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Semantic Service Co-Ordination for Emergency Assistance in Mobile e-Health Environments*

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Abstract. Emergency assistance requires the timely delivery of relevant patient data in order to improve high quality of treatment. For this, both physicians and patients can benefit from access to services and data via mobile devices, and the underlying system must be able to detect the most suitable services based on the current context of their user. From a systems point of view agent technology, semantic Web Services, peer-to-peer techniques, and mobile computing provide the basis for a novel type of software architecture which facilitates advanced service co-ordination, that is, provision, discovery, composition, and execution of services. The CASCOM project has developed a software architecture that combines all these aspects to provide value-added support for business service providers and users across mobile and fixed networks, especially for e-health environments. The contribution of this paper is twofold. First, we introduce the CASCOM system that seamlessly combines the aforementioned technologies in an innovative way. Second, we report on the evaluation of the system in real world settings in the emergency health care domain.

1 Introduction

Information Technology is more and more influencing the daily practice in healthcare. Examples are the proliferation of electronic health records, workflow support for medical processes and therapy protocols, etc. Together with the ubiquitous availability of

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relevant information, information technology also found its way into emergency care – both in pre-hospital and in hospital emergency care. Emergency physicians are given access to most relevant patient information in order to avoid adverse events and to better tailor emergency treatment to the patient's profile. For this, physicians can benefit from timely access to services and data via mobile devices. Similarly, also patients in emergency situations can take advantage if they can efficiently access most suitable services based on their current context. From a systems point of view agent technology, semantic Web Services, peer-to-peer (P2P) techniques, and mobile computing provide the basis for a novel type of software architecture which facilitates advanced service co-ordination, i.e., *provision*, *discovery*, *composition*, and *execution* of services.

The CASCOM project (Context-Aware business application Service Co-Ordination in Mobile computing environments) follows a novel approach to combine all these aspects to provide value-added support for business service providers and users across mobile and fixed networks. The system has been deployed and tested in real world settings in the emergency healthcare domain. The paper introduces the CASCOM architecture and also reports on the trial activities which have proven the applicability of the system in emergency assistance applications.

The paper is structured as follows. Section 2 presents the healthcare emergency assistance scenario we focus on in CASCOM. The different technologies needed to support this scenario and how they were combined by the CASCOM coordination infrastructure are briefly introduced in Section 3. A detailed technical description can be found in [1]. In Section 4, we report on the evaluation of the system by usability tests and by field trials in real world settings. After a section on related work (5) the paper concludes.

2 Emergency Assistance e-Health Application Scenario

When people traveling abroad for business or holidays face emergency situations regarding their own health condition (i.e., they need medical *emergency assistance*), they usually also suffer from difficulties in contacting emergency medical services, in communicating with emergency physicians in a foreign language, in sharing their case history with them, etc. From the physicians point of view, the problems are similar. The CASCOM vision is to overcome all these problems by equipping patients and doctors with a software environment on their mobile device (e.g., smart phone) so that they can better deal with such situations. Patients, for example, will be able to quickly request medical assistance or even repatriation. Emergency physicians can get early access to the health record of a patient they have never seen before, etc.

Assume that a tourist from Finland is having summer vacation in Austria. During the trip, she seriously suffers from pain in the upper part of her chest. A software pre-installed on her smart phone discovers and invokes specialized services that provide assistance in directing her to a local healthcare institution or to request a local ambulance. Local physicians, or even emergency physicians in an ambulance, can use other specialized services, based on the same platform, to access information from health records of the patient, probably stored in her home country. Early access to this kind of data allows to better prepare for upcoming medical cases, to learn about the former

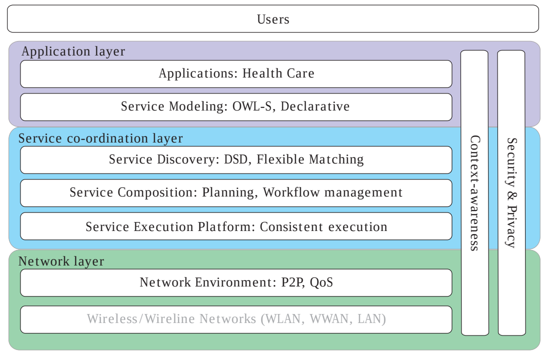

Fig. 1. Layered Model of the CASCOM Architecture

health state of a patient, or to avoid redundant and/or unnecessary examinations. Subsequently, it might turn out that repatriation of the patient is necessary. Again, the mobile device can be used to discover and use a specialized service provider—probably located in the home country—that initiates and co-ordinates this.

It is important to note that usually data is not accessible directly but provided via a service interface. In a real-world setting, the system has to cope with a very high number of users and services. Since applications have to be created ad hoc, services must be discovered dynamically based on queries against directories which are able to express exactly the semantics of what is needed. When no single service is available that supports the current needs, complex functionality needs to be provided by composing services according to their semantics. Thus, from a technical point of view, the application induces complex requirements, which raise the need for on-demand *initiation*, *composition*, *co-ordination*, and *supervision* of various activities, ideally represented through services.

3 Architectural Support for Semantic Service Co-Ordination

The essential approach of CASCOM is the innovative combination of agent technology, semantic Web services, P2P, and mobile computing for intelligent P2P mobile service environments. The services of the CASCOM environment are provided by software agents exploiting the CASCOM coordination infrastructure to efficiently operate in highly dynamic environments. The architecture relies on a layered approach (cf. Figure 1) [1]. The four main components of this architecture (i) Networking Layer, (ii) Service Coordination Layer, (iii) Context Subsystem, and (iv) Security and Privacy Subsystem link the application layer with the underlying data communication networks.

The Networking layer provides a generic, secure, and open Intelligent P2P network infrastructure taking into account varying Quality of Service (QoS) of wireless communication paths, limitations of resource-constrained mobile devices, and contextual variability of nomadic environments. Especially, the Networking layer comprises the following functionality to provide a solid basis for implementing various applications to nomadic environments:

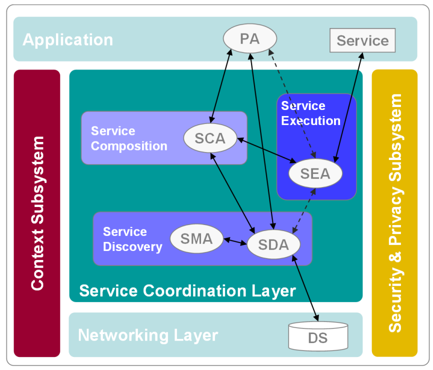

Fig. 2. Agent Interactions of the CASCOM Architecture

1. Efficient, secure, and reliable agent message transport communication over wireless (and wireline) communication paths independently of the access technology,
2. provision the context subsystem with network-related context information,
3. low-level service discovery in IP2P environment based on semantic service directories (DS), and
4. FIPA-compliant [2] agent execution environment (agent platform) for resource-constrained mobile devices.

Setting out from the services of the Networking layer, and based on the functionalities offered by both the context-awareness and the security and privacy subsystems (see below), the Service Coordination layer takes an agent-based approach towards flexible Semantic Web Service discovery and coordination. Its main functionality is twofold: Semantic service discovery (service discovery and semantic matchmaking) and service coordination (service composition, service execution, and execution monitoring). In our architecture, semantic service discovery functionality is realized by two different types of agents: *Service Discovery Agents* (SDA) and *Service Matchmaking Agents* (SMA). The service coordination functionality is realized by *Service Composition Agents* (SCA) which create composite services that match specific service specifications and *Service Execution Agents* (SEA) which manage the execution of composite service descriptions generated by SCAs. All of these agents are application independent and thus can be employed in various applications.

The interactions among the different agent types are depicted in Fig. 2. Additionally to the abovementioned agents, *Personal Agents* (PA) are meant to realize application domain specific end-user functionality like the (graphical) user interface, etc. In the CASCOM architecture PAs can interact with SDAs to discover application services that directly provide a needed functionality. When no single services are available that support the current needs, PAs interact with SCAs to request ad hoc composition of several services into new composite services that altogether provide the complex functionality needed. Subsequently, SEAs take over responsibility for reliable execution of the single and composite services; thus, PAs can also directly interact with them.

The context subsystem, orthogonal to the above described layers, is in charge of acquiring, storing, and providing context information to both layers as well as to the applications. Generally speaking, there will be contextual information for each of the system components. Each of them will be able to acquire it using the following set of functionalities: Discovery and acquisition of context information, subscription of context listeners and acquisition of context events/changes in the environment, and access to context information repository.

The Security and Privacy Subsystem, also orthogonal to the Networking and Service Coordination layer, is responsible for ensuring security and privacy of information throughout the different components of the infrastructure. One of the main things we need to protect is the information (data) that every node of the network maintains. In detail, data confidentiality, integrity, and availability are topics of concern that any approach to security must address. The security and privacy functionality was considered at every level of the CASCOM architecture. This enables instant take-up of the CASCOM concepts for service-oriented business applications. Security and privacy are especially important in emergency assistance applications as such applications potentially handle confidential patient data that should not be revealed.

On the application level, we consider to employ state-of-the-art Web services that use current technologies for accessing them (SOAP) and functional description (WSDL). Conceptually, REST style Web services do not conflict with the system approach but are currently not supported by the implementation. Furthermore, Web services are supposed to be enriched by semantic descriptions. We decided to apply OWL-S [3] (formerly known as DAML-S) for this purpose as it is one of the main efforts in the Semantic Web services domain. The high-level objectives of OWL-S are (i) to provide a general-purpose representational framework in which to describe Web services; (ii) to support automation of service management and use by software agents; (iii) to build, in an integral fashion, on existing Web service standards and existing Semantic Web standards; and (iv) to be comprehensive enough to support the entire lifecycle of service tasks [4]. In the context of the CASCOM project OWL-S is used as a main building block to facilitate automation of Web service tasks, such as automated Web service discovery, composition, execution and interoperation.

4 Practical Evaluation in Emergency Assistance Applications

The scenario introduced in Section 2 has been used for the implementation of a series of usability studies and field trials to evaluate the system in a real-world setting. Two main trial rounds were conducted: (i) usability lab tests in Helsinki, Finland and (ii) field trials at the Innsbruck University Hospital, Austria.

4.1 Usability Tests

Usability is a key success factor of software systems. In particular in health care applications, it is an important aspect since misunderstandings or errors could have severe implications. Moreover, user interaction with mobile devices is usually limited in many ways making complex interactions difficult. For this reason, dedicated usability tests of the CASCOM system took place at TeliaSonera's usability labs in Helsinki with both paramedics and medical laymen as testers.

Hence, the focus of this first round of trial activities has been put on the user interaction and interfaces, rather than on the functionality of the system. To support the subsequent evaluation of the usability tests, the user's view on the system interaction was recorded with a miniature camera and displayed on a TV set.

The feedback gained has been highly valuable to improve the system and to bring it to a level of maturity that is necessary for applications in emergency assistance.

4.2 Field Trials

The field trials focused on the interaction with the overall system and problems that cannot be recognized under laboratory conditions. The physicians' view of the system has been evaluated in close collaboration with the IT department and emergency physicians of TILAK at the University Hospital in Innsbruck, one of the most renowned medical centers in Europe. In two comprehensive tests, the CASCOM system has been used in a driving ambulance as well as at the trauma center. All activities were recorded with a video camera and supplemented by structured interviews.

Hardware For the field trials we used the following hardware as end user devices: HTC TyTN smart phones, Asus R2H Ultra Mobile PCs (UMPCs), and ANYCOM GP-700 Bluetooth GPS receivers. The smart phone was running Java ME (MIDP 2.0) while on the UMPC a Java SE was running. As backend system, standard Intel Pentium based machines have been used. WLAN was used in the stationary emergency department. All activities carried out in the ambulance relied on UMTS 3G resp. GPRS based communication. Patient data which has been accessed during the trial activities were provided by the Health@Net project via dedicated semantic Web services.

System Architecture The system architecture is depicted in Figure 3. The trial primarily tested the pre-hospital phase of the application scenario. The Personal Agent (PA), i.e., the patient's application of the CASCOM system, is running on the smart phone. After placing an emergency call (done by the PA), the Finnish emergency center (EMA) and a local emergency number are contacted. In the test scenario, the EMA agent is running on the EMA server in Finland and the OneOneTwo Agent which is simulating the local emergency number is running locally on the TILAK server. For security reasons the TILAK server is located in a DMZ.

When issuing the emergency call, the patient has to answer very few questions about the symptoms. These are submitted to the EMA Agent as well as the OneOneTwo Agent. Additionally, the identity of the patient is automatically determined. The OneOneTwo Agent calls the ambulance. Different agents, running at the TILAK server, are used find relevant patient data, in a way which is transparent to both patients and physicians. These agents are namely the Service Matchmaking Agent (SMA), which is matching the request and puts it in a form the Service Discovery Agent (SDA) can work with to find relevant services in the Registry (WSDir). The Service Composition Planner Agent (SCPA) orchestrates found services and the Service Execution Agent (SEA) executes the services to get the relevant patient data as result. In the trial, real services from the Health@net project have been used to retrieve patient data. These services access test data of the Clinical Information System (KIS) of TILAK. Furthermore, the

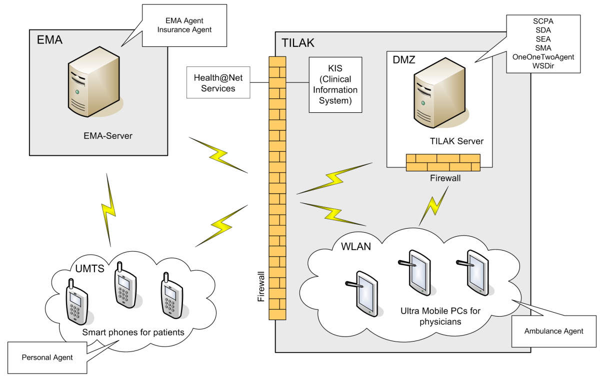

Fig. 3. Test Environment of the Field Trials

patient's position is determined by a location-based service running on the PA. This allows for directing the emergency car. The Ambulance Agent running on the UMPCs of the physicians presents all this data.

After primary care, the ambulance physicians decide about the local hospital for the patient and bring her there. Mostly this would be a local hospital with an emergency department. The OneOneTwo service contacts the chosen local hospital and informs about the medical case of the patient. This basically contains the information collected on the initial questionnaire, the identification of the patient, and the patient data that was automatically resolved in the above described process.

Software and semantic services Health@Net is a national Austrian research project, led by UMIT in Hall in Tyrol. It was developed and is being advanced within the setting of the CEMIT (Center of Excellence for Medicine and IT). The aim of this project is to give citizens of the European Union the possibility to possess and administrate, via Internet, their individual electronic, lifelong health record. Such a shared electronic health record across national borders represents an enormous improvement in efficiency for the health care system. Standardized procedures such as data collection and anamnesis, coordination of medications etc. can be achieved in a few seconds through the authorized access of the attending physician to the database of his patient, regardless of where patient or doctor are located.

TILAK is one of the participants of the Health@Net project. The main objective in this cooperation is to create an interface to the clinical information system of TILAK and to offer access to this system from the outside via Web services. The services have primarily been designed for usage by family doctors who send their patients for examination to one of the hospitals of TILAK. It has turned out that CASCOM is an even more challenging use case. Due to the cooperation with Health@Net, CASCOM has received excellent support and has been able to make use of the Health@Net services (for privacy reasons on non-productive data from the TILAK clinical information system, i.e., on anonymous patient data). We enriched the Health@Net Web services by OWL-S service descriptions to formalize the properties and capabilities in an unambiguous, computer-interpretable form.

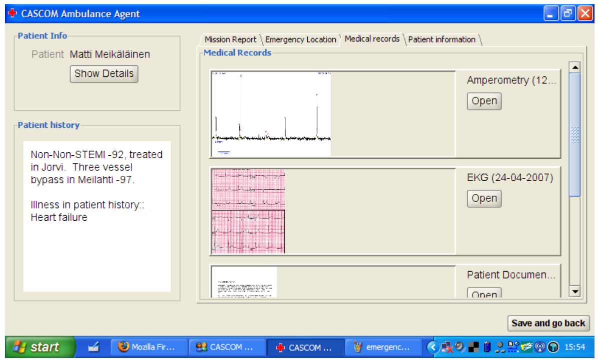

Fig. 4. Physician's View: Early Availability of Patients' Medical Records

4.3 Results of the Practical Evaluations

The physician's view of the system has been evaluated very positively both from a functional and a non-functional point of view. The feedback from the emergency physicians indicated that the user interface is comfortable and easy to use, design and handling are consistent, the structure is clear and data is well readable. In particular, early availability of patients' medical records was highly appreciated because it enables better preparation of upcoming medical cases. Physicians also stated that the system can help to reduce false diagnoses and to save live of elderly people and people with chronic diseases. Figure 4 shows a screenshot of the physician's device with health record information.

5 Related Work

Regarding the architectural topology used in CASCOM, other similar approaches have been devised in the past. Agents2Go [5] is a agent-based architecture to provide services to mobile users. It is based on a centralized server, whereas we employ the distributed P2P paradigm. Furthermore, it does only support service discovery and execution. The Ronin and DReggie system [6] is an agent discovery architecture which provides semantic service matching functionality. Context-information is not taken into account in this architecture, and as in Agent2go, the architecture does not support service coordination. MyCampus [7] is yet another agent-based environment for context-aware mobile services. The main difference to the CASCOM architecture is that MyCampus is based on a centralized server and supports only semantic service discovery.

5.1 Semantic Service Coordination

Research efforts to advance dynamic service discovery, selection (matchmaking), composition, and execution based on semantic-aware techniques underwent intensive interest during the past years. Enabling aspects were the development of semantic service markup languages such as OWL-S [3] and WSMO [8].

Regarding service discovery, most of the service matching algorithms that have been proposed in the literature are profile-based. This means that the matching process bases on comparisons between a given, requested service profile and advertised service descriptions. Some approaches that rely on ontology-based languages are LARKS [9], OWL-S/UDDI Matchmaker [10], and MAtchMAker-Service [11].

Automated composition of semantic Web services relies on AI planning techniques. There are currently only few approaches and software tools available for OWL-S service composition planning. One of the most prominent approaches is the SHOP2 composition planner[12].

Reliable execution of composite services (processes) is widely addressed by process management and transactional information systems. Many methods and systems have been devised to enable execution in local and distributed environments as well as languages to formalize process models. However, the execution of (composite) services that are described based on OWL-S still appears to be in its infancy. A comparable – although non-distributed and not agent-based – system has been devised in [13].

5.2 Mobile e-health

The healthcare application scenario presented in Sec. 2 is currently not implemented in this form in practice and no software system is presently widespread in use to address it. Similar existing systems focus on the possibility to send emergency calls only – independent from the aspect whether this is done automatically or manually. In particular, they do not include the possibility to provide further assistance. Seen from a technical point of view, large-scale environments are not considered important aspects yet. Existing systems are most of the times organized centrally and spread across local restricted areas only. Some application areas where these kinds of systems are already in use are in sports and the outdoor sector, e.g., avalanche rescue systems.

Mobile e-health (in short *m-health*) applications are driven by the demand to ubiquitously access medical information in a mobile setting. The most prominent m-health applications are physiological telemonitoring, assistive living, and smart hospitals.

Assistive Living applications aim at creating a smart-home environment to support elderly or handicapped people to independently live at home [14, 15].

The goal of *Smart Hospital/Smart Emergency Assistance* applications like, for instance, Akogrimo [16] is to improve daily activities of doctors and nurses by providing access to patient records or scheduling and tracking of patients and hospital resources via mobile devices. The Codeblue project [17] uses wireless sensors to collect and integrate vital data into clinical information systems. Applications like Pervasive Healthcare [18] focus on giving physicians a very early access to patient records and providing the location of emergencies.

6 Conclusions

In this paper, we have presented the CASCOM agent-based approach to semantic service discovery and coordination, complemented by orthogonal techniques to support context-awareness and ensure security and privacy. The overall system design is application independent and especially supports seamless mobility independent of available wireless technologies and (resource-constrained) device types used. The evaluation of the system within the challenging emergency assistance healthcare domain indicated that it can be efficiently used in practical settings and provided valuable feedback for further improvement.

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