H. Yasuura. Towards the Digitally Named World - Challenges for New Social Infrastructures based on Information Technologies. In *Euromicro Symposium on Digital System Design*, pages 17–22, September 2003.