 32nd Annual International Conference of the IEEE EMBS Buenos Aires, Argentina, August 31 - September 4, 2010 Mobile Healthcare Information Management utilizing Cloud Computing and Android OS Charalampos Doukas, student Member IEEE, Thomas Pliakas, student Member IEEE and Ilias Maglogiannis, Member, IEEE Abstract—Cloud Computing provides functionality for managing information data in a distributed, ubiquitous and pervasive manner supporting several platforms, systems and applications. This work presents the implementation of a mobile system that enables electronic healthcare data storage, update and retrieval using Cloud Computing. The mobile application is developed using Google's Android operating system and provides management of patient health records and medical images (supporting DICOM format and JPEG2000 coding). The developed system has been evaluated using the Amazon's S3 cloud service. This article summarizes the implementation details and presents initial results of the system in practice. INTRODUCTION MOBILE healthcare systems focus towards achieving two specific goals: the availability of e-health applications and medical information anywhere and anytime and the invisibility of computing [1]. Mobile pervasive healthcare technologies can support a wide range of applications and services including mobile telemedicine, patient monitoring, location-based medical services, emergency response and management, personalized monitoring and pervasive access to healthcare information, providing great benefits to both patients and medical personnel ([1], [10]). The realization however of health information management through mobile devices introduces several challenges, like data storage and management (e.g., physical storage issues, availability and maintenance), interoperability and availability of heterogeneous resources, security and privacy (e.g., permission control, data anonymity, etc.), unified and ubiquitous access. One potential solution for addressing all aforementioned issues is the introduction of Cloud Computing concept in electronic healthcare systems. Cloud Computing provides the facility to access shared resources and common infrastructure in a ubiquitous and pervasive manner, offering services on demand over the network to perform operations that meet changing needs in electronic healthcare application. In this context @HealthCloud has been developed; a pervasive healthcare information management system for mobile devices utilizing Cloud Manuscript received April 23, 2010. Charalampos Doukas is with the University of the Aegean, Samos, Greece (e-mail: doukas@aegean.gr). Thomas Pliakas is with the Nokia Siemens Networks, COO Converged Core, Athens, Greece (e-mail: thomas.pliakas@nsn.com). Ilias Maglogiannis is with the University of Central Greece, Lamia, Greece (e-mail: imaglo@ucg.gr). Computing and Android Operating System (OS) [2]. MOBILE HEALTHCARE SYSTEMS AND CLOUD COMPUTING Several studies have demonstrated that the limited access to patient-related information during decision-making and the ineffective communication among patient care team members are proximal causes of medical errors in healthcare ([8], [9]). Thus, the pervasive and ubiquitous access to healthcare data is considered essential for the proper diagnosis and treatment procedure. Cloud Computing is a model for enabling convenient, on-demand network access to a shared group of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model promotes availability and is composed of five essential characteristics, three service models, and four deployment models. The major characteristics of Cloud Computing can be summarized into the following [11]: (A) On-demand self-service. A consumer can unilaterally obtain access to computing capabilities, such as server computing time and/or network storage, as needed automatically without requiring human interaction with each service's provider; (B) Broad network access: Resources are available over the network and accessed through standard mechanisms that promote use by heterogeneous thin or thick client platforms (e.g., smart phones); (C) Resource pooling: The provider's computing resources are pooled to serve multiple consumers using a multi-tenant model, with different physical and virtual resources dynamically assigned and reassigned according to consumer demand. Examples of resources include storage, processing, memory, network bandwidth, and virtual machines; (D) Rapid elasticity: Resources can be rapidly and elastically provisioned, in some cases automatically, to quickly scale out and rapidly released to quickly scale. Given the characteristics of Cloud Computing and the flexibility of the services that can be developed, a major benefit is the agility that improves with users being able to rapidly and inexpensively re-provision technological infrastructure resources. Device and location independence enable users to access systems using a web browser regardless of their location or what device they are using (e.g., mobile phones). Multi-tenancy enables sharing of 978-1-4244-4124-2/10/$25.00 2010 IEEE 1037 resources and costs across a large pool of users thus allowing for centralization of infrastructure in locations with lower costs. Reliability improves through the use of multiple redundant sites, which makes Cloud Computing suitable for business continuity and disaster recovery. Security typically improves due to centralization of data and increased security -focused resources. Sustainability comes about through improved resource utilization, more efficient systems. A number of Cloud Computing platforms are already available for pervasive management of user data, either free (e.g., iCloud [13] and DropBox [15]) or commercial (e.g., GoGrid [12] and Amazon AWS [14]). The majority of them however, do not provide to developers, the ability to create their own applications and incorporate Cloud Computing functionality, apart from Amazon AWS. More information on the latter issue is provided in Section V, while the following section discusses related work in the context of mobile pervasive healthcare. RELATED WORK The application of mobile devices for pervasive healthcare information management has already been acknowledged and well established ([6], [7]). Authors in [3] present the benefits of using virtual health records for mobile care of elderly citizens. The main purpose of the work is to provide seamless and consistent communication flow between home health care and primary care providers using devices like PDAs and Tablet PCs. Smart cards and web interfaces have been used in [4] for storing patient records electronically. The MADIP system [5] is a distributed information platform allowing wide-area health information exchange based on mobile agents. In [10] authors present a mobile platform for exchanging medical images and patient records over wireless networks using advanced compression schemes. The majority of the aforementioned works is based on proprietary architectures and communication schemes and requires the deployment of specific software components. Furthermore, the works focus mostly on delivering data to healthcare applications and do not address issues of data management and interoperability issues introduced by the heterogeneous data resources found in modern healthcare systems. The usage of Cloud Computing provides data management and access functionality overcoming the aforementioned issues as discussed in previous sections. The concept of utilizing Cloud Computing in the context of healthcare information management is relatively new but is considered to have great potential [16]. To our best knowledge there is no other work in the literature utilizing Cloud Computing for providing pervasive healthcare information management services on mobile devices. IV. APPLICATION OVERVIEW This section discusses the main features of the @HealthCloud application and presents implementation details. The prevalent functionality of the application is to provide medical experts and patients with a mobile user interface for managing healthcare information. The latter interprets into storing, querying and retrieving medical images, patient health records and patient- related medical data (e.g., biosignals). The data may reside at a distributed Cloud Storage facility, initially uploaded/stored by medical personnel through a Hospital Information System (HIS). In order to be interoperable with a variety of Cloud Computing infrastructures, the communication and data exchange has to be performed through non-proprietary, open and interoperable communication standards. @HealthCloud utilizing Web Services connectivity and Android OS supports the following functionality: Seamless connection to Cloud Computing storage: The main application allows users to retrieve, modify and upload medical content (medical images, patient health records and biosignals) utilizing Web Services and the REST API [17]. The content resides remotely into the distributed storage elements but access is presented to the user as the resources are located locally in the device (see Figure 1e). Patient Health Record Management: Information regarding patient's status, related biosignals and image content can be displayed and managed through the application's interface (see Figure 1a). Image viewing support: The DICOM [18] medical image protocol is supported, while the JPEG2000 standard has been implemented to support lossy and lossless compression, progressing coding and Region of Interest (ROI) coding. The progressive coding allows the user to decode large image files at different resolution levels optimizing this way network resources and allowing image acquisition even in cases network availability is limited (see examples in Figure 1c and Figure 1d). The code for performing wavelet decoding on mobile devices in [10] has been modified to support the JPEG2000 standard on the Android platform. Image annotation is also supported, using the multi-touch functions of the Android OS. Proper user authentication and data encryption: User is authenticated at the Cloud Computing Service with SHA1 hashing for message authentication and SSL [20] for encrypted data communication. PROPOSED SYSTEM ARCHITECTURE AND IMPLEMENTATION DETAILS

Figure 2 illustrates the proposed system architecture for developing and deploying the mobile healthcare applications that utilize Cloud Computing. The main components of a Cloud Computing Service usually are [11] the platform front-end interface that communicates directly with users and allows the management of the storage content. The interface can be a web client or a standalone application. The Cloud Storage Facilities manages the physical infrastructure (e.g., storage elements) and is also responsible for performing maintaining operations (e.g., backing up data, etc.) 1038 (a) (b) (c) (d) (e) (f) Figure 1. Screenshots of the @HealthCloud mobile application: a) Displaying a patient health record, b) illustration of DICOM header extraction, c) JPEG2000 progressive decoding of a CT scan at frist resolution level (out of five), d) final output of JPEG2000 progressive decoding of a CT scan, e) The main application interface displaying available files on the Cloud and available operations, f) illustration of the uploading procedure of a file into the Cloud. The Cloud Platform interface is also connected to the Cloud Service module, which handles and queues user requests. Finally, the Cloud Infrastructure module manages user account, accessibility and billing issues. Previous work by authors ([10]) has demonstrated the applicability of mobile devices into retrieving medical image data from remote repositories wirelessly utilizing proper content coding (i.e., wavelet compression with region of interest support). This work has been now extended to include the functionality of communicating with Cloud Computing platforms and support communication through Web Services. In this context, @HealthCloud has been developed based on Google's Android mobile Operating System (OS) [2] using the appropriate software development kit (sdk). Android is a mobile operating system running on the Linux kernel. Several mobile device vendors already support it. The platform is adaptable to larger and traditional smart phone layouts and supports a variety of connectivity technologies (CDMA, EV-DO, UMTS, Bluetooth, and Wi-Fi). It supports a great variety of audio, video and still image format, making it suitable for displaying medical content. Finally, it supports native multi-touch technology, which allows better manipulation of medical images and generally increases the application's usability. The Cloud Service client running on Android OS consists of several modules. The Patient Health Record application acquires and displays patient records stored into the cloud. The Medical Imaging module is responsible for displaying medical images on the device. Figure 2. Illustration of the proposed system architecture It decodes images in DICOM format displaying both image and heard information data. When JEPG2000 compression is used, the appropriate sub-module decodes the image. The communication with the Cloud is performed through an implementation of Web Services REST API that is supported natively by Android. The inherent interoperability that comes with using vendor, platform, and language independent XML technologies and the ubiquitous HTTP as a transport mean that any application can communicate with any other application using Web services. Data in Cloud are seamlessly stored and presented to the user as if they reside locally. This means that the Cloud repository is presented as a virtual folder and does not provide the features of a database scheme. In order to provide the user with data querying functionality, medical records and related data (images and biosignals) are stored into a SQLite [21] file. SQLite is the database platform supported by Android. The file resides into a specific location at the Cloud and is retrieved on the device every time user needs to query data. The query is performed locally and the actual location of the data in the cloud is revealed to the applications. The database file is updated and uploaded into the Cloud every time user modifies data, respectively. UTILIZING AMAZON S3 CLOUD SERVICE For the realization of the mobile healthcare information management system the Amazon Simple Storage Service (S3) has been utilized. The main reason for selecting the specific Cloud Computing platform is that it is a commercial service well established and used successfully in several applications ([22]). It provides users with several interoperable web interfaces for managing data (SaaS model) and developers with the ability to create their own applications for accessing the latter (PaaS model) and is suitable for managing healthcare information ([23]). INITIAL EVALUATION FROM THE SYSTEM IN PRACTICE In order to prove the system's usability, some initial experiments evaluating the system's performance have been conducted. Experiments concern the time needed to transmit data to the Amazon S3 Cloud storage service. Due to the fact that textual data like a patient's health record or a biosignal sequence do not consist of large data files and do 1039 not require high bandwidth, the presented results involve the transmission of medical images. The @HealthCloud application as presented in previous sections has been used on a HTC G1 mobile phone running Android OS version 1.6. A number of medical images of different modalities (MR, CT, PET, OT and Ultrasound) and different file sizes have been used. The transmission times are displayed in Table I. As indicated, two different wireless network infrastructure types have been utilized; a WLAN and a commercial 3G Network. TABLE I TRANSMISSION TIME OF MEDICAL IMAGES USING AMAZON S3 CLOUD SERVICE AND DIFFERENT NETWORK TYPES Image Type (encoding) File Size Time (secs) (MB) 3G Network WLAN Network OT (24-bit JPEG2000 6.8 42.532 7.894 Lossless Color) CT (Uncompressed) 0.528 4.023 2.382 CT (JPEG2000) 0.102 1.223 0.892 MR (JPEG Lossless) 0.721 9.738 3.894 PET (JPEG2000 Lossy) 0.037 0.923 0.793 Ultrasound (sequence of 10 0.487 3.892 3.251 images, JPEG2000 Lossless) The performance of both WLAN and 3G networks can be easily biased by traffic and other network conditions, since commercial networks have been utilized in both cases. Also, the response time of the Amazon S3 Cloud service can play an important role on the total transmission time. However, the acquired results can be considered as indicative since the experiments reflect a real case scenario where the specific service and commercial wireless networks are utilized in order to transmit medical data. In addition, the time needed to decode and present the specific images used in the experiments has been measured. For the HTC G1 mobile phone used, the time needed by @HealthCloud to display uncompressed CT images at a resolution of 512x512 pixels was 0.52 sec, compressed CT images with JPEG2000 coding at a resolution of 512x512 pixels was 4.53 sec. The time needed to decode OT images compressed with JPEG2000 at resolution of 3072x2048 was 21 sec. and 7.5 sec. for a sequence of 10 ultrasound images of 600x430 pixels. CONCLUSION The sharing of medical information resources (electronic health data and corresponding processing applications) is a key factor playing an important role towards the successful adoption of pervasive or mobile healthcare systems. The concept of Cloud Computing and applications similar to the one presented in this article will attract the interest of scientists, developers and industrial partners working in the field of biomedical informatics. This paper has presented @HealthCloud: a prototype implementation of a mobile healthcare information management system based on Cloud Computing and Android OS. The system enables the management of patient health records and medical images (supporting DICOM format and JPEG2000 coding) and utilizes the Amazon's S3 Cloud Storage Service. Future work might include improving security by implementing advanced user authentication techniques on the mobile device (e.g, through voice recognition) and deploying the platform in real healthcare environment for evaluating the system in terms of user acceptability and performance. REFERENCES

Upkar Varshney, "Pervasive Healthcare", IEEE Computer Magazine vol. 36, no. 12, 2003, pp. 138-140. The Android mobile OS by GoogleTM, http://www.android.com/ Sabine Koch, Maria Hägglund, Isabella Scandurra, Dennis Moström, "Towards a virtual health record for mobile home care of elderly citizens", presented in MEDINFO 2004, Amsterdam, 2004. Alvin T.S. Chan, "WWW_smart card: towards a mobile health care management system", International Journal of Medical Informatics vol. 57, 2000, pp. 127-137. Chuan Jun Su, "Mobile multi-agent based, distributed information platform (MADIP) for wide-area e-health monitoring", Computers in Industry, vol. 59, 2008, pp. 55–68. Khawar Hameed, "The application of mobile computing and technology to health care services", Telematics and Informatics, vol. 20, 2003, pp. 99–106. Eneida A. Mendonça, Elizabeth S. Chen, Peter D. Stetson, Lawrence K. McKnight, Jianbo Lei, James J. Cimino, "Approach to mobile information and communication for health care", International Journal of Medical Informatics, vol 73, 2004, pp. 631—638. L.L. Leape, "Error in medicine", J. Am. Med. Assoc, vol. 272, 1994, pp. 1851—1857. J.T. Reason, Human Error, Cambridge University Press, Cambridge, 1990. Maglogiannis I., Doukas C., Kormentzas G., Pliakas T., "Wavelet-Based Compression With ROI Coding Support for Mobile Access to DICOM Images Over Heterogeneous Radio Networks", IEEE Transactions on Information Technology in Biomedicine, vol.13, no.4, pp.458-466, July 2009. George Reese, Cloud Application Architectures: Building Applications and Infrastructure in the Cloud, O'Reilly Media, Paperback (April 17, 2009), ISBN: 0596156367. GoGrid Storage Services, http://www.gogrid.com iCloud, http://www.icloud Amazon Web Services (AWS), http://aws.amazon.com/ DropBox, https://www.dropbox.com Ofer Shimrat, "Cloud Computing and Healthcare", April 2009 "San Diego Physician", pp. 26-29. Leonard Richardson, Sam Ruby, and David Heinemeier Hansson, Restful Web Services, Paperback, O'Reilly Media, May 2007, ISBN: 0596529260. The Digital Imaging and Communications in Medicine (DICOM) standard, http://medical.nema.org/ US Secure Hash Algorithm 1 (SHA1), http://www.faqs.org/rfcs/rfc3174.html Eric Rescorla, SSL and TLS: Designing and Building Secure Systems (Paperback), Addison-Wesley Professional (October 27, 2000), ISBN: 0201615983. The SQLite Database Engine, http://www.sqlite.org/ Amazon's AWS Success Case Studies, http://aws.amazon.com/solutions/case-studies/ Creating HIPAA-Compliant Medical Data Applications with Amazon Web Services, White Paper, available online at: http://awsmedia.s3.amazonaws.com/AWS_HIPAA_Whitepaper_Final. pdf 1040