Semantic Web in Ubiquitous Mobile Communications

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Abstract: The world becomes ubiquitous, and mobile communication platforms become oriented towards integration with the web, getting benefits from the large amount of information available there, and creation of the new types of value-added services. Semantic and ontology technologies are seen as being able to advance the seamless integration of the mobile and the Web worlds. We provide background information on the Semantic Web field, discuss other research fields that bring semantics into play for reaching the ontology-enabled ubiquitous mobile communication vision, and exemplify the state of the art of ontology development and use in telecommunication projects.

Keywords: Semantic Web, Ontology, Mobile Communication, Ubiquitous, Knowledge Base, Data Schema

INTRODUCTION

Nowadays, mobile and Web environments converge in one shared communication sphere. Technologies stemming from Semantic Web and Mobile Communication fields get combined to achieve this convergence towards the vision of ontology-enabled ubiquitous mobile communication. Knowledge Management and Semantic technologies fields produce ways to describe, specify and manage information in a machine processable form, in particular, acquire, evolve, reuse, and combine knowledge (Fensel, 2001). Certain formats and protocols stemming from these fields are already being applied to telecommunications: vCard[1], CC/PP[2], UAProf[3]. However, these specifications are only applicable to a limited number of telecommunication scenarios, and management of information about resources in mobile environment could be substantially improved, e.g., by alignment of heterogeneous information sources in knowledge-based service enablers.

Ontologies and architecture knowledge layers play an ever-increasing role in service platforms and mobile communications. As integration of Telco, Internet and the Web takes place, in order to achieve interoperability, telecommunication systems and services tend to rely on knowledge represented with the use of shared schema, i.e., on ontologies similar to as envisioned on the Semantic Web (Tarkoma et al., 2007). However, specific ontology-based implementation solutions for mobile systems are rare, and best practices for such interoperability are not established. In this paper, we address a problem of ontology-based interoperation in order to integrate independent components in a system providing value-added mobile services.

We present the overall state of the art ontology-related developments in mobile communication systems, namely, the work towards construction, sharing and maintenance of ontologies for mobile communications, reuse and application of ontologies and existing Semantic Web technologies in the prototypes. Social, collaborative and technical challenges experienced in the project showcase the need in alignment of ontology experts' work across the mobile communication projects to establish the best practices in the area and drive standardization efforts. We indicate certain milestones in integration of Semantic Web-based intelligence with Mobile Communications, such as performing ontology construction, matching, and evolution in mobile service systems and alignment with existing heterogeneous data models.

The paper is structured as follows. In Section 2 we provide a motivation for discussing the convergence between the areas of Semantic Web and ubiquitous mobile communications. Section 3 gives an overview of the core ontology technologies involved, related and relevant research and development fields and challenges in the area. In Section 4, two illustrative case studies for the converged area are described. Section 5 concludes the paper and Sections 6 indicates future research directions.

WHY SEMATICS IN UBIQUITOUS MOBILE COMMUNICATIONS?

In this section we motivate why combination of Semantic Web technology with ubiquitous mobile communications is beneficial. Semantic technologies in mobile communication have been somewhat considered to the less extent comparing to other fields, such as semantics in e-sciences, e-government, e-enterprise, e-communities, etc. However, as the mobile world starts to integrate with the Web world in delivering new value-added services, the area of semantics ubiquitous mobile communication inevitably gains a larger importance and potential.

Ubiquitous computing, also referred to as pervasive computing, is the seamless integration of devices into the users every day life. Applications should vanish into the background to make the user and his tasks the central focus rather than computing devices and technical issues (Weiser, 1991). When applying to mobile communication scenarios, ubiquitous computing can be viewed as when user moves around and changes circumstances, he can always be connected and well served without being aware of the technical issues under the scene. To achieve the goal, information from all the involving participants, such as user, network, service provider etc., needs to be collected, shared and interoperable with each other, known by one or more operational agents but agnostic to the user. Such information is diverse in their language, format and lack of semantic meaning for autonomous processing by computer or operational agent. The Semantic Web can be a rescue with its vision to achieve global information sharing and integration.

An example of combination of the two fields can be a service enabler that could be used by other services and thus make their construction simpler. For example, such an enabler could access distributed information on user's location, availability and friends and inform other services about which groups of friends are available and located at the same place. Services that assist with scheduling business meetings or parties, or the ones that are targeted at selling products for groups of users can be among the services that need such information from the enabler. To achieve the output, the enabler would take external structured data represented in a formal way (e.g., in RDF): for instance, information about user's availability from PIDF files, information on who is a friend of whom from FOAF profiles, information about location from data stemming from such standards as IETF RFC4119, RFC4589. Then the enabler would combine the gathered information, apply certain rules to deduce the result and pass it to other mobile services via an interface.

GROUNDING FOR SEMANTICS IN UBIQUITOUS MOBILE COMMUNICATIONS

In this section, we describe existing developments relevant for the combined field of ubiquitous mobile communications and the Semantic Web.

Ubiquitous Mobile Communication Existing Developments

A lot of work has been undertaken to implement the vision of ubiquitous mobile communications by investigating the underlying technologies. Examples include, but not limited to, user-related context collection, such as sensor network, Bluetooth, GPS, user-related context modelling and transmission, such as CC/PP, UAProf, 3GPP, MPEG-21, multimedia content description, such as MPEG-7, service discovery and service context modelling, such as UPnP, Jini, Bluetooth SDP, agent technologies, such as FIPA, ACL. Network mobility, security and QoS management, such as Hierarchical mobile IP, IPSec, DiffServ etc. The combination of these technologies with Semantic Web has become an inevitable trend in a ubiquitous mobile communication environment. Some of such joint developments are presented later in Section: Relevant research fields

Semantic Web Existing Developments

Existing developments of the Semantic Web include languages (i.e. core formalisms to specify domain knowledge or services), methodologies and tools. In this section we outline the major developments in these areas and indicate their role and contributions in the area of Semantic Web enabled mobile platforms.

Languages and Formalisms

RDF(S)

RDF (Lassila & Swick, 1999; Manola & Miller, 2004) became a W3C recommendation in 1999. It is a general-purpose language for representing resources on the web in terms of named properties and values (McBride, 2004). With RDF it is not possible to define the relationships between properties and resources. For this purpose, RDF Schema (Brickley & Guha, 2004) has been specified. It became a W3C recommendation in 2004 and is basically an extension of RDF. More specifically, it is a formal description language for eligible RDF expressions. In particular, a schema defines the kinds of properties available for resources (e.g., title, author, subject, size, colour, etc.) and the kind of resource classes being described (e.g., books, Web pages, people, companies, etc.). RDF Schema is a simple ontology and a simple ontology definition language. RDF and RDF Schema are usually denoted RDF(S).

RDF(S) bases on some syntactical principles of XML (e.g. URIs) and has been equipped with an XML syntax as well. The most basic Semantic Web language which provides the syntactical basis for all other Semantic Web languages is RDF(S). RDF(S) is not provided completely with a formal logical semantics, thus reasoning is only on partially supported.

Topic Maps

Topic Maps are a data modelling language and became an ISO standard (ISO/IEC 13250) in 2000. A Topic Map offers a means to create an index of information which resides outside of that information. It describes the information in documents and databases by linking into them using URIs. A Topic Map consists of topics, associations (relationships between topics), occurrences (information resources relevant to a topic). Topics and occurrences can by typed. Types in Topic Maps are themselves topics and thus there is no real difference between a topic and a type.

There exists SGML, XML and RDF language support for Topic Maps. However, they are very simple and do not have a formal semantics and thus no sophisticated inference support. Nevertheless, because of their simplicity, they are often used in industry applications.

OWL

OWL (Dean & Schreiber, 2004) became a W3C recommendation in 2004. OWL is mainly based on OIL and DAML+OIL, which are obsolete Semantic Web languages and therefore not mentioned further here. OWL is equipped by an RDF syntax and includes three sub languages:
OWL-Lite roughly consists of RDF(S) plus equality and 0/1-cardinality. It is intended for classification hierarchies and simple constraints. OWL-Lite corresponds semantically to the formal Description Logic *SHIF(D)* and cannot express the whole RDF vocabulary.
OWL-DL contains the language constructs of OWL-Lite. OWL-DL corresponds semantically to the Description Logic *SHOIN*(D). Although strictly more expressive than OWL-Lite, it still provides computational completeness and decidability.
OWL Full does not correspond to a formal logic anymore as it builds upon the complete RDF(S) vocabulary which also lacks a correspondence to a formal logic. The language incorporates maximum expressive power and syntactic freedom, but offers no computational guarantees.

Semantic Web Languages in Progress

In this subsection, we consider Semantic Web languages which have been submitted to the W3C and thus have communities promoting them. At least some of them can be expected to become W3C recommendations. Examples of such languages are

- *Languages based on the Logic Programming Knowledge Representation paradigm* – the trend to the aforementioned paradigm exists already since the year 2000 when the development of RuleML[4] has started. RuleML is a set of languages revolving around the Logic Programming paradigm and being equipped with an RDF syntax. Other examples of Semantic Web Languages with Logic Programming semantics are WRL[5], a set of three layered rule languages of increasing expressivity, and SWRL[6], a language which combines OWL and RuleML but is computationally intractable. Furthermore, a W3C working group[7] has been formed for establishing standards for Semantic Web rule languages.

- *Semantic Web Service Modelling Languages* – Semantic Web Services will play an important role in the Semantic Web as they combine Web Services with semantics. Examples for Semantic Web Services Languages are WSML[8] and SWSL[9]. The languages serve for the specification of ontologies describing Semantic Web Services. E.g., WSML is used to describe WSMO[10] and SWSL is used to describe SWSO[11].

Ontologies and Tools

Apart from the languages to describe data, specific ontologies related to the mobile communication domains and appropriate ontology management tools are necessary to implement the vision of ubiquitous mobile communications.

In a nutshell, the state of the art in development of the ontologies addressed by ubiquitous mobile communications comprises:

- ad-hoc small-size schemata on certain general purpose topics are specified in ontology languages;
- detailed, XML-based standards on certain narrow telecommunications topics.

Certain standardisation schemata and activities to be considered for the development of the ontology framework for mobile communications are listed later in Section: Mobile Ontology. Additional efforts coming from the Semantic Web community are listed in **Error! Reference source not found.**.

Typically, existing ontology management tools are adopted and explored in the semantic telecommunications projects. Stemming from the SPICE project (Zhdanova et al., 2006), examples of relevant and popular ontology management tools used, as well as encountered problems in their exploitation and an expected resolution times, are provided as follows.

Name……………………….Protege
Website…………………….. http://protege.stanford.edu/
White page………………… n/a
Main characteristics……….. Ontology editor

Open problems	Relevance					Term		
	1 Very low	2 Low	3 Normal	4 High	5 Very high	0-3 short	3-6 medium	6-12 long
Needs improvement of usability features, robustness	☐	☒	☐	☐	☐	☐	☒	☐

Name……………………….Jena
Website…………………….. http://jena.sourceforge.net/
White page………………… n/a
Main characteristics……….. A Semantic Web Framework for Java. Ontology API and implementation, supports RDF(S), OWL, performs basic ontology management and reasoning (similar idea as Xerces for XML)

Open problems	Relevance					Term		
	1 Very low	2 Low	3 Normal	4 High	5 Very high	0-3 short	3-6 medium	6-12 long
Scalability: works slowly on large volumes of data	☐	☐	☐	☐	☒	☐	☒	☐

As the ontology data are processed within the ubiquitous mobile communication applications, exploration and reuse of further ontology management technology is on the roadmap of the research and development field

Ontology Name	Producer	URL	Description	Development Status
MeNow	Chris Schmidt	http://crschmidt.net/foaf/menow/menow.rdf	The motivation for the MeNow schema is to be able to describe a variety of aspects of the current status of someone, either online or off, in a way that the data can be easily aggregated or retrieved. This schema allows the definition of a variety of terms that would be common in many applications: describing the current book you are reading, music you are listening to, mood you are in, and more.	
Pervasive SO – Describing User Profile and Preferences	Harry Chen, UMBC	http://pervasive.semanticweb.org/doc/ont-guide/part1/	Pervasive Computing Standard Ontology (PERVASIVE-SO) is a set of RDF/OWL ontology documents. Each ontology document is identified by a unique XML namespace and defines the ontologies of a specific domain. In a pervasive computing environment, computer systems often need to access the profiles and the preferences of a user in order to provide services and information that are tailored to the user. The profile of a user includes typical contact information (telephone numbers, email addresses, name, etc.) and information that describe other computing entities that can act on the behalf of the user (e.g., the personal agent of a user). The preference of a user is a description of the environment state that the user desires the computer systems to honor or achieve whenever it is possible.	Frozen in 2004
Platform for Privacy Preferences	Brian McBride, HP	http://www.w3.org/TR/p3p-rdfschema/	The Platform for Privacy Preferences Project (P3P) enables Web sites to express their privacy practices in a standard format that can be retrieved automatically and interpreted easily by user agents. P3P user agents will allow users to be informed of site practices (in both machine- and human-readable formats) and to automate decision-making based on these practices when appropriate. Thus users need not read the privacy policies at every site they visit.	Frozen in 2002
Gadget	Morten Frederiksen	http://www.wasab.dk/morten/2004/10/gadget	Definitions of various terms related to (typically) electronic gadgets such as GPS receivers, cameras and mobile phones.	Frozen in 2004
ConOnto: Context Ontology	Mohamed Khedr	http://www.site.uottawa.ca/~mkhedr/contexto.html	ConOnto describes the different aspects of context-aware systems. ConOnto includes location, time, activities, software and hardware profiles. ConOnto also includes meta-information that describes negotiation and fuzzy ontologies to be used in systems that will negotiate and infer about context information.	
Ambient Networks: General, Cost, QoS Ontology	Anders Karlsson, TeliaSonera	http://kiwi.intra.sonera.fi/an_costs.owl		Created in 2005

Table 1: Ontologies Related to the Mobile Ontology

Major Challenges and Approaches

In this section, we define major challenges that are under development or need to be developed in the joint area. From ubiquitous mobile communication point of view, the challenges can be viewed from three perspective, i.e., from the user, the network operator, and the service provider. From user's point of view, there is an expectation of autonomous, non-stop service being provided with satisfying quality whatever terminal he/she uses, whenever he/she needs and wherever he/she goes without having to set the configuration. From network perspective, there is a challenge of ensuring the service delivery by providing a smooth handover, a guaranteed QoS and security level etc. when delivery circumstance changes, for example, from one type of network to another. From service provider point of view, the anticipation is to provide only one version of service, which, however, can be used by any device via any networks. To face these challenges, when designing a ubiquitous service delivery based on ontologies, the information from and about the user, network condition, the content/service being provided, together with any context information (to support personalization and service push to the user), need to be described in an unambiguous and interoperable manner in order to perform effective service delivery. Therefore, common ontologies describing such domain knowledge, as well as best practices in their reuse are required. Generally, challenges faced from ontology point of view include

- heterogeneity: resolving inconsistencies, format differences (syntactic and semantic differences in formalization), business process mediation,
- versioning when merging or combining ontologies representing different knowledge domains, ontology and instance data evolution and maintenance during updates,
- scalability: scalable repositories for ontology instance data (currently popular ontology management toolkits such as Jena and Sesame do not always meet industrial standards),
- ontology and instance data visualization, user interfaces,
- user/community generated content: formalization, acquisition and employment (when building innovative mobile services in Web 2.0 style of social applications alike to YouTube, Flickr, LinkedIn, Google Base, etc.),
- semantically described mobile and web services (no yet widely accepted "standard" solutions),
- service composition and discovery, user-driven creation of new services by composing service enablers, mash-ups,
- integration with the non-semantic web services and formats, which use traditional technologies such as WSDL, SOAP and UDDI, XML,
- integration with legacy applications, which are not terminologically a service, but can be upgraded to be a service, e.g. MPEG codec.

Relevant Research Fields

The following research areas are related to, impact and will be potentially impacted by the described involvement of the Semantic Web in Mobile Communications.

- **Multimedia**

Today, the amount of digital multimedia information is growing over the World Wide Web, in broadcast data streams and in personal and professional databases. One of the major challenges for ubiquitous mobile communication is to enable any mobile devices, e.g. mobile phone, PDA, to access, exchange and consume a rich set of multimedia content seamlessly over dynamic and heterogeneous networks. The need of semantic description of the multimedia information becomes apparent. The MPEG-7 and MPEG-21 are the dominant efforts for multimedia content and service description framework.

MPEG-7 is known as the multimedia description standard and offers several tools, i.e. Description Schemes, to annotate multimedia content at different levels. The main parts are: Description Definition Language (DDL), Visual, Audio and Multimedia Description Schemes (MDS). The DDL is a language that allows the creation of new Description Schemes and, possibly, Descriptors. It also allows the extension and modification of existing Description Schemes. The DDL is based on XML Schema Language, but with MPEG-7 extensions specifically for audiovisual description. The Visual description tools provide structures to describe basic visual features, such as color, texture, shape, motion and localization etc. The Audio description tools provides structures for the description of audio features that are common across many applications, such as spectral, parametric, and temporal features, and that are application-specific features, such as audio indexing, recognition and signature. MPEG-7 Multimedia Description Schemes provides the description tools for generic media entities, such as vector, time and more complex media entities. The latter can be grouped into 5 different classes according to their functionality: Content description, Content management, Content organization, Navigation and access and User interaction.

MPEG-21, the 21st century multimedia framework, goes further and provides tools to describe the environment to enable transparent multimedia creation, delivery and consumption between heterogeneous environments. The main parts are Digital Item Declaration (DID), Digital Item Identification (DII), Intellectual Property Managements and Protection (IPMP), Rights Expression Language (REL), Rights Data Dictionary (RDD) and Digital Item Adaptation (DIA). The Digital Item Declaration (DID) specification contains three normative sections, a model to describe a set of abstract terms and concepts to form a useful model for defining Digital Items, a representation to describe the syntax and semantics of each of the Digital Item Declaration elements, and a Schema comprising the entire grammar of the Digital Item Declaration representation in XML. The DII specification provides mechanisms to uniquely identify Digital Items, Intellectual Property related to the Digital Items such as abstractions, Description Schemes and types of Digital Items. IPMP is an extended efforts based on MPEG-4 to develop new systems and tools with enhanced interoperability. The REL, together with the RDD that supports the REL and provides extensive semantics, provides a universal method for specifying rights and conditions associated with the distribution and use of digital items and thus facilitates the creation of an open DRM architecture. DIA provides tools to describe the Digital Item usage environment including: Usage characteristics, such as user info, usage history, User preferences and physical characteristics such as disabilities, Device characteristics such as display, memory and battery, Network characteristics, such as error characteristics and bandwidth, and Natural environment characteristics such as noise and illumination. This is to facilitate transparent access to distributed digital items by shielding users from the technical complexity, such as network and terminal installation, management and implementation issues.

- **Web Service (SOA)**

Service-Oriented Architecture (SOA), especially a Web service-based SOA, has the potential in speeding up the application development process and the agility in responding to the change of business needs. This is due to the loose coupling of client from service and the set of standard protocols and technologies used by the Web service, such as XML, WSDL, SOAP, and UDDI. The inherent features of SOA, i.e. reusability, interoperability, scalability and flexibility, can virtually meet the requirement of a supportive framework for ubiquitous mobile communication.

Coming along with Semantic Web is Semantic Web service, where Web service is described with added computer-processable semantics, and thus a number of services can be concatenated autonomously to compose a new service for a more complex task. This will benefit service provision in a ubiquitous environment where all information from user, network, together with the requested service and any intermediate service are required to make a delivery decision autonomously. In accordance with this advance, the set of standard protocols and technologies for Web services are evolving to reach their semantic counterparts or brand new standards are created. For example, the ontology languages, RDF, RDFS, and OWL are developed to add computer-processable semantics on top of the exiting syntax provided by XML. WSDL specifies a way to describe the abstract functionalities of a Web service and concretely how and where to invoke it. Semantic Annotations for WSDL (SAWSDL)[12] defines mechanisms using which semantic annotations can be added to WSDL components based on an earlier effort, namely WSDL-S[13], which adds semantic expressivity to the service description by extending original WSDL elements. SOAP, as the message exchange protocol and originally XML-based, can be combined with RDF and OWL in order to introduce semantics to assist the flexible service invocation (Zhao, 2004). Similarly, enabling UDDI to store semantic markup and handle semantic enquiries has been investigated in recent years (Luo et al., 2006). Correspondingly, service-oriented architectures require machine-processable semantics to achieve its full potential. In particular, DERI[14], targets this challenge by offering a set of tools and techniques ranging from ontology construction to description language. The later include Web Service Modelling Ontology (WSMO), Web Service Modelling Language (WSML) and a Web Service Execution Environment (WSMX)[15].

- **Security, privacy, trust**

In recent years, the security and trust aspects of Web services are standardised by OASIS[16] with a WS-security specification released in 2004. WS-security insets security-related information to Web service messaging that provides for message integrity and confidentiality using security token and digital signatures. The use of Semantic Web technologies enables Web into a genuinely distributed and global content and service provider. Inherent with this are the issues of more widespread security, trust, information quality and privacy.

To achieve a security solution for Semantic Web service, the traditional security solutions can be described as one of the contextual information attached to the service and can be interpreted on the other end at semantic level. This solution has the advantage of not requiring to design a bottom-up Semantic Web service security architecture and provides service provider with flexibility of control. However, embedding security and trust policies into every Web service may not appear to be an attractive solution and can result in tight coupling between services and particular security implementations. An alternative is to design an integrated Semantic Web security framework with security mechanisms available at various layers of the network. This may provide a comprehensive solution when more security and trust issues and challenges arise from the traditional communication domain. For example, when seamless inter-connecting heterogeneous networks, particularly when security issues are jointly considered with other issues, such as QoS and mobility management, in the overall communication process.

- **Human Communication Interface**

The design of the Human Communication Interface (HCI) for Web applications has always been of great importance. The Web technology is evolving with Semantic Web, the interaction must also evolve. With the emergence of the Semantic Web and Semantic Web services, which give information well-defined meaning and enable computer work in cooperation with humans, the interactions with Web-delivered information has become possible and thus the complexity of the human communication interface has increased. For example, instead of being an information receiver only, user can interact with information to construct new information and build knowledge. In addition, with the user terminal getting smaller and smaller in size like PDA, Pocket PC, together with services being more customized to the user's personal need and preference, the human interface design becomes even more challenging than ever.

In ubiquitous mobile communication environment, human computing interfaces form one of the major contextual information of the user as well as one of the major component in the delivery path. Therefore, it is essential to bring interaction design principles with other contextual information into the semantically structured information in order to facilitate this evolution of the Web. On the other hand, with the popularity of Semantic Web and wide acceptance of its technology in integrating knowledge from various heterogeneous parties, embedding Semantic Web technology into the HCI design is envisioned to be a necessity for automating the deployment of rich user interfaces.

- **Lower Layer of Mobile Communication**

One of the important contextual information to be included, and maybe semantically described, when customizing Semantic Web content and service to the user ubiquitously are the network conditions in the delivery path, e.g. bandwidth, QoS, Security, latency, jitter etc. Signalling and/or information exchange is required between the application layer and the underlying network layers for request and response. Enhancements to the communication protocols with semantic capabilities are envisaged to be required in order to assure user's satisfaction in ubiquitous service delivery. In addition, there have been extensive efforts to tackle the network layer integration of QoS, security and mobility management over heterogeneous network in a mobile environment.

- **Autonomous Computing**

The vision of autonomous computing is to enable computing system operate in a fully autonomous manner. The challenges of autonomous computing are robustness, simplicity for the end-user and seamless integration (Hercock, 2002). With the vision of being a global information integrator by making information computer-interpretable, Semantic Web technologies can help realizing the vision of autonomous computing, particularly in a ubiquitous mobile communication environment where constant changes take place and autonomous process are expected.

- **Grid, Semantic Grid**

Grid development is targeted at the problem of efficiently using computing power of distributed resources for achieving a common set of tasks. Typical Grid toolkits include GLOBUS[17]. Semantic Grid is oriented towards enhancing typical Grid services or processes with ontology-based descriptions (Goble et al., 2004). Different types of Grid resources can be used by ontology–enabled mobile services to reach their goals.

ONTOLOGY FRAMEWORK STUDIES

In this section, we describe ongoing research and development combining the areas of ubiquitous mobile communication and Semantic Web. One can view convergence of Semantic technologies with mobile communication from two sides: inclusion of the Semantic technologies in solutions delivered by mobile communication project from one side; and mobile communication use cases in core Semantic technology projects from the other side. On the one hand, work on development of mobile communication applications, enablers and services with involvement of ontologies has been carried out in the following mobile communication projects: SPICE[18], MobileVCE[19], Mobilife[20], OPUCE[21], Ambient Networks[22], etc. On the other hand, research and development involving mobile aspects has been carried out in the following Semantic Web projects: TripCom[23], SWING[24], ASG[25], SmartWeb: Mobile Access to the Semantic Web[26], etc. In this section, we provide detailed illustrating examples of the ontology work carried out for mobile communication solutions, specifically, Mobile ontology (SPICE project) and an ontology solution for multimedia (MobileVCE project).

Mobile Ontology

Mobile environments and the Web converge forming a shared Distributed Communication Sphere (DCS). This causes the appearance of new settings to be supported, e.g., when the user utilizes mobile and fixed devices to interact with systems. Interaction and connectivity of mobile applications with the Internet increase. To ensure interoperation of mobile and Web services, applications and tools (running on heterogeneous various service platforms in such a sphere), developers need to have a shared specification of objects belonging to the sphere and their roles. Certain ontologies have already been developed for the mobile communication domain by employing area with employment of Semantic Web formalisms (Korpipää et al., 2004; Pfoser et al., 2002). However, widespread and global adoption of such ontologies remains a challenge.

Approaching the problem of interoperation between the Web and mobile service technologies, Mobile ontology, a comprehensive "higher-level" ontology for mobile communication domain, is being developed. Currently, definition and implementation of the Mobile ontology is managed as a collaborative effort amongst participants of the EU IST SPICE Integrated Project.

Mobile Ontology Introduction

What's Mobile Ontology for?

Mobile Ontology is being developed as a comprehensive “higher-level” ontology for mobile communication domain. The ontology is a machine readable schema intended for sharing knowledge and exchanging information both across people and across services/applications, and it covers domains related to mobile communications, specifically, addressing persons, terminals, services, networks.

The added values of Mobile Ontology are:

- Providing an easy and formal way to reference objects from the mobile communication domain (in particular, to serve as an exchange format between mobile service enablers);
- Providing an opportunity to implement enhanced, ontology-based reasoning;
- Providing a formal representation of the domain to be used in research and development projects, and for educational purposes.

Mobile Ontology Overview

DCS-related vocabulary terms, grouped in broad categories, are presented in Figure 1.

DCS Basics

- **CommunicationSphere**
- **AccessMethod**
- **Availability**
- **PhysicalLocation**
- **Modality**
- **InputModality**
- **OutputModality**
- **Cost**
- **Time**
- **AccessParameter**
- **consistsOf**
- **associatedWith**
- **characterizedBy**
- **providesAccessTo**
- **hosts**
- **PhysicalSpace**
- **Outdoors**
- **Indoors**
- **Building**
- **Roomspace**
- **Hall**
- **Floor**
- **Stairway**
- **isInsideOf**
- **hasInside**
- **isOnFloor**
- **isPhysicallyConnectedTo**
- **hasAboveFloor**
- **isAboveFloor**
- **isWithinRangeOf**
- **belongsTo**
- **owns**

Users and Groups, Personalization

- **Person**
- **UserGroup**
- **Mood**
- **UserRule**
- **CurrentActivity**
- **isUserDefaultActivity**
- **isWillingToCommunicate**
- **Recommendation**
- **RecommendedItem**
- **Feature**
- **hasWeight**
- **hasRelevanceScore**
- **hasSupport**
- **hasConfidence**
- **hasPreferred**
- **hasMeanRelevanceScore**
- **hasMeanSupport**
- **hasMeanConfidence**
- **Profile**
- **Subset**
- **hasType**
- **hasDescription**
- **hasSubset**

Devices

- **Terminal**
- **Device**
- **EmbeddedDevice**
- **SensorNode**
- **MultimodalityDevice**
- **ConfigurationElement**
- **DescriptionElement**
- **DataElement**
- **Datastore**
- **Module**
- **TerminalParameter**
- **hasParent**
- **hasModule**
- **hasAdditionalConfiguration**
- **hasAdditionalParameters**
- **hasAdditionalDescription**
- **hasData**
- **hasDescription**
- **hasConfiguration**
- **hasSize**
- **hasVersion**
- **hasName**
- **hasEncoding**
- **hasTStamp**
- **hasLocation**
- **hasDisplayName**
- **hasCategory**
- **hasMimeType**
- **hasVendor**
- **isEquippedWith**
- **isAvailableAt**

Services

- **Service**
- **QoS**
- **MultimodalityService**
- **InformationService**
- **KnowledgeService**
- **ContextService**

Networks

- **Network**
- **BluetoothNetwork**
- **WiFiNetwork**
- **GSMNetwork**
- **UMTSNetwork**
- **canBeAccessedVia**
- **isConnectedTo**
- **hostedBy**

Figure 1: DCS-related Classes and Properties of Mobile Ontology

Mobile Ontology, in particular, its DCS Vocabulary (Zhdanova et al., 2006) definitions are written using RDF and OWL (Manola & Miller, 2004; Dean & Schreiber, 2006) that makes it easy for software (both Web-based and mobile-oriented) to process facts about the terms in the DCS vocabulary, and consequently about the things described in DCS documents. A DCS document/instance data can be combined with other DCS documents to create unified sources of information.

Example

Here is a very basic annotation describing the state of the communication model:

```
<?xml version="1.0"?>
<rdf:RDF
    xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
    xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
    xmlns:owl="http://www.w3.org/2002/07/owl#"
    xmlns:p1="http://www.owl-ontologies.com/assert.owl#"
    xmlns="http://www.ist-
spice.org/mobile_ontology/2006/5/26/mobile_ontology.owl#"
  xml:base="http://www.ist-
spice.org/mobile_ontology/2006/5/26/mobile_ontology.owl">


…
<Device rdf:ID="BlueSonyEriccson">
    <belongsTo>
      <Person rdf:ID="AnnaZ">
        <owns rdf:resource="#BlueSonyEriccson"/>
        <rdfs:comment
rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
        ></rdfs:comment>
      </Person>
    </belongsTo>
  </Device>
…
</rdf:RDF>
```

RDF/S and OWL have been chosen as formats to represent the mobile ontology, as they are current recommendation ontology languages of W3C and have a relatively large tool support for implementation of enablers and applications.

Starting from the DCS ontology, the Mobile ontology has developed a new structure and evolved in Mobile ontology Core and Mobile subontologies. Mobile ontology Core comprises the telecommunications domain concepts and properties that occur most commonly and in various subdomains or application types. Mobile subontologies contain further details related to specific topics in telecommunications, and its items are linked to the items of the Mobile ontology Core. The Mobile ontology Core overview is depicted at Figure 2.

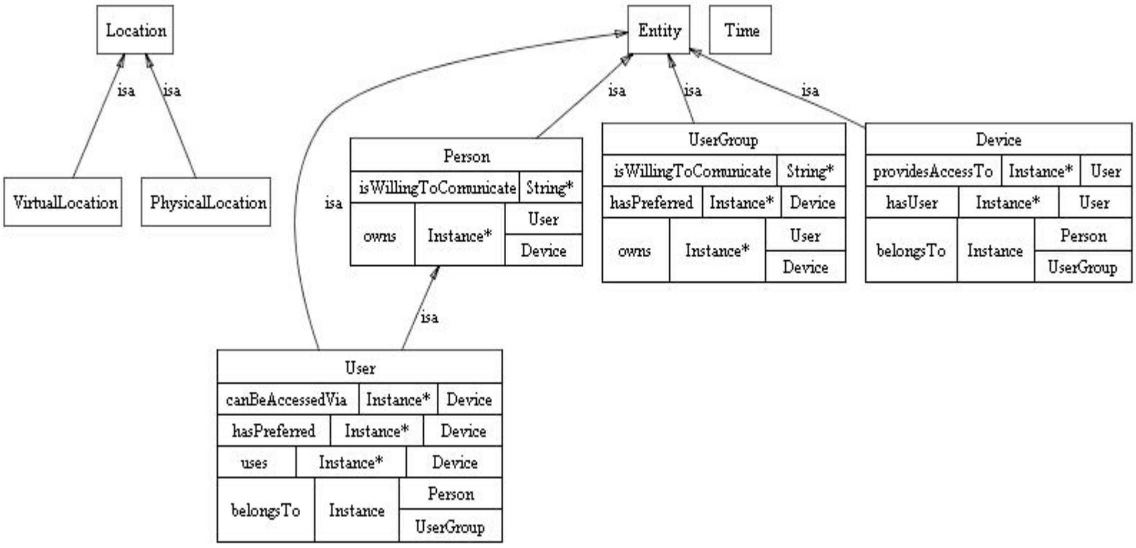

Figure 2: Mobile Ontology Core Visualization

Currently the subontologies on the following topics are being represented in the Mobile ontology infrastructure: Profile, Service, Service Context, DCS, Service Roaming, Rules and recommendations, Presence, Location, and Content. The up-to-date ontology versions and the status of the work are represented at the Mobile Ontology website[27].

Reuse of Schemata and Ontologies

Certain schemata covering the domains of the Mobile ontology exist and have already acquired significant communities. Such schemata can be either an output of the standardization bodies or coming in a "bottom-up" manner from companies and individuals and being widely accepted by the masses. These schemata and ontologies can be specified in different knowledge representation formalisms. We address external sources represented via the most popular formats, namely OWL, RDF/S and XML/S.

Relating and mapping these schemata to the Mobile ontology is mainly beneficial for interoperation of the Mobile ontology community with other mobile communities. Thus:

- mobile ontology developers and users benefit acquiring additional knowledge in the mobile communication domain captured in the existing OWL, RDF, XML schemas (i.e., reusing the present knowledge);
- users of the related ontologies and schemas benefit from a straightforward mapping of their schemas to the Mobile ontology that enables a simpler move to/involvement or extension of the Semantic technologies for these communities.

Technically, two different approaches to combine the Mobile ontology with the existing common ontologies and schemata will be considered, depending on whether the data is encoded via an ontology language (such as PDF/S and OWL) or only via XML.

Approach 1: RDF/S or OWL encoding

The following principles are valid when considering integration of Mobile ontology with ontologies of relevant topics expressed via RDF/S or OWL formalisms:

- when necessary directly reusing the agreed ontologies or their parts when modelling processes;
- establishing and using the library of mappings of these ontologies with the "higher" level Mobile ontology classes and properties that have similar items as the used external ontology. Such a mapping library would not be re-modelling, but stating relations between items in a machine readable format. Equivalence, for example, can be stated using constructions "owl:sameAs" so that applications and enablers can "understand" that an item from the Mobile ontology and an "imported" agreed upon ontology are the same.

The RDFS and OWL-based standard schemata considered for this approach are listed in Table 1.

Ontology name	**Ontology Web address**
UAProf	http://www.openmobilealliance.org/release_program/uap_v2_0.html
FOAF	http://www.foaf-project.org/
vCard	http://www.w3.org/TR/vcard-rdf

Table 1: OWL and RDFS -based Relevant Standards

Approach 2: XML encoding

The following principles are valid when considering integration of Mobile ontology with schemata of relevant topics expressed via XML formalisms:

- re-modelling XML schemata in OWL and providing the new sub-ontologies as relatively independent ontology sub-modules under the umbrella of the Mobile ontology;
- creation of the converters lifting up the instance data represented solely in the XML format to RDF.

So the ontology work with the existing XML schemas would focus on ontologizing/considering the knowledge present these schemas, and combining it with the Mobile ontology, and not extending these schemata.

The XML-based standard schemata considered for this approach are listed in Table 2.

Schema name	Schema Web address
Presence simple specification	http://www.openmobilealliance.org/release_program/Presence_simple_v1_0.html
Basic Presence Data model	http://www.ietf.org/rfc/rfc3863.txt
Generic Presence Data Model	http://www.rfc-editor.org/rfc/rfc4479.txt
Rich Presence Information	http://www.rfc-editor.org/rfc/rfc4480.txt
Location Types Registry	http://www.ietf.org/rfc/rfc4589.txt
A Presence-based GEOPRIV Location Object Format	http://www.ietf.org/rfc/rfc4119.txt

Table 2: XML-based Relevant Standards

The following goals addressed by Mobile Ontology are open challenges for the current state of the art:

- the first comprehensive higher level ontology for mobile communication domain that is constructed with involvement/support of major players in mobile communication area, i.e. the ontology (i) responds to the needs of mobile service developers, (ii) is evolving, (iii) representatively captures the domain in an unbiased fashion;
- the most large scale international investigation on the use of Semantic technology in mobile communication domain.

Collaboration Aspects

Mobile Ontology construction has been initially implemented within two major deliverables of SPICE EU project. 25 persons from 10 industry and research organizations stemming from 6 European countries have been initially involved in this specific cross issue. Therefore, apart from the definition of the up-to-date ontology infrastructure for Mobile services, the results of this study include observation of collaboration aspects of developers and users in the ontology construction.

Here we show how involved parties collaborated on the ontology construction, and what personal involvement expectations for a larger scale ontology infrastructure would be. In Figure 3, the extent to which the developers have been typically involved in initial definition of the ontology is demonstrated. The figure shows that most contributors tend to provide minor extensions to the ontology or choose a role of the user, which also confirms the previous research (Zhdanova, 2006).

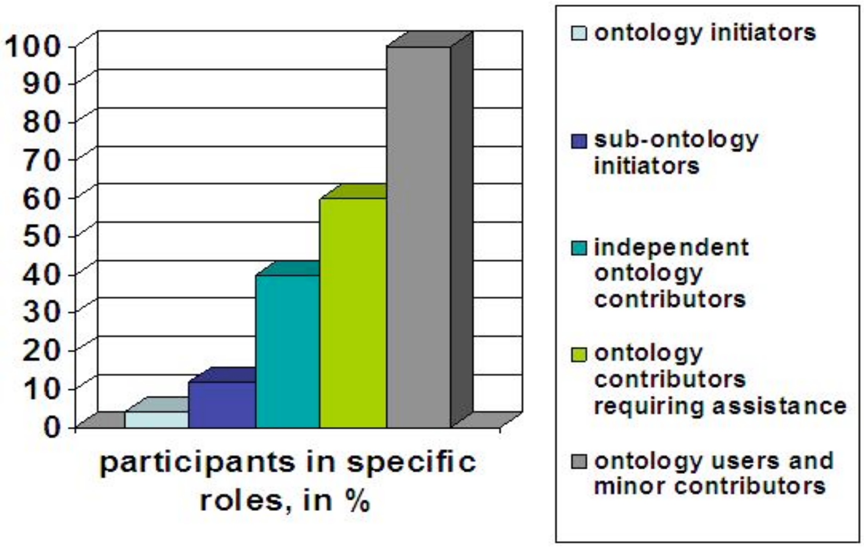

Figure 3: Collaboration Patterns in Mobile Ontology Construction

Summarising, the main challenges identified in collaborative ontology construction as they have been observed are as follows:

- **Educational:** people with no/little knowledge on ontologies require *at least an introduction to the field*;
- **Methodology:** yet *no widely accepted or best practice solutions* on how to acquire ontologies from people in such a setting;
- **Basic technology:** current ontology language standards (such as OWL) cause *confusion and awkward modelling solutions*;
- **Tool support:** *better tools for ontology construction process coordination, documentation* would help to avoid ad-hoc solutions and manual work.

Ontology-based Multimedia

Nowadays, network access technologies, such as Bluetooth, WiFi, WiMAX, are bringing the dream of ubiquitous service provision closer to reality. Ubiquitous service provision is of interest to service providers, telecommunication operators and technology manufactures for their future revenue prospect. However, the barriers to the delivery of ubiquitous services arise from the desire to deliver a wide service mix to users having a wide range of access devices via a multitude of heterogeneous access networks with different preferences and likings. Most of the existing applications and services are created and provided assuming a traditional pre-set delivery method and homogeneous transport media, which indicates a great importance and necessity for content and service adaptation in order to deliver them in such a ubiquitous environment. Such adaptation must be 'context-aware' and must facilitate user and situation specific content and service provision.

Therefore, the information from all the parties involved in the content and service delivery chain will form a contextual knowledge base that is shared by different operational agents in order to come up with a delivery or adaptation decision autonomously. These agents are generally heterogeneous in nature and distributed across networks. How to describe and represent such a knowledge base is fundamental to the development of a content and service adaptation framework which supports ubiquitous service delivery. This work has formed part of the Ubiquitous Services Core Research Programme of the Virtual Centre of Excellence in Mobile & Personal Communications, Mobile VCE.

Ontology has been recognized as the knowledge representation scheme and OWL as the knowledge representation language. However, to define a set of commonly-agreed vocabularies for the adaptation domain remains as a challenging issue. The ubiquitous content/service adaptation domain involves multiple sub-domains, i.e. the user domain, the content/service domain and the adaptation operation domain. Many efforts have been seen in recent years aiming to reach a description standard including vocabularies in order to achieve maximum acceptance and interoperability among communities. So far, the widely-acknowledged standards include usage environment description standards describing user information, device and network characteristics etc., such as CC/PP, UAProf and MPEG-21, and content description standards such as MPEG-7. Among those, MPEG-7 (ISO/IEC JTC1/SC29/WG11 N3752, 2000) and MPEG-21 DIA (ISO/IEC 21000-7, 2004) provide a good combination to linking content description with user environment description besides their well-established comprehensiveness in describing the respective domains. MPEG-7 offers several tools, i.e. Description Schemes (DS), to annotate multimedia content at different levels. These include Description Definition Language (DDL), Visual Schemes, Audio Schemes and Multimedia Description Schemes etc. MPEG-21 provides tools to describe the environment to enable transparent multimedia creation, delivery and consumption between heterogeneous environments. The most relevant part within MPEG-21 standard for the adaptation domain is Digital Item Adaptation (DIA). It provides tools to describe the user environment including: user characteristics, such as user info, preferences, usage history and physical characteristics, Device characteristics, such as display, memory and battery, Network characteristics, such as error characteristics and bandwidth, and Natural Environment characteristics such as noise and illumination.

Recent research efforts have reflected the recognition of using MPEG-7 and MPEG-21 DIA, together with ontology-based technologies, to construct an ontology to support the content/service adaptation (Soetens et al., 2004; Jannach et al., 2006). Though OWL has been chosen as the description language, Soetens et al. adopted limited usage of MPEG-21 vocabularies due to the immaturity of this standard at the time of writing (Soetens et al., 2004). In (Jannach et al., 2006), though MPEG vocabularies are adopted to form the domain ontology, the representation remains its original format of XML. With the actual adaptation operations being described in OWL-based language, this work realizes the integration of the different representation formats on the technical level using XML-based and logic-based technologies. Therefore, although MPEG-7 and MPEG-21 standards have been acknowledged for their strengths in multimedia domain description and delivery, their strengths can be still greatly enhanced by adding machine-processable semantics via ontology representation languages, such as OWL and RDF(S).

There exist several efforts to construct ontology representations of MPEG-7 and MPEG-21 (Hunter, 2001; Garcia, 2005). Those efforts construct ontology automatically by means of XSLT transformation according to the rules specified in (Garcia, 2005). By automatically converting the XML tree structure, the obtained ontology describes the relationship between the types of the tree element instead of describing the relationships between the semantics embodied by the tree elements. Although this approach expresses the XML-based standards in an OWL or RDF format, it does not add much semantic expressiveness to them. Such approach would be applied in any automatic XML schema to OWL conversion regardless of the semantics of the respective domain. In (Li et al., 2007), it argues that, for an expressive OWL representation of the XML-based standards, manual conversion is necessary. The manual conversion may result in some XML elements being discarded or treated with another XML construct as one OWL concept as a consequence of its semantic interpretation. There are no rules on how to manually convert an XML schema description into OWL ontology. Different from automatic conversion, which merely translates the XML syntax to OWL syntax, manual conversion has to examine the elements and the attributes of the XML schema, study their semantics, and translate them into OWL constructs.

CONCLUSIONS

State of the art and trends in convergence of the Semantic Web and mobile communication fields are presented in this article. Knowledge representation formalisms, relevant research fields, relevant ontologies are detailed, and the challenges of Semantic technology application to the mobile communications have been discussed. State-of-the-art examples of the work in this area have been outlined, including the development and use of ontology infrastructures that can serve as a semantic basis for applications and enablers within the convergence of the mobile and the Web worlds.

In a nutshell, one may conclude that (i) there exist a large number of ontologies addressing context-awareness and mobile communication issues, (ii) these ontologies are difficult to find and they are not or weakly linked and connected to each other. Factually, most of the time they do not form Semantic Web as the Web is about linking the data (and the users thus obtaining the typical Semantic Web benefits, such as interoperability), which is not the case for the current Semantic Mobile Communications.

FUTURE RESEARCH DIRECTIONS

The questions for the further research and development include: How to make these ontologies collaboratively constructed, linked to each other, easily found, used and evolved? And more specific, follow-up questions thus are:

1. How to involve developers and users in community-driven ontology construction and to what extent one should expect their involvement?
2. Which technical infrastructure is needed to implement this vision?

Ontologies are evolving as the domain is evolving and capturing the whole domain and all the needs by a (small) group of ontology developers alone is ineffective (Zhdanova, 2006). The ontology infrastructure for ubiquitous mobile communications should provide a user-friendly support to the ontology-based context-aware application and service developer with the following methods:

1. key-word based ontology search (e.g., similar to OntoSelect[28], Swoogle[29]),
2. extraction and segmentation of the required ontology parts (e.g., operated on a level of triples and eventually on demand arranged in a stand-alone schemata),

3. in case no existing relevant ontology parts are found in the ontology platform infrastructure, possibility to plug in freshly developed ontologies and extensions,
4. simple ontology instantiation, with a subsequent simple discovery and use of the instance data,
5. ontology matching and alignment to the existing ontologies in case of duplicated modeling discovery, e.g., in a community-driven manner (Zhdanova & Shvaiko, 2006),
6. search of relevant data within the instances (e.g., employing technologies such as YARS (Harth et al., 2006),
7. in case the developer made new ontology design/extensions, allow him/her easily plugging in the evolved versions of his/her ontologies/extensions, keeping up with the agreed ontology versioning practices.

In conclusion, the starting points for the integration of the fields of Semantic Web and ubiquitous mobile communications exist both on the ontology schemata level as well as on the tools level. However, practices and processes for the common usage of the technologies originating from these two fields are still to be acquired. It is expected, that the new practices and processes are also to influence the future development of applications, services and tools appearing in the unified field.

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ENDNOTES

1 vCard: http://www.w3.org/TR/vcard-rdf
2 CC/PP: http://www.w3.org/Mobile/CCPP/
3 UAProf: http://www.openmobilealliance.org/release_program/uap_v2_0.html
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