A Mobile Agent Approach for Ubiquitous and Personalized eHealth Information Systems

Panagiotis Germanakos[1], Constantinos Mourlas[1], George Samaras[2]
[1]Faculty of Communication & Media Studies, National & Kapodistrian University of Athens, 5 Stadiou Str., GR 105-62, Athens, Hellas
{pgerman, mourlas}@media.uoa.gr
[2]Computer Science Department, University of Cyprus, CY-1678 Nicosia, Cyprus
cssamara@cs.ucy.ac.cy

Abstract. The past years have witnessed a heavy investment and research in the eHealth sector. The work of medical practitioners at all levels is becoming more information intensive as sophisticated medical equipment and computer applications are more widely used. At the same time, the demands of the patients / citizens are increasing due to the innovative medical and scientific advances. Digital technologies are becoming more important in health management aiming to reduce the cost and to deliver health care services at a distance. In addition, the Internet is increasingly used by citizens to obtain medical information, therefore it is critical that the Web-based eHealth content and services are developed efficiently, complying with the established quality criteria and being available for all in an adaptive and personalized manner delivered by multiple and ubiquitous delivery channels. In this context, the aim of this paper is to argue that in the face of the existing systems and platforms diversity and information sparsity, mobile agent technologies can provide the base for ubiquitous, transparent, secure, interoperable, and integrated eHealth information systems for the provision of adapted and personalized sustainable services to the citizens.

1 Introduction

During the last few years several initiatives (public and private) were undertaken addressing different applications of mobile and ubiquitous eHealth issues, ranging from doctor mobility (remote access to medical data), to patient mobility (remote monitoring of vital signals, tele-consultation, mobile medical record, wearable medical sensors) up to web based medical data access. Nevertheless, the scope of these initiatives was focused and the different approaches were designed in an ad-hoc way. As a result, it is not possible to integrate the different technological innovations and services into an integrated system. Furthermore, many issues that are crucial for the deployment of an integrated ubiquitous mobile health system were not addressed, like for example social and economic aspects, changes in medical work practices and even standardization of technologies and integration with existing medical information systems. It is for these reasons that most of the technological innovations were either rejected by the market or their scope and usage remained limited [1].

Following the improvement of the wireless transmission technologies [2], the primary objective of many researches today, realizing the ubiquitous mobile health problem, is to design and implement integrated ubiquitous eHealth mobile services systems and platforms emphasizing on socio-economic, technological and innovation research aspects. More broadly, these aspects include standardization of technological innovations, development of new working practices for health professionals (supporting patient and health professional mobility by enabling cooperative working over distance and time between virtual healthcare teams and the patients), integration of a complete service chain (ranging from medical personnel training, to device maintenance services and billing), and strategies towards the deployment of new services (i.e. personalized eHealth information systems for the provision of quality services to citizens) and technologies.

Subsequent to the growing citizens' demands and requirements as well as the rapid development of the technological advancements and communication platforms capabilities the development of eHealth personalized service provision should not only focus on making the service available on the PC-based Internet, but also examine the different broadband delivery platforms. "Two new developments will have a major impact on the further development of the Internet: multi-platform access / convergence and broadband" [3]. Broadband stimulates the use of the Internet and enables the usage of rich applications and services. Its benefits emphasize in the areas of e-business, e-learning, e-health, and e-government, improving the functionality and performance of those services, and further extending the use of the Internet. A multi-channel (WAP, UMTS, MMS, SMS, Web, Satellite etc. [4]) and a multi-device (PC, 3G and 4G mobile systems, PDA, tablet PC, Satellite handset etc.) access mix will improve the access of the eHealth services offered, since will be available anytime, anywhere and anyhow through a single point of access entry. Indisputably, this is the vision of an interoperable, transparent and secure eHealth continent whereby multi-channel service delivery integration is considered fundamental. This could be achieved, with the proper reengineering of the front and back office processes and implementation of new multi-channel personalized ways of interaction, driven by common International medical standards (e.g. WHO, ICD-10, ICD-0, HL7 [5, 6, 7]), and adjusted to the citizens' needs and requirements.

The aim of this paper is to realize the common challenges and implications of the current eHealth environment. Special emphasis will be placed on the emergence of the wireless and mobile technologies and advancements in the specific area and how this affect the designing and development of ubiquitous information systems for the provision of eHealth adaptive and personalized services. Eventually, the mobile agents paradigm will be presented, examining its characteristics, arguing that it could effectively used for the composition of such personalized, multi-modal, and interoperable component-based eHealth information systems for sustainable services provision.

The paper is structured in 5 sections. Section 2 gives an overview of the trends and implications of the eHealth services sector. Section 3 describes the mobility emergence and the challenge for ubiquitous information systems development. Section 4 identifies certain key attributes and characteristics of adaptive Web personalization and mobile agents, and argues that they represent a well suited technology to implement eHealth personalized information systems, and section 5 concludes this paper.

2 The eHealth Sector – Current Trends and Implications

Today's information age is accelerating at quantum speed. Advances such as the Internet and high-speed networks have propelled the never-ending quest for information. An infinite amount of information is being created and accessed by people around the globe everyday. However, since we live in an information intensive society, there remains a significant amount of information inaccessible to those most in need. Pertinent information is stored in various systems, in a range of media, employing a number of technologies, all across the globe. What is lacking is a content management framework, that is, highly scalable information architecture capable of managing infinite amounts of data of all types and provides it in an adaptive and personalized manner. A clear example of the latter observations is the healthcare sector.

Healthcare today remains one of the most information intensive and least automated of all industries. It remains a "paper world", in which most institutions have implemented a central registry, in which the "official" records are maintained. In fact, much of what is maintained in the healthcare institution's central registry is generated by computer based systems, yet the printed version is the official record. The problem here is often the time delay experienced in the continued efforts to maintain an accurate paper based record, such as a patient's medical file in an environment of constant updates. Furthermore, this approach is being replicated by each institution, with no opportunity for electronic sharing of clinical data. Among others, this problem is intensified with the lack of common standards and methodologies that could support the design of interoperable eHealth information systems and their integration with legally stand-alone ones.

Nevertheless, European Commission through its eEurope 2005 Action Plan [1] has drawn some specific innovative guidelines and objectives for advancing the current eHealth situation. These include the creation and dissemination of electronic health cards, the set up of European-wide information networks of public health data, and the provision of online personalized health services through intelligent information systems to the citizens. For the scope of this paper, the latter eHealth information systems should be distinguished from key characteristics such as management of complex data, scalability, security, control, transparency, interoperability and being able to be integrated with existing applications and systems. Moreover, since Web structures nowadays are large and complicated resulting to the spatial disorientation of the citizens, Web personalization, implying adaptive and intelligent personalized interfaces and processes, is considered critical for the sustainable provision of eHealth services and must therefore incorporated to the eHealth information systems. Eventually, another vital consideration is the standardization of the different pertinent elements (in cooperation with the various standardization bodies like ETSI, ITU, CEN / CENELEC, ISO), defining communication and transmission protocols and interfaces that will allow the systems to work in an interoperable, coherent and cohesive way.

3 The Mobility Emergence

The "New Adaptive Web" generation strives to move eHealth beyond traditional borders of desktop Health systems embracing such modern Web trends as "mobile Web", "open Web", and "Semantic Web". In this section, a reference to mobile Health (mHealth) will be made, identifying the mobility emergence and physical constraints and challenges that should be addressed by new advanced adaptive personalization information systems.

3.1 Towards the mHealth Reality

Even if it is quite clear so far the reason of its "birth", it would be considered fundamental to emphasize more on mHealth's imperative existence, since in the future statistically the related channels will take over as the most sustainable media of services provision. mHealth could be considered as a new kind of front-end access to public services with specific capabilities of delivering on demand real time information. Nowadays, as an integral part of eHealth, many governments should start offering eHealth services via a variety of service delivery channels apart from the Web. One of this mobile service delivery channels is mobile telephony. This channel becomes more relevant considering the much faster growth of mobile penetration rate compared to desktop based Internet access. Moreover, the growth of mobile communications has had a profound economic and social impact in Europe and beyond. The mobile phone is now pervasive and is used in every human activity, private, business and governmental. While penetration levels are likely to continue to increase, the most significant future development will be the growth of mobile broadband services, as the potential provided by third generation mobile (3G) and its enhancements, as well by other wireless technologies, including RLAN, satellite and others, is realized. The dissemination of these technologies represents a paradigm shift that will enable the emergence of new data services, combing the benefits of broadband with mobility [3]. Looking forward, the convergence of telecommunications, broadcasting and internet will result in the proliferation of high speed multimedia services delivered over mobile networks. The 2.5G / 3G and

R-LANs will co-exist and provide complementary services. The research environment has changed dramatically, since 1998, when ETSI adopted the UMTS standard for 3G. Citizens can benefit from the high-speed wireless access when near a hot-spot, and receive mHealth 3G services over a wider area. Continued technological innovation will also affect other platforms which, in turn, may affect the development of 3G by giving a broader technology base from which new innovative mHealth services could be developed to the benefit of all. The convergence of fixed and mobile services, for example, through unified fixed / mobile offerings, will also bring additional opportunities for innovation.

3.2 General Mobility and eHealth Cross-Road Considerations

The needs of mobile users differ significantly from those of desktop users. Getting personalized information "*anytime, anywhere and anyhow*" is not an easy task. Researchers and practitioners have to take into account new adaptivity axes along which the personalized design of mobile Health would be built. Such applications should be characterized by flexibility, accessibility, context-awareness, quality and security in a ubiquitous interoperable manner in order to provide the citizens with quality on demand information (services). User interfaces must now be friendlier enabling active involvement (information acquisition), giving control to the citizen and provide easier means of navigation supported by the small screens of the mobile devices and enable adaptation of hypermedia, multi-media, and multi-modal intelligent and personalized user interfaces [8, 9, 10, 11, 12].

Various attempts have been made so far to comply with the aforementioned demands. These emphasize mainly on re-engineering existing Web sites and services. However, creating and maintaining a Web site to support multi-channel access is proved to be quite costly and also require a significant amount of work. An example of such a solution is the use of specialized wrappers that export a different view of a Web page or service without requiring any modifications to the underlying Web site as such. These are quite costly to set up in the first place and need updating whenever the corresponding Web site or service changes. Another solution would be to use proxies that filter and reformat Web content. However, these are general purpose proxies and do not perform any kind of personalization [13].

Moreover, mobility applications can suffer from a handful of noteworthy problems. These could be summarized into: local mobility, limited mobility, closed mobility and interrupted mobility. Local mobility describes the situation when some mobile applications have been successfully delivered in a local environment, but are not cost-effective when applied at a trans-national mobility level. Limited mobility describes cases where an impressive coverage has been reached nevertheless encountering local problems, non-covered local areas or not enough capacity. Closed mobility describes situations where mobile services are restricted for example to GSM technology (both CSD and SMS), without any generalized use of complementary mobile technologies for local environments as well as non-terrestrial areas; and finally, interrupted mobility describes cases where there is a lack in the availability of frameworks that make possible business models in which complex interactions between different sectors are performed by means of mobile applications.

To overcome these problems intelligent techniques have to be implemented to enable the development of adaptive and mobile Web-based systems [8] that will enhance the more direct and personalized eHealth services delivery. Fundamental characteristics should include openness, high connectivity speed, reliability, availability, context-awareness, broadband connection, interoperability, transparency and scalability, expandability, effectiveness, efficiency, personalization, security and privacy [14, 15, 16, 17, 18].

4 The Web Personalization Imperative

4.1 User Service Requirements and Delivery

To get the right information at the right time and the right place is not so easy for the citizens. The eHealth sector working at its front or back office, it has encountered in several times and occasions the particular problem. Citizens' interaction with the services has to be improved, and a serious analysis of user requirements in the area of eHealth has to be undertaken, documented and furthermore analyzed taking into consideration its multi-application to the various delivery channels and devices in order to design effective and personalized eHealth information systems that will provide quality eHealth services.

This paper will present, based on studies conducted [19, 20, 21], some of the user (citizen) requirements and arguments anticipated. They could be clearly distinguished into:

4.1.1 General User Service Requirements

- *Flexibility: anyhow, anytime, anywhere*. (a) Technological developments have introduced a wide variety of new channels over which different forms of contact can take place (i.e. web technology, has introduced e-mail, which in many situations has replaced regular mail, or has opened the possibility of consuming services by means of self-service on a 24x7 basis; moreover, mobile technology makes it possible to consume services irrespective of location); and (b) many service delivery processes consist of two more interaction sessions between the citizen and the provider (i.e. if the organization is flexible in terms of its service delivery, it will allow the user to choose the channel or location for the interaction processes, and allow him to switch between channels at any preferable time).
- *Accessibility*. (a) Citizens should be able to locate the required services (awareness); (b) citizens should be able to identify the channels that they can use to access the service they need; (c) once a service is located and accessed, citizens should be able to consume the information provided by the service; (d) the legal basis of eHealth services stipulates that they must be accessible for all potential citizens; and (e) a pricing policy for services should guarantee that the intended target groups can afford the services.
- *Quality*. (a) There are many situations in which a citizen needs more than just one service to deal with a particular situation. In an one-stop shop approach, a single interaction would be able to address all requirements, thus saving the citizen's considerable amount of time; (b) eHealth services are usually regulated by means of strictly defined specifications. Quality can be described as satisfactory if the service is provided in conformance with the relevant specifications; (c) in user-centric approach, services must be offered pro-actively. A timely service is a service that is offered at the moment a citizen may need it, even though he may not yet be aware of it; and (d) quality comes at a price (i.e. faster delivery of a service may involve more costs than delivery at a regular speed).
- *Security*. (a) A trusted exchange of information depends on an assured security level. If a channel is not secure, or if citizens do not trust its security, the channel will not be used for services that involve sensitive information; (b) security is not only a technical matter, it is also one of perception. Due to a lack of trust in security matters, relatively large segments of the user population are less inclined to use channels that they do not fully trust, especially when payment is involved.

4.1.2 Requirements for a Friendly and Effective User Interaction

- *Information Acquisition*. Support active involvement.
- *System Controllability*. Give the citizens the control.
- *Navigation*. Provide easy means for navigation and orientation.

- *Versatility*. Support alternate interaction techniques.
- *Errors*. Tolerate citizen's errors and support error system-based and context-oriented correction of citizen's errors.
- *Personalization*. Enable customization of multi-media and multi-modal user interfaces to particular citizen's needs.

4.2 Challenges in the Adaptive and Personalized eHealth Design

As the number and usage of the wireless communication media and mobile devices grows considerably, the design and implementation complexity of adaptive eHealth information systems and applications rises significantly. These could be summarized by the small size (leading to inherently limited user interfaces), bandwidth constraints (imposing limitations on the amount of information to be transferred), costs (due to expensive wireless transmission of information), processor computing power (due to the different architectural design), memory and storage space (due to the small size), small screen (with little resolution capabilities), high latency and data entry constraints (due to the restricted size of the keyboard if even present)

The "Mobile" generation is now extending the basis of the adaptation by adding models of context such as location, time, computing platform and bandwidth to the classic user model and exploring the use of known adaptation technologies to adapt to both an individual user and a context of their work [22]. Adding to the challenges of classic eHealth information systems the new advanced m- and eHealth techniques will need to address considerations having to do with the heterogeneous nature of the multiple platforms as well as the position in space (and time) of the user (citizen) in order to produce an effective adaptive and personalized result. Now, by user needs it is implied both, the *thematic preferences* (i.e., the traditional notion of profile) as well as the characteristics of his mobile device, the *device profile*. Therefore, adaptive personalization here is concerned with the negotiation of user requirements and device abilities.

It is an indisputable fact, that user population is not homogeneous, nor should be treated as such. To be able to deliver quality eHealth services, they should be tailored to the needs of each individual citizen providing them personalized and adaptive information at the requested moment. Although one-to-one service provision may be a functionality of the distant future, user segmentation is a very valuable step in the right direction. User segmentation means that the population is subdivided (ideally per service or group of related services), into more or less homogeneous, mutually exclusive subsets of users who share an interest in the service. The subdivisions are based on one or more user characteristics. These could be d*emographic characteristics* (i.e. age, gender, urban or rural based, region), s*ocio-economic characteristics* (i.e. income, class, sector, number of employees, volume of business, channel access), p*sychographic characteristics* (i.e. life style, values, sensitivity to new trends), or i*ndividual physical and psychological characteristics* (i.e. disabilities, attitude, loyalty).

The issue of personalization is a rather complex one with many aspects and viewpoints that need to be analyzed and resolved. Some of these issues become even more complicated once viewed from a moving user's perspective, in other words when constraints of mobile channels and devices are involved [23]. Such issues include, but are not limited to, the following: *what content to present to the user*, *how to show the content to the user*, *how to ensure the user's privacy*, or *how to create a global personalization scheme*. In addition to these considerations, there are also many approaches and each one of them usually focuses on a specific area, i.e. whether this is profile creation, machine learning and pattern matching, data and web mining or personalized navigation. This is leading to the selection of the Web personalization methodologies to be implemented and varied from Link, Content, and Context, to Authorized and Humanized personalization, with several paradigms developed to implement them. Among others these include, content-based filtering, rule-based filtering, collaborative filtering, Web-usage mining, demographic-based filtering agent technologies, and cluster models.

Eventually, as clearly viewed so far, citizen characteristics, determining user segmentation and thus provision of the adjustable eHealth service information, differ according to the circumstances and they change over time. This is one of the reasons why citizens should be offered a choice of channels when they access services.

4.3 A Mobile Agent Approach for Web Personalization

In previous sections it has been presented the current eHealth situation underlying its challenges and weaknesses. Moreover, it has been identified the new requirements and demands of the citizens (users), for more quality and "anytime, anywhere and anyhow" information (and not only) services, emerged mostly from the rapid development and dissemination of the wireless and mobile technologies. In this section, it will be placed special emphasis on the mobile agents paradigm. Their main characteristics and capabilities will be discussed, arguing why this could be considered the most suitable technology to be used for the development of ubiquitous and personalized intelligent m- and eHealth information systems that will offer sustainable services to all from any device.

There are a number of different approaches and architectures that have been implemented in building eHealth information systems, each one of which with different strengths and weaknesses. This paper will be focused on the intelligent mobile agent approach, since the mobility dimension is henceforth incorporated, and therefore needs as to locate the required information, on time, under any circumstances are considered vital. Agents are processes with the aim of performing tasks for their users, usually with autonomy, playing the role of personal assistants [23, 24]. More broadly, according to Lange and Oshima, an agent could be defined as a software object situated within an execution environment and possesses a number of mandatory properties. Specifically, it should be reactive (sense the changes in the environment and act accordingly) autonomous (control its own actions), goal-driven and able to execute continuously. Furthermore, an agent may be communicate (communicate with other agents), be mobile (travel between hosts) and able to learn (adapt its behaviour based on previous experiences) [25].

Agents usually solve common problems users experience on the Web such as personal history, shortcuts, page watching and traffic lights [26]. Some of the agents' main characteristics could be distinguished according to their abilities used and according to the tasks they execute. The former include characteristics such as *intelligence* (the degree of reasoning and learned behaviour, the agent's ability to accept the user's statement of goals and carry out the task delegated to it), *autonomy* (the agent's capacity to control its own actions), *social capacity* (the agent's ability to communicate with other agents, and with the users, generally through a language of communication among agents), and *mobility* (the agent's capacity to move in the environment; a mobile agent software is the one capable of being transported from one machine to another during its execution); while the latter classify the agents into *information filtering agents*, *information retrieval agents*, *recommendation agents*, *agents for electronic market*, and *agents for network management* [24].

Consequently, all the aforementioned considerations are leading to six main agent types which are: the *collaborative agent* (emphasize autonomy and co-operation with other agents to perform the tasks that are assigned to them by their owners. They usually act in open and time-constrained multi-agent environments); the *interface agent* (except for autonomy, also emphasize learning in order to perform tasks for their owners); the *information / internet agents* (their main task is to manage, manipulate and collate information from many distributed sources); the *reactive software agents* (also known as autonomous agents, represent a special category of agents that do not possess an internal model of their environment. Instead, they act based on a number of "stimulus-response" couples. More specifically, for every stimulus they accept from the environment, and depending on their current state, the corresponding response is selected and executed); the *mobile agents* (are software processes capable of roaming the web, interacting with foreign hosts, performing tasks on behalf of their owners and returning "home" having performed the duties assigned to them [27, 28]); and the *intelligent agents* (agents are called *intelligent* when they use machine learning techniques, like neural networks, rule learning, Bayesian networks or data mining, in order to be able to learn the interests and habits of the user and offer him valuable help) [23, 29].

Furthermore, several mobile agent platforms could be proposed in order to base the development of an efficient mobile eHealth information system. These could be broadly categorized as *Java* and *non-Java based ones*. There is an increasing interest in Java-based platforms due to the inherent advantages of Java, namely, platform independence support, highly secure program execution, and small size of compiled code. These features of Java combined with its simple database connectivity interface (JDBC) that facilitates application access to relational databases over the Web at different URLs, make the Java approaches very attractive to work with [30, 31, 32]. The Java-based mobile agents' platforms include IBM'Aglets Workbench, Recursion Software's Voyager [33], Mitsubishi's Concordia, IKV++ Grasshopper and General Magic's Odyssey. The non-Java-based systems include, for example, TACOMA and Agent Tcl. While all these systems provide the basic functionality expected from such mobile platforms, they differ significantly in their system architecture, the communication mechanism employed, the additional functionality they provide and their performance.

The main reason that the particular approach of intelligent mobile agents is proposed for a given wireless environment is that they are being identified by some specific capabilities that could enable the more efficient implementation of the adaptive and personalized eHealth information systems. These advantages of the intelligent mobile agents are focused upon: (a) *Reduction of the network load*, instead of relying on numerous communication protocols to achieve network interaction, which would increase the network traffic, mobile agents can carry with them the data that is required for an interaction and process it locally; (b) o*vercoming network latency*, mobile agents can help in critical real-time systems where a response to environment changes is required in real time and latencies will not be tolerated. Mobile agents can be dispatched from a central controller to act locally and directly execute the controller's directions; (c) *asynchronous and autonomous execution*, after a task is assigned to a mobile agent, the agent will be dispatched into the network and become independent of the creating process. It can operate asynchronously and autonomously, relieving its owner from having continuously an eye on its activities. The agent's owner will be able to collect it at some later time, if needed; and (d) *dynamic adaptation*, mobile agents are capable of monitoring the environment in which they operate and react to the changes accordingly. Last but not least, mobile agents are naturally heterogeneous, robust and fault-tolerant, and able to encapsulate protocols considered vital for the universal development of open, modular, ubiquitous and personalized eHealth information systems [23, 34, 25].

Having seen some of the physical constraints imposed by the size of the mobile devices and by the bandwidth restrictions of the wireless communication channels and having also seen the advantages of using mobile agents, it is quite obvious that mobile agents technology could be considered one of the most suitable technologies that can be used in the face of the increasing needs and requirements of the citizens and provide ubiquitous and personalized eHealth information systems.

5 Conclusion

In conclusion, this paper presented the current eHealth sector situation in further realization of the technological environment divergence and citizens' disorientation, due to, in the former case ad-hoc development of systems, while in the latter sparsity of information. The growing demands of the citizens for "anytime, anywhere and anyhow" information (services) delivery as well as the mobility and wireless platforms and devices emergence, intensified the imposition of the development of common standards and protocols as well as technologies that could be used for the design of interoperable, ubiquitous, secure, adaptive, personalized and transparent m- and eHealth information systems. Eventually, in the face of the mobile Health reality the mobile agents paradigm has been examined arguing that it could serve the core technology for the development of the aforementioned systems.

In particular, section 2 presented the current trends and implications of the eHealth sector. In Section 3 the mobile and wireless emergence has been described, realizing the "birth" of the mHealth and the subsequent citizens' increased needs and requirements for continuation and creation of new quality services delivery, accessible on demand from any communication channel. Moreover, further mobility and eHealth cross-road consideration have been investigated. Finally, in section 4 these citizens' extended requirements have been identified and listed, and the Web personalization imperative has been comprehensively declared. An overview of the mobile agents technology took place discussing how the advantages of adopting mobile agents intelligent paradigms could help ease the limitations stated. Based on this, it has been argued that mobile agents technology it could be considered the most suitable technology for the implementation of m- and eHealth information systems.

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