Developing Smart Emergency Applications with Multi-Agent Systems

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ABSTRACT

Multi-agent systems have been importantly contributing to the development of the theory and the practice of complex distributed systems and, in particular, they have shown their potential to meet critical needs in high-speed, mission-critical, content-rich, distributed information applications where mutual interdependencies, dynamic environments, uncertainty, and sophisticated control play a remarkable role. Therefore, multi-agent systems are considered a suitable technology for the realization of e-health applications where the use of loosely coupled and heterogeneous components, the dynamic and distributed management of data, and the remote collaboration among users are often the most relevant requirements. This paper describes some of the main reasons why multi-agent systems are today considered one of the best technologies for the realization and deployment of advances for e-health applications and, in particular, of smart emergency applications. After an introduction on the inherent characteristics of the use of multi-agent systems for e-health, the paper presents the results of EU-scale project CASCOM: a real multi-agent system for the execution of smart emergency tasks.

Keywords: *CASCOM, E-Health, Emergency Rescue Missions, Intelligent Agents, M-Health, Multi-Agent Systems*

INTRODUCTION

Multi-agent systems are one of the most interesting areas in software research and they have been importantly contributing to the development of the theory and the practice of complex distributed systems (see, e.g., Bordini et al., 2005). In particular, multi-agent systems have shown the potential to meet critical needs in high-speed, mission-critical, content-rich, distributed information systems where mutual interdependencies, dynamic environments, uncertainty, and sophisticated control play a singular role (Gasser, 2001).

Agent and *multi-agent system* are buzzwords that found their way into a number of technologies and they have been largely used, e.g., in Artificial Intelligence, Databases, Operating Systems and Computer Networks. Although there is no such thing as an accepted definition of an agent (see, e.g., Genesereth & Ketchpel, 1994; Wooldridge & Jennings, 1995), all proposed definitions agree that an agent is essentially an autonomous software entity that

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provides an interoperable interface and that behaves like a rational actor working on behalf of some client in pursuit of its own agenda. Agents are designed to operate in dynamic and uncertain environments, taking complex decisions at run-time, and the learning capabilities of some agents make them capable to improve their performances over time, thus avoiding repeated negative conditions and persisting on successful behaviours.

Even if a complex system can be realized in terms of a solitary agent working within its environment–that may or may not comprise users–usually, agent-based systems are made of multiple, interacting agents: agent-based systems are normally multi-agent systems. Multi-agent systems are generally considered an appropriate means for modelling complex, distributed systems, even if such a multiplicity naturally introduces the possibility of having different agents with potentially conflicting goals. Agents in a multi-agent system may decide to cooperate for mutual benefit, or they may compete to serve their own interests. They may take advantage of their social ability to exhibit flexible coordination behaviours that make them able to cooperate in the achievement of shared goals or to compete on the acquisition of resources and tasks. Finally, agents in a multi-agent system have the ability of coordinating their behaviours into coherent global actions. Coordination among agents is handled by means of a variety of approaches including negotiation (Jennings, 2001), organizational structuring (Horling & Lesser, 2005) and multi-agent planning (Durfee, 1999).

The very fact of characterizing agents in terms of the properties that they exhibit rather than in terms of a crude and often inapplicable definition, allows a plethora of software systems to be considered as first-class multi-agent systems. This makes multi-agent systems much more than a single technology supporting the realization of complex distributed systems. Multi-agent systems are *abstractions* capable of capturing the essence of many software systems at different levels of detail. In particular, agents and multi-agent systems are often considered the highest system level (Jennings, 2000) of today computing systems and they are meant to provide a truly novel level of abstraction in the analysis, design and implementation of complex software systems (Bergenti & Huhns, 2004). This is the reason why we can correctly account many recent software systems as multi-agent systems, even if no agent-based development technology were adopted in their realization. The agent-based nature of a system comes from the characteristics of its components and of the interactions among them, rather than from a hypothetical "agent based" label attached on the box of the development tool adopted for their realization. Notably, multi-agent systems are often developed using technologies that have no built-in notion of agent.

A lot of work has been done in the last decade for spreading the use of multi-agent systems for the realization of real-world software applications and services. Several technological specifications are the results of such a work. Among them, the two main results to date are: *(i)* FIPA specifications (FIPA, 2009), a set of specifications intended to support the interoperability between heterogeneous agent-based systems; and *(ii)* the JADE (Bellifemine et al., 2008; JADE, 2009) development framework that implements FIPA specifications and that supports interoperability between agents using consolidated technologies to provide for a transparent and dynamic allocation of fixed and mobile users and agents (Bergenti et al., 2001).

This paper shows the main reasons why multi-agent systems are a suitable technology for the realization of e-health applications and it presents the results of the EU-funded project CASCOM: a real multi-agent system for the execution of smart emergency tasks. Next section discusses the main points of using multi-agent systems for the realization of e-health applications and it lists some of the most interesting agent-based e-health applications. We will present the results of project CASCOM as a good example of the use of multi-agent systems for advanced e-health services. Finally, the paper concludes with a discussion of main reasons why multi-agent systems are not yet cited as the reference technology for e-health.

MULTI-AGENT SYSTEMS FOR E-HEALTH

There is common agreement in the field that the buzzword *e-health* was introduced around 1999 as a consequence of the *e-* mania* to address the provision of healthcare services through the Internet (McLendon, 2000). Notably, such a buzzword was heavily promoted by the industry and by application and service vendors and soon the academic community started using it instead of the over-abused *telemedicine*. Such a widespread adoption of this new buzzword was so wide and deep that anything that had to do with technology and health was quickly included. In order to clarify the obvious misunderstandings that immediately arose and to support such an important idea, the European Commission itself felt the urge to provide a common and generally acceptable definition of the word e-health as: *"the use of modern information and communication technologies to meet needs of citizens, patients, healthcare professionals, healthcare providers, as well as policy makers."* (European Commission, 2003)

Technological Characteristics

Besides the clarity–or possibly the confusion, someone may say–that the mentioned de jure definition created, it is common understanding that e-health uses ICT for the provision of health-related services to sparse users. This pushes interaction and communication as central themes of e-health and it immediately promotes multi-agent systems as ideal candidates to support next-generation e-health services and applications, for the inherent characteristics of multi-agent systems quickly recalled in the previous section.

Similarly, e-health deals naturally with mobile users, e.g., in tele-assistance scenarios, and it is common understanding that e-health should transparently accommodate fixed and mobile users. So called *m-health* is yet another buzzword that has been recently proposed to stress this fact: m-health services should be accessible anyone, anywhere, anytime, anyhow, and any-*. m-Health addresses mobile scenarios where devices are used to collect, transmit and process vital patients' data, e.g., heart rate and blood pressure, in real time (De Mola et al., 2006). Such systems are especially important in applications that remotely monitor patients with chronic ailments or in homecare. Broadly speaking, such systems are designed to access medical information in a mobile and ubiquitous setting. Such an access of medical information may be either *(i)* the retrieval of relevant medical information for use of healthcare practitioners, e.g., a hospital doctor on his/her ward round; or *(ii)* the acquisition of patient-generated medical information, e.g., tele-monitoring of patient's health state outside the hospital. In both cases, it is extremely important to ensure that the person who retrieves or generates information interacts with a ubiquitous and pervasive e-health system without any obstruction or adaptation of the normal workflow.

The most notable characteristics that m-health systems should exhibit are: *(i)* context and location awareness are to be smoothly integrated, i.e., the access and the visualization of health-related information always depend on the overall contexts of the patient and of the user (Bricon-Souf & Newman, 2007), *(ii)* fault-tolerance, reliability, security and privacy-awareness are needed in order to accommodate the strict requirements of all healthcare applications, *(iii)* effective mobile devices are to be used to provide access to relevant health-related information independently of the current physical location and physical condition of the user, and *(iv)* unobtrusive sensor technology is needed to enable the gathering of physiological information from the patient without hampering his/her daily life.

All in all, mentioned requirements immediately recall the characterizing features of multi-agent systems and it comes with no surprise that many ubiquitous and pervasive e-health systems are realized using multi-agent abstractions and technologies. In particular, there has been a notable interest in the use of JADE (Bellifemine et al., 2008; JADE, 2009) and its lightweight version JADE-LEAP (Bergenti et al., 2001) in ubiquitous and pervasive e-health systems because they do take special care of transparently and dynamically allocating users and agents on heterogeneous networks of different types of devices.

Another important issue in e-health is about supporting the interoperability of (legacy) medical information systems in order to enable the integrated provision of services for accessing information from different, remote sources. The dream of a single, universally-accepted middleware supporting the development of new services together with the renewal of legacy services was quickly abandoned and recent technologies–that were originally intended to support the (semantic) interoperation between heterogeneous services–are commonly adopted in practice. This, again, emphasizes the role of multi-agent systems for providing important contributions to e-health because of the inherent semantics-awareness of the interaction between agents, which makes them ready to deliver semantic interoperability (see, e.g., Bergenti & Huhns, 2004).

Then, an important issue that most e-health services address regards the possibility of jointly supporting professionals in their highly specialized work. Computer-Supported Cooperative Work (CSCW) is already common practice in tele-surgery and tele-assistance and it seems an important ingredient of next-generation e-health services. Notably, the inherent cooperative nature of agents and the very fact that many CSCW technologies are already based on agents is another important contribution of multi-agent systems to e-health.

Finally, the central venue that security and privacy-awareness have in multi-agent systems stresses their importance with respect to e-health. In the agent realm, the issues of privacy-awareness are treated under the umbrella of the more expressive and abstract notion of *trust* (Castelfranchi & Falcone, 2000). Likewise, e-health strongly remarks the importance of preserving confidentiality and guaranteeing a high level of security for classified information about patients.

Functional Characteristics

Even if the mentioned facts regarding the adoption of multi-agent systems for next generation e-health services and applications can be convincing, we now try to sustain our statement by adapting the well-known grouping criteria proposed in (Barnes & Uncapher, 2000). We say that multi-agent systems contribute to next-generation e-health from three points of view: *(i)* improving the quality of healthcare; *(ii)* facilitating the access to healthcare; and *(iii)* reducing costs.

The most important contribution that multi-agent systems provide to the overall quality of healthcare relies essentially on the possibility of feeding highly specialized healthcare professionals with the right information tailored to the patient, at the right time, in the right place. The proactive nature of agents and their semantic interoperability support such a need with the possibility of feeding users with information acquired from diverse sources and tailored to the concrete patient at hand. Thanks to the computerization of health records, that is now common practice in Western Countries; the transfer of complex health records globally and quickly increases the accessibility, unifies stages of complex healthcare processes and improves care continuity. Moreover, the longstanding tradition of expert systems that still lives behind the scenes of multi-agent systems supports healthcare professionals in using the provided information for taking the right decisions at the right time. Finally, the transparent integration of mobile terminals helps collecting data to quickly support contextualized healthcare decisions in the right place.

Notably, the scenario of allowing a quick and contextualized access to healthcare-related information from anywhere, at anytime and in the most appropriate way promotes the long-waited universality and equality of access to healthcare, especially for geographically or socially isolated patients. Such a scenario may seem visionary for the current lack of supporting infrastructures, e.g., universally-accessible communication networks and power supplies, but the inherent decentralization that is always assumed in multi-agent systems is vital to facilitate the access to healthcare both in everyday and remote scenarios. This is the case, e.g., of homecare to older, disabled and chronic patients. The widespread adoption of multi-agent systems at homes helps reducing medical visits and related waitlists drastically. Moreover, the proactive nature of agents assists in creating a trusted link between agents and patients by having agents constantly pushing valuable information to patients, with no need of explicit demands. Agents are good tools to help patients following preventive strategies and supporting self-care on a day-by-day basis.

The last grouping criterion in (Barnes & Uncapher, 2000) is about cost reduction of healthcare processes. This is an issue of notable importance for the inherent costs of quality healthcare and multi-agent systems are beneficial also from this point of view. The mentioned possibility of agents to provide the right information tailored for the patient, at the right time, in the right place supports efficiency in the overall management of treatments. Moreover, the semantic interoperability of agents enables instant acquisition of information from its natural source, with minimal, or even absent, pass of information along chains of intermediaries. Finally, the trusted and privacy-aware support that agents provide to healthcare processes is a valuable means to speed up and optimize many administrative procedures. All in all, we can summarize the contribution that multi-agent systems provide to healthcare from the point of view of cost reductions with an incisive assertion: agent technology provides means for earlier assistance and structured prevention of the causes of further care.

The case of Smart Emergency Applications

From what we described above, multi-agent systems have a potential of becoming a key ingredient of next-generation e-health services and applications. Actually, in the last ten years, they have already been used for realizing e-health applications targeting diverse needs, e.g., assistive living (Jih et al., 2006; K4CARE, 2007), diagnostic (Croitoru et al., 2007; Hadzic et al., 2006), physiological telemonitoring (Amft & Habetha, 2007; Gao et al., 2007; Laleci et al., 2008; MobiHealth, 2004; Rialle et al., 2003; U-R-SAFE, 2005) and smart hospital and smart emergency applications (Akogrimo, 2007; Mabry et al., 2004; Schumacher & Helin, 2008).

The successful results of mentioned projects suggest that multi-agent systems provide the right level of abstraction and the needed tools to concretely provide users with a whole spectrum of healthcare applications and services. Notably, we believe that smart emergency applications are the sorts of applications that better capitalize the use of multi-agent technologies. The main reason for this lies in three main architectural characteristics of smart emergency applications that we briefly summarize here. Such characteristics have a common root in the consolidated opinion that the realization of a worldwide, centralized repository of patients' records is a dream for reasons that are obvious today, and therefore, smart emergency applications are inherently dealing with an unstructured universe of diverse systems providing sparse pieces of the information needed to (quickly) respond to the needs of patients. Actually, from an architectural point of view, smart emergency applications *(i)* are made of loosely coupled, complex, legacy systems that enable the quick retrieval of relevant information about the patient; *(ii)* are used to dynamically manage distributed data and resources and no centralized control would ever be appropriate; *(iii)* must be aware of all issues related to security and privacy to provide concrete warranties to all subjects that take part of emergency processes. Multi-agent systems very well accommodate all such architectural characteristics because of the intrinsic features that distinguish agents and that we briefly reported. Moreover, it is worth noting that some of the intrinsic features of agents that we mentioned have not yet explored, e.g., autonomy, pro-activity and goal-orientation, and we frankly believe that they would bring notable benefits in the realization of healthcare applications, and smart emergency applications in particular.

CASCOM: A MULTI-AGENT SYSTEM FOR SMART EMERGENCY

CASCOM (CASCOM, 2008; Schumacher & Helin, 2008) is one of the most recent attempts to bring the notable characteristics of agents to e-health, and to smart emergency in particular. CASCOM is a technology-driven project that brings together three notable new technologies: multi-agent systems, Semantic Web services and peer-to-peer networks in the scope of mobile and context-aware environments.

The main delivery of CASCOM is a general-purpose, open-source middleware that implements a generic architecture for agent-based coordination and execution of Semantic Web services in a so called Intelligent Peer-to-Peer (IP2P) network, i.e., a decentralized network of loosely coupled, proactive peers with no restriction on the actual means of connectivity. Such a middleware transparently accommodates both mobile and fixed users into a seamless environment and, in short, CASCOM provides easy, seamless and contextualized access to Semantic Web services anytime, anywhere and using any device. CASCOM was funded by the European Commission and it groups a value-added chain of research institution, application providers and end users spread across Europe. Namely, the partners of the project were: DFKI (Germany), TeliaSonera (Finland), ADETTI (Portugal), EMA Group (Finland), EPFL (Switzerland), FRAMeTech (Italy), URJC (Spain), University of Basel (Switzerland).

From a technological point of view, the distinguishing feature of CASCOM regards its openness and dynamism. No a-priori link is set between agents and/or Semantic Web services and the pattern of communications is structured on the fly to satisfy the goals of agents. Similarly, CASCOM service discovery agent identifies all relevant services and respective providers by means of the hierarchies of directory services. Afterwards, the CASCOM planner agent creates an ad-hoc plan which composes the invocations to the services identified in the previous step. The CASCOM execution agent finally invokes all services specified in the plan and it applies failure handling mechanisms, just when needed.

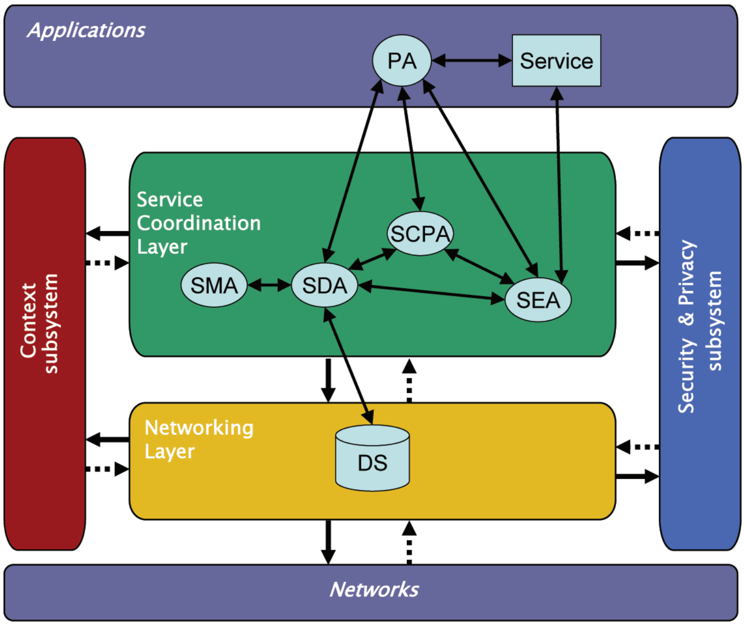
Figure 1 depicts the coarse grained architecture of the CASCOM platform together with a Personal Agents (PAs) and (Web) Services used to implement the concrete functionality of an application. In particular, Figure 1 includes in the CASCOM platform Service Composition and Planning Agents (SCPAs) that are used to dynamically set up a plan to bring about the goals of the agents. SCPAs use the synergy of Service Directory Agents (SDAs) and Service Matchmaker Agents (SMAs) to retrieve the information needed to dynamically build a plan whose execution would eventually satisfy the needs of agents. Concrete execution of such a plan is then delegated to Service Execution Agents (SAEs) which directly interact with involved Web services.

Further details on CASCOM project, its partners and its platform are publicly available on the Web at the address: http://www.ist-cascom.org.

The Motivating Scenario

CASCOM finds its motivations in the following smart emergency scenario that was modelled after the daily work of EMA Group (see http://www.ema.fi). EMA Group was founded in 1989 and it is the oldest and largest emergency assistance organization in Finland. The company provides medical services for travellers in foreign countries in terms of monitoring and ambulance transfers on a 24/7 basis; its customers count Finnish insurance companies and multinational enterprises. EMA Group also cooperates with similar organizations all over the world and, annually, its medical consultants estimate and monitor the adequacy of care of about 1200 travellers, arrange nearly 100 transfers by ambulance flights and manage more than 250 transfers by charter flights or even by vehicles.

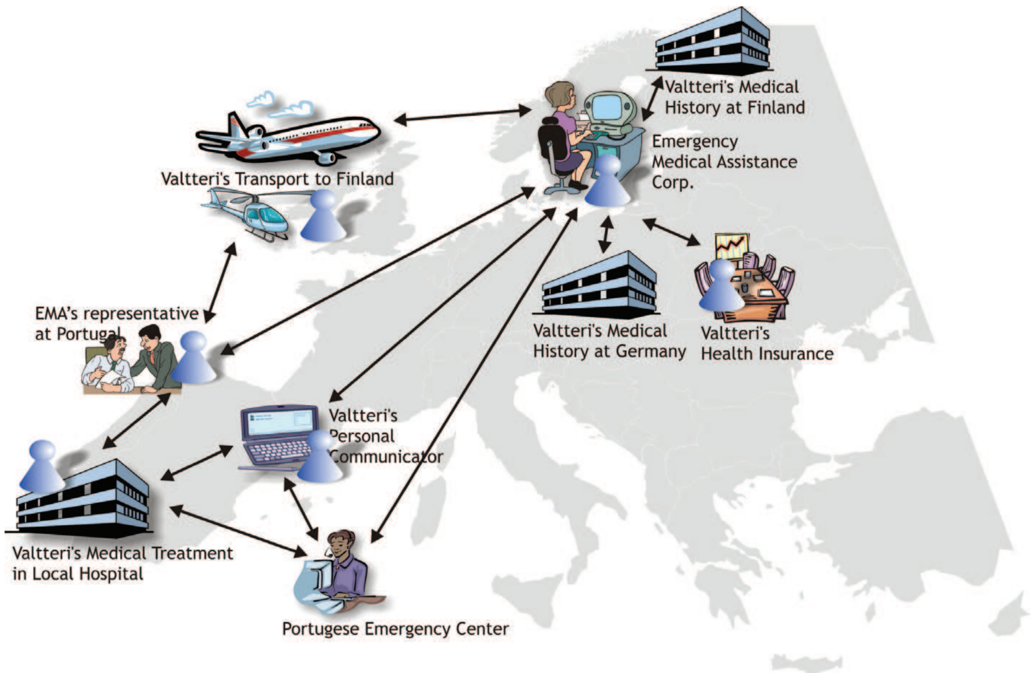
Figure 1. CASCOM architecture



The scenario (see Figure 2) involves Valtteri, a tourist from Finland, who is visiting Portugal during his summer vacation. Before leaving Finland, he loaded the CASCOM mobile agent suite on his mobile phone so that he could access CASCOM agents anywhere, anytime. Unfortunately, after one week in Lisbon he suffers from a serious sickness that he cannot easily identify. This is the first time that something like this happens to Valtteri and he does not know what to do. Luckily, he has his personal communicator device with him and his personal agent situated at his communicator quickly finds out the contact information of a local emergency centre. Using his personal communicator, Valtteri calls the local emergency centre (in Portugal) and he gives the noticeable symptoms of his sickness to the local representative. At the same time, Valtteri's personal agent transfers general information, i.e., non-sensitive information about him together with his current location, to the local emergency centre. The local representative at the Portuguese emergency centre notices that Valtteri's symptoms are very serious and he orders to immediately go to the nearest hospital. The contact information of the nearest hospital as well as a map showing Valtteri's current location and hospital location are pushed to Valtteri's personal communicator by the emergency centre agent. The local emergency centre agent informs the hospital agent that Valtteri is arriving, and within a few minutes after the call, Valtteri reaches the hospital and he is admitted for care.

Immediately after Valtteri's call, Valtteri's personal agent located at his personal communicator contacts the Emergency Medical Assistance (EMA) agent in Finland about Valtteri's situation and it requests to send Valtteri's medical history to the local hospital in Portugal. Because of the Finnish regulations, such sensitive information can not be sent without the explicit permission of the patient. Therefore, EMA agent contacts Valtteri's personal agent about the situation. Valtteri's personal agent asks him about giving the permission and eventually Valtteri gives the permission to disclose the information. The informed consent is sent by Valtteri's personal agent to EMA agent adequately signed with Valtteri's electronic signature. EMA agent forwards the request for information to the hospital in Finland which is held responsible for Valtteri's medical history. An agent at that hospital then sends

Figure 2. CASCOM motivating scenario



necessary information to the local hospital in Portugal. Since Valtteri has spent several years in Germany during his studies, parts of his health record are not available to EMA since they are stored in the information systems of the settled physician and of the hospital he visited at that time. Valtteri's personal agent knows about all agents that have to be contacted and it sends requests to the agent of the German hospital and to the one of the settled physician. Given appropriate permission by Valtteri, they both forward the requested information to the Portuguese hospital.

EMA agent retrieves data about Valtteri's situation from the Portuguese hospital and it makes a first level analysis of Valtteri's situation. Based on such information, EMA makes an assessment of the situation. Then, EMA agent contacts Valtteri's insurance company for ensuring that it would cover the costs. The insurance company agent confirms that it would cover all costs. Based on the information given by the Portuguese hospital, EMA decides that a local representative from Finland should fly to Portugal to take care of Valtteri's situation. EMA agent makes all travel arrangements and it downloads necessary information about the travel arrangements as well as information about Valtteri to the EMA representative's personal communicator.

In Portugal, the EMA representative negotiates with several hospitals to find the best place for arranging a stay for Valtteri to wait for further actions. EMA representative also contacts an EMA local representative in Portugal to negotiate whether Valtteri should be transferred back to Finland or treated locally in Portugal. They make a decision that Valtteri should be transferred back to Finland as soon as possible. The personal agent situated at EMA representative's personal communicator automatically finds out possible flight arrangements and it informs doctors and escorts involved in the travel. The agent also makes an arrangement with a Finnish hospital for ensuring special care once landed. In Finland, Valtteri is treated at a hospital in Helsinki.

From a functional point of view, CASCOM motivating scenario addresses well-known requirements of future smart emergency systems and services. Actually, a major challenge in smart emergency systems and services is to take the best decision on the treatment of the patient, with no background knowledge of patient's medical history, e.g., known allergies and current medical treatments. CASCOM addresses such needs by providing physicians with contextualized information on the fly. Such information is acquired as needed directly from its source because CASCOM agents directly interact with the Semantic Web services that medical institutions provide to access their databases in a secure and privacy-aware manner. This is by far a visionary scenario, because many institutions (see, e.g., Springmann et al., 2007) are now in the process of opening their information systems via Semantic Web services to allow third-party physicians to access patients' data, especially in emergency situations.

Field Trials

The presented scenario generated independent runs of field trials that involved real healthcare operators in very realistic settings and that concentrated on different parts of the scenario in three places across Europe: Innsbruck, Basel and Helsinki. Such trials were run in order to have an assessment on the functionality that CASCOM provides and to acquire some understanding on the feasibility of CASCOM approach. The feedback obtained from all user groups has been very positive and encouraging (CASCOM, 2008).

In all trials, patient data was provided by the Health@Net project (see http://www.healthnet.or.at) via dedicated Semantic Web services. Health@Net is an Austrian research project whose main objective is to open the clinical information system of the Tyrolean Provincial Hospital Company (TILAK) and to offer access to this system via Web services. The Health@Net services have primarily been designed for usage by family doctors that indent to send their patients for examination to one of the hospitals of TILAK.

The most articulated trial was run in Innsbruck and was meant to analyze the physician's view of the system. A first round of trials was run at the trauma station of the Innsbruck University Hospital and at TILAK premises. Two renowned physicians tested the physician's application view in their daily working environment both at the emergency department and in an emergency car. Two paramedics were also involved and gave feedback during the tests in the emergency car.

A second round of trials in Innsbruck included the Austrian Car, Motorbike and Touring Club (ÖAMTC) and was run in the ÖAMTC air emergency base and in a flying helicopter. The main objectives of this second round were to check if the system would work in such a critical environment and how it would react in high altitude, under very high speed and under potentially low quality network coverage. This second round of trial has been proposed by the emergency physicians of TILAK who participated in the first round. Their main motivation was that in areas like Innsbruck and surroundings the number of emergency situations that require an emergency helicopter is considerably high.

During the weeks before the start of the trials, TILAK requested a special permission for using mobile devices in trial flights. The permission has finally been granted from the local flight authorities under the precondition that pre-flight Electromagnetic Compatibility/Interference (EMI) tests positively showed that all CASCOM devices were fully compatible with the aviation systems of the helicopter. The trial has been carried out with a fully equipped emergency helicopter crew, i.e., the flying staff and an emergency physician. The latter contributed to the evaluation of the software from the physician's point of view.

The technical equipment used for the trials in Innsbruck was the following: HTC TyTN smart phones connected via UMTS for testing the patient application and Asus R2H ultra mobile PCs for testing the physician's view. In addition, ANYCOM GP-700 Bluetooth GPS receivers were used for the HTC TyTNs. The backend system was hosted on a HP ML530 G2, Dual Xeon 2.4 GHz server with 6 GB RAM located within the TILAK network infrastructure. For security reasons, the backend server was placed inside the local demilitarized network zone (DMZ), as shown in Figure 3.

The feedback collected from all users involved has been very positive and encouraging; it proved both the adequateness of the overall CASCOM concepts, and the value of its implementation.

In Innsbruck, the main focus was on emergency physicians of the Innsbruck University Hospital in three different situations: in the emergency room, in an emergency car on the road, and in a flying emergency helicopter. The feedback from emergency physicians was very satisfying. Similar positive results have been given by emergency physicians in the trials which have been performed in Helsinki. Finally, a dedicated series of tests has been done in Basel where the patient's view of the system has been evaluated with highly positive results.

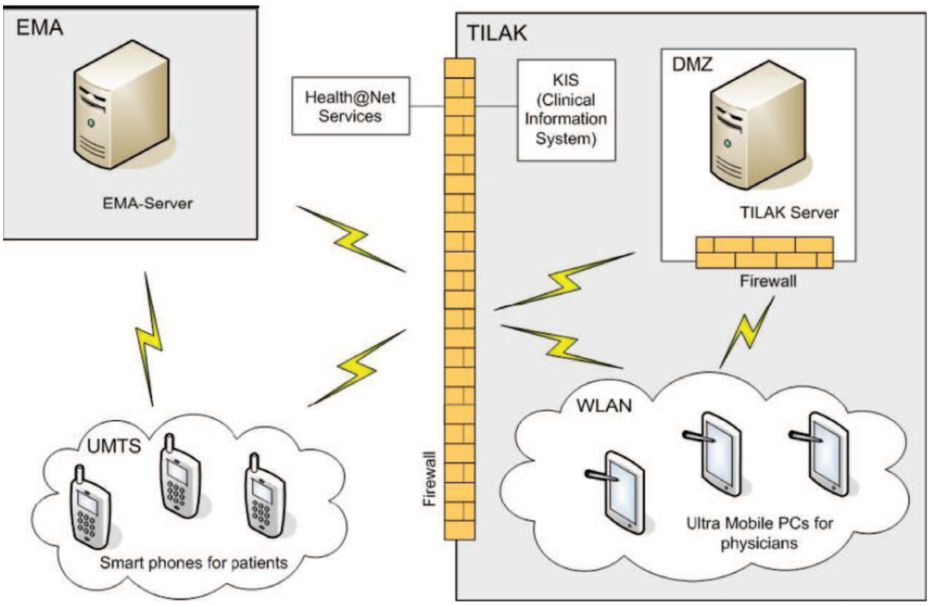
A summary of the results of field trials and of performance and usability tests can be found in (CASCOM, 2008).

CONCLUSIONS

In this paper, we discussed about the use of multi-agent systems in the realization of next generation e-health. Moreover, we provided a concrete example of an application realized through the use of such systems, i.e., CASCOM, that could drive the adoption of multi-agent systems as a paradigm in the realization of healthcare applications and services, and smart emergency applications in particular.

Multi-agent systems proved as one of the most interesting technology for the development of complex and distributed applications. However, multi-agent systems are not only a development technology, rather they provide a novel level of abstraction that is concretized into different technologies depending on the concrete needs of applications (see Jennings, 2000 and Bergenti & Huhns, 2001 for a an in-depth discussion). This allows describing various projects and applications that concretely use diverse technologies in terms of agents and multi-agent systems. Healthcare is a vast, open environment characterized by shared and distributed decisions and the management of care requires the communication and coordination of complex and diverse forms of information between involved organizations and people. Therefore, both multi-agent systems and healthcare have mutual advantages from their coupling: multi-agent systems exhibit the suit-

Figure 3. Field trial network architecture



able features for the modelling and realization of future healthcare applications; healthcare scenarios offer the right requirements for experimenting multi-agent technology and, so, for giving a great contribution to their evolution and success.

Unfortunately, the adoption of agent technologies in e-health is taking place quite slowly and, despite the number of research projects on the topic, this is not yet an assessed practice. In fact, there are some technical problems associated with the use of multi-agent systems for healthcare; some of them are identifiable in any application domain, such as user expectations and acceptance, and lack of centralised control; others are typical of the healthcare domain, such as legal and ethical issues like privacy, integrity and authentication in the exchange of patient information between agents.

Our future work will be oriented, besides to the enhancement of the CASCOM software infrastructure, to realize multi-agent applications and services that could be more acceptable inside healthcare organizations. In particular, our goal is to realize systems where the autonomy level of the agents is customizable by the user; therefore, the user can enable/disable the operations that the agents can execute autonomously and so she/he can maintain the direct control of the most critical tasks (e.g., an agent can exchange patient information with another agent only after her/his approval), but she/he can take advantage of their autonomy for making faster and simpler a large number of her/his tasks (e.g., the collaboration with remote colleagues, the remote interaction and monitoring of patients and the retrieval of the new healthcare documents available on the Internet that are of her/his interest).

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