Ubiquitous Attentiveness – Enabling Context-Aware Mobile Applications and Services

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Abstract. We present a concept called 'ubiquitous attentiveness': Context information concerning the user and his environment is aggregated, exchanged and constitutes triggers that allow mobile applications and services to react on them and adapt accordingly. Ubiquitous attentiveness is particularly relevant for mobile applications due to the use of positional user context information, such as location and movement. Key aspects foreseen in the realization of ubiquitously attentive (wearable) systems are acquiring, interpreting, managing, retaining and exchanging contextual information. Because various players own this contextual information, we claim in this paper that a federated service control architecture is needed to facilitate ubiquitous attentive services. Such a control architecture must support the necessary intelligent sharing of resources and information, and ensure trust.

1 Introduction

Nowadays, our everyday world offers us a heterogeneous environment with multiple network providers, several mobile and wireless technologies, numerous terminals, manifold administrative domains and various application providers. On the other hand millions of users co-exist that all have different interests and priorities. Providers may want to tailor their services to the end-user preferences and available resources. In addition, knowledge about situational contexts, such as location, nearby facilities, available resources, and preferences of (other) parties, can be quite beneficial in tailoring as well. Hence, there is a clear need for open service architectures that enable these ubiquitous attentive services.

Context can refer to any relevant fact in the environment. Examples are users' location and related parameters (coordinates, being indoors or outside, velocity, temperature, humidity etc). Also the facilities users have at their disposal (cellular phone, PDA, Operation System and software running on mobile device, graphical capabilities, etc) form bits and pieces of the context. Further context information includes users' preferences. What do we like (e.g. spoken or written messages: while driving a car possibly spoken messages, while at the same time the car stereo volume should be

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lowered) and who may interrupt us (e.g. while being in a meeting, or giving a presentation: in these cases a disturbance normally is not preferred for a social chat, in contrast to the case that a serious accident has happened to one of your family members). Also nearby persons and services have a relevancy to mobile users as well as to mobile application providers. All these (and more) information pieces form integral parts of the (user) context. Context information can thus be defined as any information that can be used to characterize the situation of an entity.

Context awareness functionality provides the means to, starting from the user, deliver optimal tailored applications, services and communication. This requires functionality to sense, retain and exchange the context in which a person is in at a certain moment in time. The facilitating technologies and supporting architectures thus need to supply context-awareness functionality, and moreover ability to take appropriate action accordingly. The latter implies an exchange between systems (platforms, domains, terminals, parties, etc) and a pro-active response of the environment are essential too. These three paradigms together constitute ubiquitous attentiveness:

- Ubiquitous computing (loads of small sensors, actuators and terminals).
- Information processing and exchange between different systems in different domains.
- Pro-active responsiveness of the ubiquitous environment.

Our current paper addresses key aspects of ubiquitously attentive (wearable) systems that need to be solved to facilitate a mobile user in a global and heterogeneous environment. The organization of the paper is as follows: after addressing key issues and requirements of ubiquitous attentiveness we illustrate them by a near futuristic mobile medical service scenario. In the following section we point out how to retain the envisioned ubiquitous attentive mobile services using commonly available technologies.

2 Key Issues and Requirements

There are many issues in the mobile and wireless settings that ask for sophisticated technological and architectural solutions:

- Information sources are heterogeneous in nature and are distributed across heterogeneous environments with unpredictable and dynamically varying network resources and varying terminal processing capabilities. On the other hand users like to access (in a transparent way, not being bothered about underlying technologies) multimedia applications that in turn typically are distributed. The mobility of users typically requires query-functionalities regarding the context (like where is…).
- The current architectures and platforms offer isolated, and sometimes also partial information. Interconnection between service infrastructures and domains is not available now. There is a strong requirement for inter-working between platforms using standardized means. One of such is by federated coupling between service platforms as investigated in the 4PGLUS project [1], see also figure 1. In that service control solution existing mobile, wireless and in-

formation access architectures are federated using connections between the service platform functionalities in each of the domains. This results in seamless service-access for end-users. Such service control layer hide technical, syntactic, schematic, and semantic heterogeneities from the user.

- User expectations need to be considered as well. Seamless roaming is expected to be possible by mobile users, with a maximum degree of freedom and flexibility (and minimal costs) while not being bothered about technological issues. Users consider their mobile device as a personal assistant that offers unique opportunities such as real-time adaptation of services to a dynamic user environment. In addition, context awareness is expected to assist both in reducing the overload of available content and services and in increasing the efficiency of content-consumption, e.g. by filtering the offered services according to the user's situational preferences and needs.

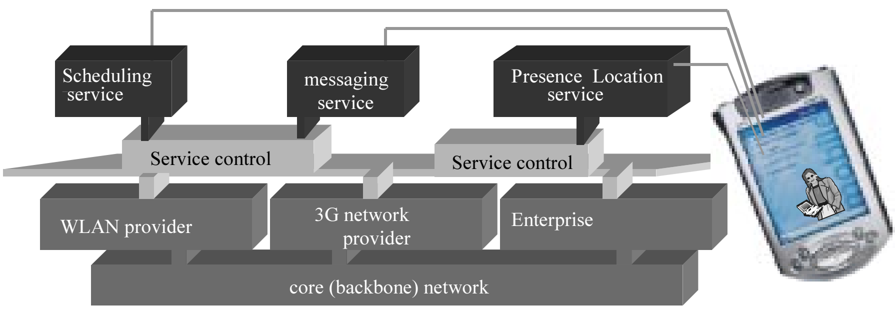

Fig. 1. Service platform based on a federated service control architecture

A ubiquitous attentive solution that enables true context-aware services and facilitates mobile users anytime and anyplace should take into account an integration of all relevant contextual aspects in relation to the communication and computational capabilities of the environment. As the mobile user is roaming across different administrative domains and different technologies services have to deal with a dynamic environment. The adaptation to this dynamic context and service brokerage in turn needed for this should be completely transparent for the user and offer mobile service providers the highest customer retention values. Vice versa, the environment of the user can be influenced by the availability and activities of the user and adapt itself accordingly.

3 Scenario: Bandaging and Salving Alice

The following scenario illustrates how several context parameters (location, presence, agenda) in a heterogeneous environment are collected, distributed, accessed, interpreted and used to pro-actively plan actions of a mobile medical assistant keeping in mind for example presence or availability information.

3.1 Scenario

Alice a highly qualified nurse pays a visit to several patients in need for bandage replacement and salving their skins. This medical treatment in the past required consultation of and treatment by a dermatologist at a hospital. Nowadays, however, Alice carries out such a treatment at the patients' premises using a remote consultation service provided by an available dermatologist.

Alice is always on and so is her consultation service. On the one hand, her mobile consultation service consists of a service providing remote videophone connection with one or more dermatologists distributed over various hospitals. On the other hand this videophone service is integrated with an agent-based scheduling service for making consultations. Either Alice or her software agent 'Consul' retrieves the availability information of the doctors by simply inspecting their agenda's and planning video meeting between Alice and one of the available dermatologists at a suitable time for them both. The dermatologist gets a notification about the arranged video meeting at an appropriate time, being at a time when he is not busy treating other patients nor while he is a meeting room. During the video meeting, the quality of the video stream is adapted to the bandwidth of the (wireless) networks available at the hospital or the patient's home.

Alice likes to spend all her time on and with her patients. She hates being bothered by the crippled MS browser that still comes with her PDA user interface – "A relict", she thinks, "that humanity better had done away with straight away". "Consul", she reflects, "takes all the hustle of (re)arranging meetings from my shoulders. Consul is my man: I can really count on him!"

4 Categories of Context

Due to the nature of mobile services and use, contextual information (often stored in profiles) is gathered by multiple parties, stored in multiple places (e.g. in the terminal, the access networks, the Service Platform and at service providers) and used and managed by multiple stakeholders. The distributed nature of context information (and profiles) must be supported by the service architecture. Exchange of part of the information between and across boundaries of administrative domains can be supported in an federated service control architecture [1]. Depending on the privacy policies, entities in different domains can share and exchange relevant profile data. Privacy policies are crucial in this respect. Moreover trust is vital between the parties involved in sharing contextual information. The user should have trust in all system-components and parties that collect and store his – privacy sensitive context and have the ability to distribute it to other parties, e.g. other users and services. Both globalization and virtualization of society have contributed to a greater privacy risk. User acceptance and his perceived privacy is a mobile business enabler [2]. Protection of profile data and trust must be addressed - to the satisfaction of the users - in the federated service architecture. Without access to user-related context data many mobile services and ubiquitous attentive systems will surely not exist.

With respect to mobile services and applications delivered over heterogeneous networks in a distributed environment we distinguish the following relevant categories of contextual information:

- User context [3], typical including the person's environment (entities surrounding the user, humidity, light), and describing the personal (physiological and mental context), task, social and spatiotemporal (location, in- or outdoors, time) domain. The user context includes user preferences about the use of surrounding (wireless) access networks, e.g. UMTS and WLAN. These preferences for using specific networks are for example based on the availability, price, quality and domain of the network. The user may also have a preference about the level of control for switching to other networks while using applications and services on its terminal.
- Service/Application context [1]: the applications currently available or used at the users terminal and the services the user is currently subscribed to. Both have requirements about the terminal (display size) and the network (bandwidth).
- Session context [1]. Description of sessions currently used by the user. With whom is he communicating (which service, which other users). What kind of data is communicated (voice or video). Is it a high bandwidth session (multimedia streaming) or a low bandwidth session (browsing, emailing, voice call).
- Access Network context [1]. The properties of available (wireless) networks in the neighborhood of the user's terminal, such as availability, domain, price and bandwidth.
- Terminal context [1]. All properties of the user's terminal that are relevant for running applications: display size, memory, communication interfaces (Bluetooth, GPRS, WLAN, UMTS)
- Service platform context [1]. The Service Platform (SP) has information about the subscriber, e.g. about its access rights and privacy aspects with respect to identity, call handling settings and location of the end-user. Furthermore, the SP has roaming agreements with other SP's to enable seamless user authentication in all visited networks, irrespective the radio technology or domain of such networks.

A relevant contextual parameter-set differs for different applications. Consider a mobile user with a terminal with multiple applications being simultaneously active. While leaving a network domain eg when leaving his office premises, a video application needs contextual information about the Access Network (bandwidth dropping from WLAN to GPRS), while another application (e.g. a restaurant "push" service) might be more interested in the activity of the user (e.g. changing from business to private role).

5 Context Representation and Modeling

To cope with incomplete context-parameter-sets and therefore changing context structure, ontologies instead of fixed (profile) schemes have to be used. An ontology gives meanings to symbols and expressions within a given domain language. It allows for a mapping of a given constant to some well-understood meaning and vice versa. For a given domain, the ontology may be an explicit construct or implicitly encoded with the implementation of the software [4]. Thus ontologies enable all participating components to ascribe the same meaning to values and structures stored in a profile.

In general dealing with dynamical changing and incomplete, distributed contextual parameters requires a set of context knowledge bases that define various typical real world situations. With these context knowledge bases user service and system adaptation preferences can be associated and thus the problem resolves to determining the appropriate user context for the environmental variables and clues provided by the real world situation, and then applying the referenced service options per user situation.

In the field of artificial intelligence, modeling of ontologies is done for quite some time. It is e.g. being applied to knowledge representation languages and DAI such as Open Knowledge Based Connectivity (OKBC). Interesting examples of context theories – enabling reasoning within and across contexts - are e.g. proposition logic [5, 6], local model semantics [7, 8] and multi-context systems [9].

In W3C and the Semantic Web a number of standard initiatives and tool developments exist that specialise in modeling of ontology services for the web, such as, RDF Schema [10], DARPA Agent Markup Language [11], Ontology Interchange Language OIL [12], DAML-S [13]. In [14] these are elaborated on. DAML+OIL [15] is the basis for the ontology web language OWL [16] that facilitates greater machine readability of Web content by providing additional vocabulary along with a formal semantics.

In the next section a very closely related topic is described, that adds processing to the modeled context.

6 Crunching

Context information is useless, unless an evaluation takes place, which can take advantage of the additional situational information, like e.g. is done in an ambient intelligent home environment [17]. The crunching functionality includes algorithms for robust and reliable interpretation of multiple contextual information streams, ontologies, context modeling, context theories, meta-profiles (metadata on processing order/sequence and algorithms to be used). Thus crunching comes very close to the previous section on context representation and modeling. Example references where contextual reasoning is tackled with regard to integration of heterogeneous knowledge and databases are [18, 19, 7].

Different parts of the actor's situation and of the context of the information may have different weights in determining the ambient of the actor. In addition, the ordering of the processing may affect the resulting context awareness.

The crunching functionality should also be able to compensate for limited and incomplete information.

This could be dealt with in several ways [20]:

- Use cached information stored during older sessions.
- Using only the parameters that are available (Fuzzy logic, estimate value or thresholds for unknown parameters).
- Let the user make decision and do the inference. I.e. just present the context that is available to the user and let him decide.
- Supervised learning the above [21, 22, 23].

7 Acquiring Context Data

In order to acquire context information, sensors or human-machine-interfaces can gather information about users and their current situation. Users can also provide this information themselves. A special category of context is position and location information. This part of the user context is mostly exploited in today's mobile services and sensory input plays a major role in providing this information. Sensor technologies will be more and more embedded in the mobile equipment and networks while services will sense better and better who the user is, where he is, what he is doing, what he is up to, what the environmental conditions are, etc. The environment itself will also be equipped with sensors that perceive users and communicate with their devices.

Advances in sensor technology and extension of sensor types are needed to reach further capabilities for adaptation of services to - and co-operation with - the environment of users. Aggregation of the sensed values in relation to a known reference is needed for a rightful, reliable and robust interpretation. As sensors can also interact, crunching of all contextual parameters is complicated even more. Many devices in our current world already adapt to a very crude and limited extend to their situational context. For example, some types of television sets adjust their image contrast to the ambient lighting level.

Many context aware applications make use of multiple sensor information inputs in order to steer one or other modality. Achieving in this respect e.g. cross-modality mapping by means of ubiquitous attentive mechanisms will be an inviting research challenge. The presence of multi-modality and the availability of relevant contextual information will require the introduction of even more intelligent human-machine-interface-management, enabling intelligent I/O behavior adaptation. This means, that the input/output behavior of a user end-system - for example the modality - can change dynamically based on the actual context. For example the user interface to an e-mail-system is typically text-based, whereas it would become speech-based if the user drives a car.

8 Access and Exchange

The access and exchange of context information must ensure that applications (executed on an end-user device) or services (executed somewhere in the universally connected world) get proper access to the information that describe the context of the device, the network, the end-user, etc. Hence, we will need in the future even more transparent access to - and exchange functionalities between - distributed, autonomous, heterogeneous information sources. Thereto, we need shared supervised learned scalable and extensible indexing, query and retrieval schemes that can stand time despite the increase in types of acquisition, processing and categorization technologies arising for new mobile service usage contexts.

The massive number of actors and objects in the wireless world make it simply impossible to have centralized solutions for access to information or exchange of contextual information. Luckily, ubiquitous network connectivity allows for building global software infrastructures for distributed computing and storage. The provisioning of context-information can profit a lot from intelligent and secure sharing of resources. We need at least the following functions in the information-provisioning environment:

- Scalable synchronization and update mechanisms. For service-oriented information provisioning (e.g. personal location services) information from several domains can be collected, and analyzed. For these types of applications, synchronization and update mechanisms for contextual information are needed that are completely different from traditional database synchronization solutions. Domain-owners (e.g. end-users for their PANs; 3G operators for their mobile networks; enterprises for their wireless LAN infrastructures) will have their own policies for this type of synchronization and update mechanisms. It is necessary that an open infrastructure will be created, that allows one to exchange information on-demand; comparable to current infrastructures for presence information (as e.g. are currently being standardized in the IETF SIMPLE group [24].
- Federated authentication and authorization mechanisms, in order to provide trust. A key issue is to ensure that the end-user is still in control: he has to be confident that only the people (or providers) that he trusts are able to use his context information. Identity protection and privacy are key requirements. We need federated solutions for this (e.g. building on architectures coming from the Liberty Alliance [25]) in order to allow for global access and distribution of private information across several domains.
- Service discovery solutions. Single-domain service discovery is already in place in the video and audio entertainment sector: HAVi (Home Audio Video Interoperability) and UPnP (Universal Plug and Play) are existing standards that are widely implemented. UPnP is one of the architectures for pervasive peer-to-peer network connectivity of PCs of all form factors, intelligent appliances, and wireless devices. However, in multi-domain situations there is a lot of work to be done. There are efforts that head for global service discovery (e.g. the UDDI directory-mechanisms used in the web-service community), but these directory mechanisms are not scalable enough for the amount of devices and services that exist in a universally connected world. New mechanisms are needed. This is of course strongly related to the synchronization and update mechanisms discussed earlier.

- Well-defined extensible data-formats for contextual information (as described in earlier sections). This calls for standardization.
- Open interfaces for context information. There is a growing need for standardization of not only the data formats of contexts, but also for the access functions towards this information, and the control-mechanisms that allow both a device or service-owner (interface provider) and the interface-user to control the behavior of the information exchange mechanisms.

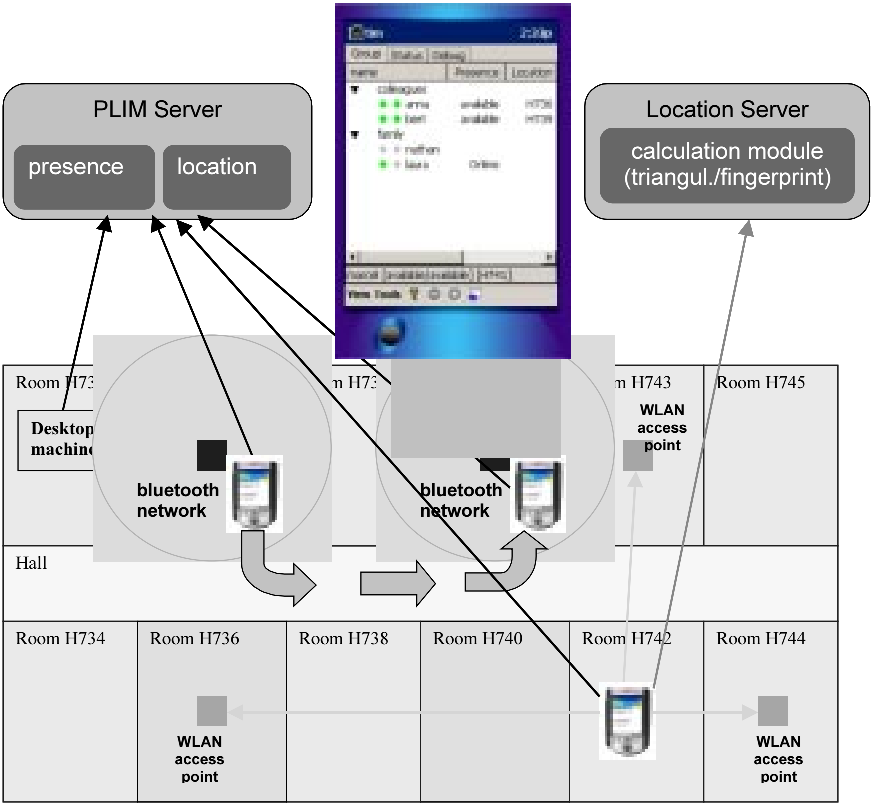

Fig. 2. The user interface of PLIM

9 Example of Implementations (Consul Says to Alice: "At Your Service")

We developed and implemented several platforms with ubiquitous attentive functionality. In the context of our scenario (described in section 3.1) we briefly describe two of them: Presence Location Instant Messaging (PLIM) [26] platform and Scheduler Agent System (SAS) platform [27].

The PLIM server (modified Jabber Instant Messaging server) stores the dermatologists' locations in its database. The location (based on Bluetooth and WLAN) is represented in technology independent XML formats. The nurse logs onto the PLIM server and has access to location/presence information of all dermatologists in the all hospitals she is subscribed to. Distribution of the location information to other users makes it possible to view (see Figure 2) each others context (situational awareness) on the same application i.e., an Instant Messaging application that wants to know if a dermatologist is available for a videoconference consult.

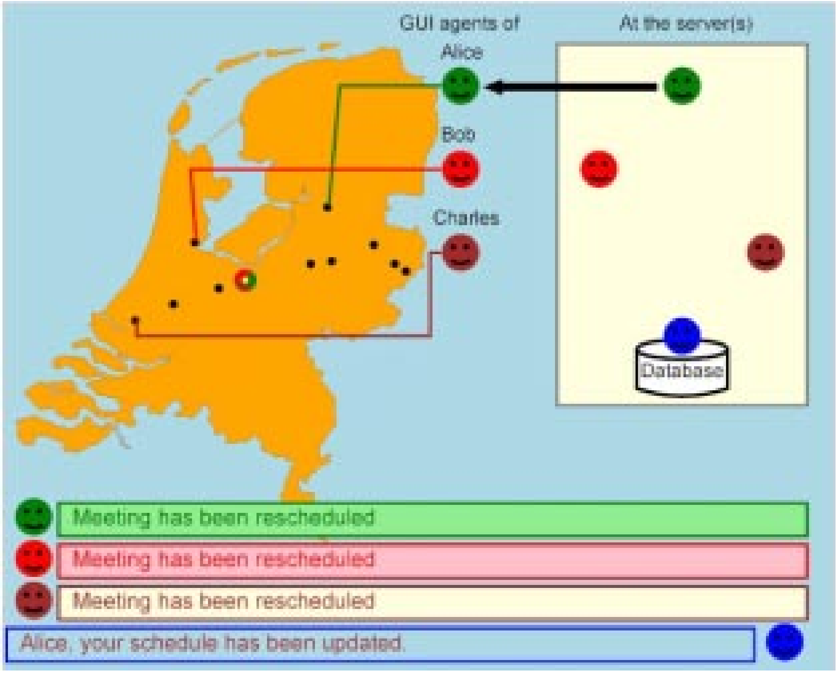

Fig. 3. The visualization of negotiations between scheduler agents that can represent the dermatologist (Bob and Charles) and the nurse (Alice)

Additionally, we build a context-aware personalized scheduling service for a mobile business-to-employee (B2E) setting, where software agents collectively arrange new meetings at different locations (in this case cities see Figure 3) and times keeping in mind the upcoming meetings of the employees (e.g. dermatologists, nurses). The software agents also simultaneously look after privacy or security policies of the dermatologists and nurses or their hospitals they work for, e.g. with respect to location information, time schedules, personal preferences or patient sensitive information. We developed and deployed our scheduling service on the JADE-agent platform using PDA's connected to a server using WLAN and GPRS networks.

10 Summary

A (wearable) system is ubiquitously attentive when it is cognizant and alert to meaningfully interpret the possibilities of the contemporary user environment and intentionally induces some (behavioral/system) action(s). Context awareness is as part of ubiquitous attentiveness, as exchanging information across and between (heterogeneous) domains and the pro-active responsiveness of the ubiquitous environment is. Key aspects of ubiquitously attentive (wearable) systems to us appear to be acquiring, interpreting, managing, retaining and exchanging contextual information.

A ubiquitous attentive solution that integrates all contextual aspects in relation to the communication and computational capabilities of the environment is needed for true context-aware services offered to mobile users anytime and anyplace. Dynamic adaptation of services to a dynamic changing user context (and vice versa) with unpredictable resources and incomplete context information should be solved in a completely transparent manner for the user. Seamless roaming of users in a global and heterogeneous setting must be supported by a open service architecture (loosely coupled), assisting in exchange of a variety of context parameters across network boundaries, such as resources, user identification, knowledge of optimal settings, session context, etc. Key aspects in facilitating connectivity and applications in a distributed heterogeneous environment are a federated service control architecture, intelligent sharing of resources, authentication and trust.

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