

Context-aware systems: a case study

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Abstract. Context aware systems are a promising approach to facilitate daily-life activities. Concerning communication services, business users may be sometimes overloaded with work so that they become temporally unable to handle incoming communications. After having surveyed the challenges to build context-aware systems, we introduce here HEP, a system that recommends communication services to the caller based on the callee's context. HEP's main context source is the usage history of the different communication services as well as the users' calendars. It has been prototyped and tested at Orange Labs.

Keywords: Ubiquitous Computing, Context-Awareness, Recommendation Systems, Communication.

1 Introduction

Nowadays ubiquity is everywhere, fully embedded with smart devices integrating intelligence for processing various kinds of data. In such an environment, the interaction and management of all various devices that a user may hold will be a tough task. Context-aware systems are an emerging solution to alleviate such tasks; they will be in charge of supervising the way users interact with the ubiquitous environment for automating users' repetitive actions. For example, a context-aware system can detect that a user never responds to phone calls while driving, and thus propose to transfer automatically all incoming calls to his/her voice box whenever he/she is driving.

Lots of definitions have been proposed to define context and context-awareness clearly. However, most researchers agree with A. Dey [Dey00] when he describes the context as:

“Any information that can be used to characterize the situation of entities (i.e., whether a person, place or object) that are considered relevant to the interaction between a user and an application, including the user and the application themselves.”

Context information may be classified according to the described entity. The context of a user may be a combination of various entities such as his/her identity, activity, location, mood, etc.; his/her social context may be the nature of his/her relationship

with other persons (e.g. family member, colleague, friend...); his/her physical context might include for instance the lighting level of the location where he/she is standing. The context of a network may be its QoS (Quality of Service) parameters like RTT (Round-trip Time). The context of a device may be its capabilities, display features or battery level.

Due to the computation complexity of managing all possible pieces of context information, context-aware systems should choose a subset of this context information that is relevant to the application. For example, a context-aware system aiming to choose the suitable network access (e.g. EDGE, Wi-Fi) based on the user's context should have as fundamental context information such as the user identity, location, time, the available access network and its QoS parameters.

A context management system (CMS) is defined as follow in [Dey01]:

"A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task".

Different approaches have been proposed for the development of CMSs. From the conceptual viewpoint, CMSs are mainly based on the Producer-Consumer design pattern where context sources (e.g., sensors) play the role of Producers, and context-aware applications play the role of Consumers. From the implementation viewpoint, CMSs can be classified into centralized or distributed architecture. In the centralized architecture, a central point often named broker [Che03b] is introduced between the producers and consumers. All context requests are handled by the broker, which forwards it to the right component. Producers and consumers are then decoupled, while in the distributed architecture, the different components have to know each other (e.g., by regularly sending multicast or broadcast messages for announcing themselves), like in the middleware-based CMS [Gu04b].

Many challenges face the field of context-awareness ranging from the collection of contextual information with the use of sensors (e.g. calendar, light, battery charge, etc.), to the modeling of context that can be anything (e.g. GPS location or a street address, time, etc.) and reasoning about it to produce an adaptive behavior (e.g. automated call transferring, the proposal of a meeting session, etc.). Starting from a real use case, our work shows how the challenges can be addressed when only relevant subset of the user's context is chosen.

In this paper, we first present the current researches in context-aware systems, by analyzing the ongoing works and the key issues for designing context-aware systems. We then introduce the major application fields of context-awareness. We finally present a case study on HEP, a centralized context-aware recommendation system designed, prototyped and experimented at Orange Labs, that takes as context information the usage of communication services.

2 Designing context-aware systems

2.1 General overview

From the functional viewpoint, context-aware systems can be represented as a layered framework [Bal07] [Lok06] (figure 1) composed from bottom to up by: sensors, raw

data retrieval, preprocessing, storage/management, and application layer. The Context Management System (CMS) is responsible of retrieving raw data from sensors, abstracting and combining the sensed data into high level context, and then of making it available for context-aware applications.

The first layer (Sensors) is a collection of sensors responsible of retrieving raw data from the user environment (e.g. user device, social network, or used access network). Context sensors can be classified into:

- Physical sensors or hardware sensors that are able to capture physical measurements like light, audio, location, temperature;
- Virtual sensors that are able to sense data from software applications or services (e.g. sensing calendar entries);
- Logical sensors that are able to aggregate information from different sources (combine physical, virtual sensors with additional sources like databases) to perform complex tasks.

The second layer (Raw data retrieval) makes use of specific API or protocols to request data from the sensor layer. These queries must be as far as possible implemented in a generic way, making possible to replace sensors (e.g. replacing a RFID system by a GPS one).

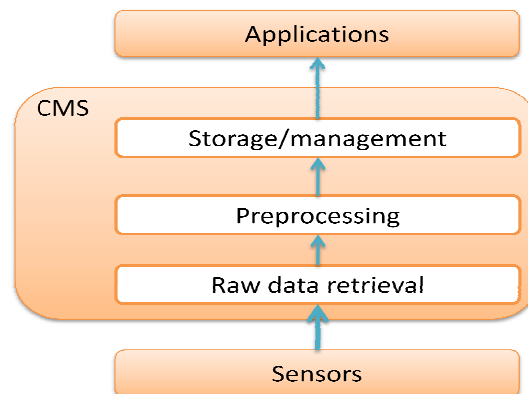


Figure 1: Layered framework for context-aware systems

The third layer (Preprocessing) is responsible for reasoning and interpreting contextual information. It transforms the information returned by the underlying layer to a higher abstraction level (e.g. it transforms a GPS position to a position like at home or at work). Not only sensed or deduced data have to be modeled, but also meta-data describing them (e.g. accuracy and recall, or life cycle information).

The fourth layer (Storage and Management) organizes the gathered data and make them available to 3rd parties applications in a synchronous or asynchronous way. In the first mode, the 3rd party applications use remote method calls for polling the server for changes. In the second mode, they subscribe to specific events of interest, and are notified when the event occurs (for example by a call back).

The fifth layer (Application) is where the reactions to context changes are implemented (e.g. displaying text in a higher color contrast if illumination turns bad). We will now highlight some key aspects of CMS.

2.2 Context modeling

Related works in the development of context-aware systems have tried different approaches for modeling the used context information [Tru09]. Most of these works distinguished between context information modeling and implementation technologies. For example, UML may be used to model the context information while XML is used to describe data instances.

Key-Value data structure (where the key is the context, and the value is the corresponding sensed information) is the simplest representation. However, it lacks of richness, and do not support interoperability and the representation of relation among context information. Key-Value has been used in some early works, for instance by Dey [Dey01b] and Yamabe [Yam05].

XML-based languages are interesting candidates for modeling context because they rely on a widely used standard that provides the possibility to hierarchically represent context and to abstract it from low to high level. Much work was done to propose a generic XML-based language for both context modeling and implementation. In [Ven10] and [Kna10], the authors propose ContextML which is an XML-based language for representing user context that has been developed as part of the C-CAST¹ European Project [Zaf10]. In [Fer06], the authors propose an XML-based language named PDDL (Pervasive Profile Description Language) to describe profile of mobile peers and to support their interaction in a pervasive environment. The profile is enriched dynamically at runtime based on changes occurring in environment conditions.

MDA (Model Driven Architecture) is another interesting approach for the development of CMS [She05]. It enables to create high level UML models or strictly speaking MOF (Meta-Object Facility) compliant models of the system, then based on these models, the implementation stubs are automatically generated alleviating tremendously the work of developers. UML-based modeling language offers the full power of object orientation (encapsulation, reusability, inheritance) and also design flexibility by separating the modeling of context and context awareness from the service components. ContextUML, as well as the SENSEI European Project [She05] are examples of such context modeling languages. The context knowledge base can then be represented in a relational database (e.g. MySQL), as in [Che04].

RDF [Rdf04] (Resource Description Framework) is a language for describing tagged oriented graphs. It is based on triplets (subject, predicate, and object). The subject is the described resource, the predicate represents a propriety type that can be applied to this resource, and the object represents data or another resource. Each triplet corresponds to an oriented arc tagged with the predicate, where the source node is the subject and the destination node is the object. RDF schema has been extensively used for context modeling [Tru08b]. Some vocabularies have been standardized on

¹ <http://www.ict-ccast.eu/>

top of RDF to define context profiles like CC/PP [CCPP] (Composite Capability/Preference Profile) and UAProf [UAProf] (User Agent Profile). They have been combined with other modeling languages like FOAF² (Friend of a Friend) for modeling Person Organization, Group, Document and Project; vCard³ for modeling addresses and personal data, Basic Geo for modeling geo-spatial context, vCal⁴ for modeling events, ResumeRDF⁵ for modeling skills and expertise of team members, and the Time ontology for modeling temporal context. However, the RDF language suffers from some limitations for the reasoning aspects, and current work is more and more relying on ontology.

Ontology is a formal and explicit description of concepts from a particular domain, and of the relationships between these concepts. It provides a vocabulary for representing domain knowledge and for describing specific situations in this domain. Using ontology for context modeling allows a semantic description of context. It enables then to share a common understanding of the context structure among users, devices and services. It also allows formal analysis of domain knowledge, i.e. reasoning using first order logic. OWL⁶ (Web Ontology Language) is an ontology language based on a RDF (Resource Description Framework) schema. It enables to define rich vocabulary and to describe complex ontologies. OWL ontologies have been extensively used for context modeling, for instance in [Alm06], [Gu04], [Ha07], [Che09], or CoBrA [Che03] ontology (COBRA-ONT).

XML, RDF and OWL-based approaches are open and interoperable. Particularly, RDF and OWL offers the reuse of the common vocabularies while for XML there is no standard way for exchanging vocabularies. Associating RDF schema with OWL ontology can increase the expressiveness of the context description by drawing the relationship between a low level context information (e.g. the user is present in room 528) and high level one (e.g. the user is attending a meeting). As for UML, it is not directly compatible with XML/RDF/OWL, but it presents the advantage of being seamlessly integrated with MDE (Model Driven Engineering). This point is especially interesting when the whole CMS is designed using the MDE software approach.

It is interesting to store historical context data because it can be used to establish trends and predict future context values. Relational databases are usually used for context storage as plenty of available libraries allow the serialization of XML, RDF or OWL data.

2.3 Quality of Context

Context information can be retrieved from different kind of sensors having different level of reliability. Also, noise or failure of sensors can introduce imperfection on the sensed context. Other types of imperfections are ambiguity, imprecision, error. The notion of QoC (Quality of Context) aims to measure the imperfection of sensed information. A good example of QoC modeling is [McK09]. The authors propose an extendable UML-based model for context quality. They define three context levels

² <http://www.foaf-project.org/>

³ <http://www.w3.org/Submission/vcard-rdf/>

⁴ <http://www.imc.org/pdi/>

⁵ <http://rdfs.org/resume-rdf/>

⁶ <http://www.w3.org/TR/owl-features/>

(sensor, abstracted context and situation). For each level a set of quality parameters is defined. At the Sensor level: Precision (indicates the maximum deviation of a measurement from the correct value), Accuracy (indicates error rate or frequency correctness of a sensed information), Frequency of sensor readings; At the Abstracted context layer: Fuzzy membership (quantify imperfections of vague context) used when fuzzy context filters are used during abstraction process, for context filters with clear boundaries (e.g. location) the Precision membership is derived from Precision readings, Reliability (error rate associated with a context event). A context Confidence is derived for each context event from a combination of context event quality parameters. At the Situation level, there is a Confidence quality parameter to assess the truthiness of the corresponding situation. This parameter value is calculated based on the used reasoning scheme (neural networks, Dempster Shafer, voting).

2.4 Context Reasoning

Inferring new knowledge (e.g. transportation mean) from raw sensed data (e.g. GPS position) is important for context-awareness and adaptation to the user's context changes. But before being able to infer any new knowledge, some processing has to be done. Context processing can be divided into aggregation and interpretation. The former refers to the composition of raw context information either to gather all context data concerning a specific entity or to build higher-level context information. The later refers to the abstraction of context data into human readable information.

The inference can be done with help of sophisticated reasoning techniques that relies mainly on context representation. For example, SPARQL-based semantic reasoning techniques can easily be done if the context representation technique is based on OWL. Ontology learning techniques can be used to derive new facts given a knowledge base of specific facts and an ontology describing concepts and relations among them. Machine learning techniques (e.g. Bayesian networks, fuzzy logic) can be used to construct higher level context attributes from sensed context. Combing both reasoning techniques can be interesting as demonstrated in [van06]. Expert Systems (e.g. JESS, CLIPS) or Rule inference engines can also be used in context reasoning. Such reasoning systems inherit from forward-chaining inference the power of inferring knowledge (i.e. logical consequences) from sensed data (i.e. facts) and from backward-chaining inference the power of recognizing relevant context (i.e. facts). Knowledge might also be deduced using the Jena framework that provides ontology inference facility, and Jess (Java Expert System Shell) to implement forward-chaining inference. Jess is used when it is not possible to reason about context information with only ontology axioms, as described in [Ram09]

Reasoning techniques are not widely supported. Also, OWL representations are hardly manageable (implementation/integration) and reasoning on XML data or UML class diagrams is not very developed. Reasoning with logical expressions like in Expert Systems allows a rich description of situations, actions and knowledge derivation due to the use of logical connectives (*and*, *or* and *not*), implications, universal and existential quantifiers.

3 Context-aware applications

Context-awareness will affect our daily life in all its dimensions (at home, at work, in public spaces, etc). It provides indeed a way to adapt the behavior of applications in order to meet user expectations, for instance by specifying the actions that an application should apply in a given situation. This service adaptation principle might apply in very various fields, such as: service selection [Tru08a], task adaptation [Tru08b], security and privacy control adaptation to apply an access control given a situation, communication adaptation [Her08] to select a communication protocol and optimize the communication, or content adaptation [Zim07] to adapt content resulting from a request and return the content in suitable form.

In this section, we focus on some usually envisaged context-aware applications: Location-Based Services (LBS), Context-Aware Communication (CAC), context-aware buildings and Context-Aware Recommendation Systems (CARS).

LBS are very developed context-aware systems that are mainly based on location as a fundamental context dimension. According to E. Kaasinen [Kaa03]

“Location aware services or systems are defined as context-aware services that utilize the location of the user to adapt the service accordingly“.

A plenty of commercial LBS for mobile devices have been developed like Nulaz (Pan07), Foursquare⁷, Gowalla⁸, Loopt⁹. These services are based on both outdoor location (mainly GPS) and social networks and sometimes augmented reality technologies (e.g. Layar¹⁰). The main idea around them is helping people to locate their friends and interesting places to visit or where to meet with friends. Another example of LBS is location-based messaging services [Num07] like Socialight¹¹, InfoRadar [Ran04], Heresay [Pac05].

Context-aware communication (CAC) applications apply knowledge of people's context to reduce communication barriers [Sch02]. Many scenarios of context-aware communication can be imagined like those presented in [Num07b] based on non-verbal and electronic communication services (e.g. SMS, MMS, chats, e-mail, electronic message boards and mailing-list):

- Seeing whether a previously sent message, especially an urgent one, has already been delivered to the recipient and whether the recipient has already read it;
- Restricting what context information about you other persons are allowed to see in different situations;
- Leaving messages to certain places for anyone that arrives at the same place to read, which can be compared to an electronic bulletin board;
- Notifying user about the reception of message in appropriate situation, for example notify a user only when he is in coffee break about a message left by a friend asking him for a week-end skiing.

⁷ <http://foursquare.com>

⁸ <http://gowalla.com/>

⁹ <http://www.loopt.com/>

¹⁰ <http://www.layar.com/>

¹¹ <http://socialight.com/>

Context-aware buildings are another promising study field. In [Mey03], the authors presented some futuristic image of what will be a house fully embedded with sensors and intelligent devices in order to support healthier everyday life of users. For example phones will ring only in the room where the callee is located to avoid disturbing everyone in house; lights and sound will be automatically adjusted based on the user who is present in the room; family member will be able to communicate as if they were in the front of each other, even if they are in different rooms; assistance of older people will be enhanced and their health conditions will be continuously assessed. According to [Fuj07], a context-aware home will change society conventional lifestyle, and especially in health management by changing the purpose of medicine from treatment to prevention, the location of healthcare from hospital to home, and the method of obtaining information on diseases from periodic to real time examination.

Context-Aware Recommendation Systems (CARS) aim to recommend a service or a product to a user based on his context. A lot of works have been conducted specially for recommending movies [Bog10], motivated by very well awarded competitions like Netflix¹². For the recommendation to be relevant, CARS need to collect and to process a great amount of data (about products rating, users preferences, historical data, etc.) to predict the most relevant product or service to a user. In this paper, we have applied CARS concepts to communication services, by processing data retrieved from the Microsoft communication suite.

4 Case study: HEP

4.1 Usage scenario

Current advances in ICT (Information and Communication Technologies), especially in professional environments, are enhancing communication between co-workers. In the same time, these technologies add a certain amount of stress to workers because they are losing the control on the way they can be reached and at what time. Also, the diversity of the used communication tools (e.g. Email, IM, Video conferencing) amplifies the amount of notifications or interruptions (e.g. when an email is received) they cause to the workers. This may cause degradation on the worker performance on his current activity or influence the choice of the future ones [Hud02]. Hence, it's important to control when interruptions occur on behalf on the user in order to not affect his performance. One possible solution is to delegate the control of interruptions to his contacts by sending to them his contextual information. The information will help users' contact to evaluate the importance, at this time, of the interruption they will cause.

In this aim, we have developed HEP a context-aware system for recommending communication means for enterprise employees. The system publishes real-time information describing their status, emotions, activities and workload. The published information are results of processing diverse input streams concerning the usage of

¹² <http://www.netflixprize.com/>

communication services (phone, IM, e-mail, calendar). The nature of the inputted information as part of the user context, how it is retrieved and how it will be processed make CMS the suitable management system, and context-aware system the suitable kind of application.

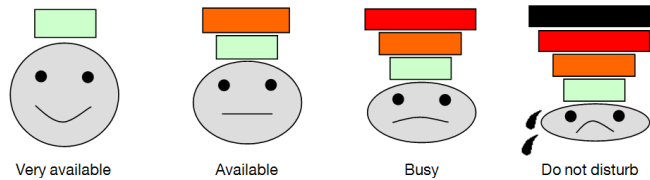


Figure 2: HEP statuses

Figure 2 presents the different statuses of a user: "Very available" corresponds to the state where user is highly available for receiving communication requests (e.g. phone call, IM request); "Available" corresponds to the state where user can receive call requests; "Busy" corresponds to the state where user can weakly respond to a call request; "Do not disturb" corresponds to the state where user cannot respond and will potential refuse incoming communication requests.

A status corresponds to the level of availability of a user on a given communication service (e.g. agenda, email, instant messaging, phone). Such information is used by the caller to decide if he can interrupt the callee, and if it is better to use a communication service (e.g. email) than another service (e.g. phone) in order to reach the callee. For instance, let us suppose that Alice wants to call Bob for an urgent matter. Bob is at this moment in a conference call, but he is still reading his emails and answering them. With HEP, Alice will see that Bob is busy on the phone, but available by email. She decides thus to send his an email instead of calling him, although her demand is urgent.

4.2 Service design

Our system (figure 3) is developed in .Net and is based on OCS 2007 (Office Communication Server). The different elements composing the architecture are: a PC client, an Outlook plug-in, and a broker.

The PC client implements the two first functions of a CMS. It is responsible for:

- Retrieving raw data from virtual sensors placed on Microsoft communication suite (Email, Calendar, Instant Messaging, fixed telephony),
- Computing user status for communication mean,
- Interacting with the broker.

The Outlook plug-in provides the user interface. It enables the user to set his preferences (e.g. the status that should correspond to a given load level), and above all it enables the user to see the statuses of each of his Outlook contacts.

The CMS storage and management functions are implemented in the broker that offers a directory service. PC clients subscribe and publish their status. And Outlook

plug-ins requests the status of other users. An administration interface is available to set global rules for status computation.

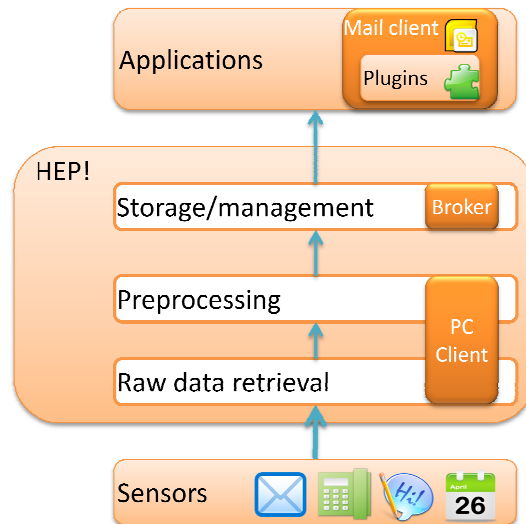


Figure 3: HEP architecture

Computation of user status is based on information about the history of usage of communication services (e.g. email) and desktop applications (e.g. Word, Excel, PowerPoint). The frequency of computation and freshness of status depends on the related communication service, but can be fixed by users when they specify their preferences.

4.3 Context modeling

We gather the different contextual information (both sensed and deduced ones) in an UML data model as illustrated in Figure 4. The BaseObject class is the root class in the model that is common to any type of context information. The InteractiveCom class gathers the shared attributes of interactive communication tools, while information specific to a communication tool is gathered in a specific class (e.g. Instant Messaging, email, phone). A specific class is dedicated to calendar information.

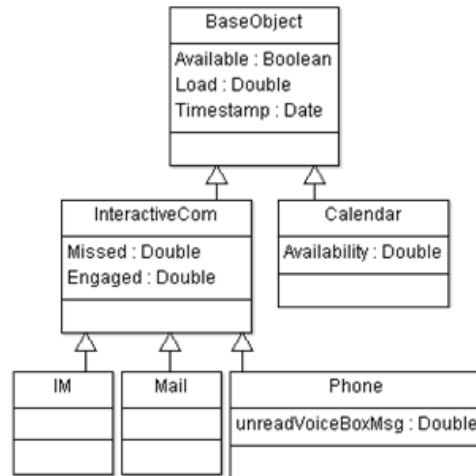


Figure 4: HEP Data Model

The description of the different attributes is as follow:

- Available: is a sensed data that represents whether or not the user is available at a given instant in a communication tool (e.g. for calendar it can be interpreted as the user is currently not in a meeting);
- Load: is a deduced data that represents work load of user corresponding to a communication tool (e.g. for calendar, load is the ration of the total amount of meeting time to work time), it correspond directly to the user status (figure 2);
- Timestamp: represents for how long the sensed information remain valid, it depends on communication tool (e.g. 5mn for Mail, 15mn for Calendar);
- Missed: represents the ratio of missed communication requests (e.g. missed phone calls, IM requests or unread mails) to the received;
- Engaged: ratio of engaged communication to the received ones;
- Availability: ratio between free time and total amount of meeting;
- unreadVoiceBoxMsg: ratio of unread message from the user's voicemail to the stored ones.

4.4 Context reasoning

The sensed information are used to compute the work load of a user on a given communication tool in order to determine the user status and whether or not he can accept incoming requests on this communication tool (figure 5). We defined rules for calculating the work load level for each communication mean (IM, mail, phone, calendar).



Figure 5: User status based on his work load level

In the case of calendar, if the user is currently in a meeting then we set his calendar work load to 100%. Then, the more the meeting start time gets closer, the more the calendar work load goes higher (e.g. 5m before a meeting, work load reaches 75% and user status become 'busy'). If the user is not in a meeting then calendar work load is the ratio of meeting duration in the rest of the day to the remaining work time.

Follow is an example of the calculation of the calendar work load of a user at different time of day. We consider that a work day start at 8:00 and finish at 18:00, and the user have a first meeting from 9:00 to 11:00 (2h duration), then a second one from 15:00 to 18:00 (3h duration). Thus, at 8:00 work load is $(2+3)/10 = 50\%$, from 9:00 to 11:00 work load is 100% (user in meeting), at 12:00 work load is $3/6 = 50\%$, at 14:00 work load is $3/4 = 75\%$, and between 15:00 and 18:00 work load is 100%. We add a layer of abstraction by introducing the user global status that reflects the global workload. It is computed by combining the status related to the different communication means, with predefined weightings that can be modified by the end-user.

4.5 Future works

HEP has been deployed on the workstations of our coworkers at Orange Labs (Caen, France), and we received very positive feedbacks. The integration with the everyday working tools (e.g. Outlook) was especially approved. From the implementation viewpoint, several lessons can be derived.

The current reasoning technique is built with a set of IF-THEN clauses implemented in a C# class. We believe it is enough for a proof of concept solution, and we plan to use more sophisticated techniques like those provided by rule engines. For the context modeling language, we used an UML data model to take benefit of encapsulation and inheritance. The current modeling approach do not include metadata especially QoC parameters, we plan to include them in our future works. We found that these parameters are as important as sensed data themselves especially for managing very common situations where software crashes.

In our current solution, context processing including reasoning are performed at the client side. Such solution makes the deployment of new reasoning techniques for new included context data (e.g. about the usage of other office tools) more complicated. To overcome this issue we are planning to transfer a part of the preprocessing layer (figure 1), namely the reasoning part, to the broker side.

5 Conclusion

In this paper we surveyed the previously conducted works in the field of context-aware systems from different viewpoints like system design, context modeling and

reasoning. After having highlighted the challenges to face when building context-aware systems and the major application fields for such systems, we proposed a context-aware system for recommending communication means. Our system helps users to choose the appropriate communication mean for contacting a person based on the context of the later. The aim behind the developed prototype is to build a context-aware system with the existing approaches in sensing, modeling and reasoning, to use it as a solution for a real problem, and experiment it with users in a real environment.

Besides the enhancements introduced in the previous section (lessons learned), we plan to expand our system with the ability to transform, in a transparent way, the format and the delivery time of a message based on the user's context. A message sent as an SMS at time t could be received, for instance at time $t + t'$ as an email, given that the user is unreachable at t but may be reached at $t + t'$ by e-mail only because he/she is still on the phone. We believe that this could lead to a new and seamlessly way to use our daily communication means.

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