Medical Cloud Enabled Ubiquitous Health System

Abstract

Ubiquitous Health System, in short UHS, is an application area of Ubiquitous Computing (Ubicomp). In this paper, we will make an effort to model and give a definite description of UHS, in a unanimous fashion. Cloud computing technology is introduced, to solve the challenges UHS are facing at the moment. The technical and economic impacts of general cloud computing technology on UHS are analyzed via SWOT methodology. Dedicated cloud computing infrastructure, Medical Cloud (MC) with special concerns about electronic health record (EHR) interoperability is proposed.

KEYWORDS: **Ubiquitous Computing, Ambient Intelligence, Health Applications, Cloud Computing, EHR Interoperability**

I. Introduction

Ubiquitous computing is one of the most prominent technological advancements, which focuses on integrating the computing power into the environment, allows the environment to be sensitive and responsive to the presence of people and their computing tasks. It is known as pervasive computing in USA and ambient intelligence in Europe. Recently, it has acquired a parlance as Everyware [1]. Ubiquitous Health System (UHS) is a derivative section of ubiquitous computing, which is dedicated to health care and welling services and applications. The concept of UHS has often been defined in abstractive ways, such as the combination of seamless wireless connections and social omni-presence, or defined by characteristics like automatic biological or environmental information capture, nature user interface, context-awareness and proactive services [2]. In this paper we will make an effort to inspect UHS and propose Medical Cloud (MC) as remedy for challenges UHS are facing at the moment.

The remaining paper is organized as follows. In Section II, the fundamental motivation behind this paper is presented. In Section III, the major components present in UHS are classified, definitive descriptions are given, and weaknesses are pointed out. Section IV reviews cloud computing on a general level. This discussion will be followed by SWOT (strength, weakness, opportunities, treats) analysis of cloud computing in the context of health care in Section V. Special requirement of cloud computing system related to health applications are illustrated and MC infrastructure is proposed in Section VI. Finally, conclusions are presented in Section VII.

II. Motivation

In recent years, the active evolution of cloud computing has quickly generated significant amount of new applications, where processing and analyzing vast amount of data is critical. Building and owning capable IT infrastructure has become an urgent matter for organizations and many consider outsourcing these processes to a cloud provider. The field of health care is no exception.

In health care, however, it is not sufficient to have the data stored and processed but the requirements for information confidentiality, data interoperability security and service quality will also have to be met. Still, introducing cloud computing to UHS presents a great deal of benefits in the form of lower costs, more ubiquitous access to information for all parties involved and significant savings in the IT services deployment and maintenance time.

III. Modeling of UHS

In the academic world, Ubiquitous Health System is loosely associated with further spreading of miniature biological sensors, intelligent cellphone or embedded devices, pervasive network connectivity and advanced user interfaces. In this section, components of UHS are identified and discussed.

Mark Weiser suggested in his paper titled *The Computer for the 21st Century* that:

"The technology required for ubiquitous computing comes in three parts: cheap, low-power computers that include equally convenient displays, a network that ties them all together, and software systems implementing ubiquitous applications."

Let us present his words in another way: UHS requires cheap, long-lasting and scalable terminals for retrieving and presenting information to users, access networks for exchanging data, and a core network which is capable of handling all the data from applications. This general framework is applied to model Ubiquitous Health System. Nonetheless, in this paper, the terminals indicated by Mark Weiser are further divided into sensors and service interfaces.

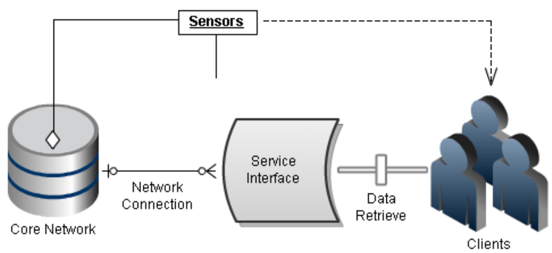

Figure 1. Simple UHS Architecture

A. Ubiquitous Sensor

The ubiquitous sensor is mainly categorized by two approaches.

<u>By its physical and locational attributes</u>

1. Implanted Biomedical Sensor

Implanted biomedical sensor monitors physiological variations in a certain biological environment. This type of sensor is injected to the target, typically beneath target's epidermis. Current research hotspot focuses on enabling implanted sensors with energy scavenging operation mechanisms [3], since any form of chemical or biological battery would cause serious consequences in case of leakage.

2. Wearable Sensor

This type of non-invasive sensor is designed to be worn by people as daily commodities, such as watches, clothing, etc. It is considered to be more secure and has fewer physical limitations compared to implanted sensor. Additionally, its applications can be quiet and versatile, and are not restricted solely to detect biological meters.

3. Environmental Sensor

Unlike the previous two types of sensor, this class has no direct physical contiguity with the target itself, instead, it is embedded to the environment where the target is located. It is able to record and react to target's motion, detect outside intruders and trigger alarms, or just simply turn off the heater when reaching certain temperature degree. Environmental sensor is one of the fundamental blocks of constructing intelligent home systems (IHS) [4].

<u>By its functionalities</u>

1. Event Detection and Reporting

The sensors under this category, some years ago, were normally intruder detection as a part of military surveillance, detecting anomalous behavior or failures in an assembly line, and detection of various nature disasters. Sensors dedicated for UHS will typically detect certain events related to health care. To cite an example, the smart pill box application, [5] which is a pillbox integrated with this type of sensors. The application could help patients to remember to take pills on time and with the correct doze. This class of a sensor is normally expected to be inactive most of the time, and be triggered to react or report activities or inactivities. Sensors have to promptly convey the event report to the sink. The report contains assistive information like the current time and location, and a description of the nature of the event. The most difficult technical challenge for this type of sensors is how to eliminate false alarms.

2. Real-Time Data Collecting

Typical examples of this class are electrocardiography (ECG) and blood pressure monitoring for patients with cardiovascular diseases, and Electroencephalography (EEG) logger for diagnosing insomnia, sleep apnea or other encephalon related ailments. In those scenarios, each sensor constantly produces data which is then conveyed to the sinks. The sinks, nowadays, could be mobile phones, wireless routers, femtocell base stations, etc.

3. Sink-initiated Querying

Some people regard this class as an add-on functionality to the previous two classes. The principle is that, the sink would send data requests to a certain group of nodes. Through this, differentiated resolution or granularity can be achieved. The applications that belong to this class are the Quality-of-Interference (QoINF) -aware context determination system in an assisted living environment [6].

B. Access Network

A framework which can fit most major networking technologies should be composed of three parts: indoor-range and outdoor-range wireless connections, and high speed wired connection. Each of these parts will now be explained separately.

1. Indoor Range Wireless

Indoor range wireless connection techniques should be very robust, and reach relatively high speed and low latency. To further categorize this class, indoor range wireless could contain two sub-classes that are local area network and personal area network.

2. Outdoor Range Wireless

Outdoor range wireless provides mobility within a large geographic area with medium speed. In contemporary telecom industry, this class mainly refers to the 3rd Generation Mobile Networks, TD-SCDMA (Time Division Synchronous Code Division Multiple Access), WCDMA (Wideband Code Division Multiple Access) and CDMA2000.

3. High Speed Wired

Optical fiber connections or so-called Fiber-to-the-X technologies are promising significantly higher data rates. Typically, a single glass fiber is capable of transferring data at the speed of 2.5 gigabits per second. As for the end users having a low price subscription, the actual speed is typically around 10 Mbps. By subscribing to a more expensive service, the users can typically enjoy a 100 Mbps connection.

C. Service Interface

Different sensors monitor and gather data, various types of connection networks transmit the data, and the service interface presents the data to the clients. The data can be raw information or information processed by the core network (see Section 3.D). A service interface consists of a hardware entity and software. The hardware entity could be personal computers, based on mobile phone platform, or embedded devices. The predominant approach is to choose the mobile phone platform, since that is the only device that people carry around daily and has the capability of processing and transferring data. The software refers to a software application installed on a PC or a mobile phone, or Web 2.0 pages displayed through a browser. The information presented on the Web 2.0 pages can be organized and distributed as social networking service (SNS) or blogs/micro-blogs.

D. Core Network

In fact, the core network of Ubiquitous Computing System has not been exactly defined by the academic society, in part, due to its extreme complexity. The main responsibility of the core network is to manage and control sensors, aggregate all the information gathered by sensors, process the information, organize the information and answer the request from service interfaces. Substantial computing power which indicates thousands of processors and RAMs would be needed to transact all the data entries. These data entries could be stored in multiple databases. Additionally, hackers would try their best to exploit the vulnerabilities of the core, modify and misuse the data. As already realized by ubiquitous computing community, an adaptive, secure and self-managing system as core network is the only answer to all the above-mentioned obstacles. In the following sections, a possible and promising approach to construct this kind of a system is introduced.

IV. A Short Survey of Cloud Computing

Since the information evolution, there are two fundamental problems that hinder industry to implement new services and applications: *the expensive infrastructure* and *the human resources*.

The infrastructure normally refers to high performance server which provides the computing capabilities, high speed network connection which transfers data from the server to the clients, and reliable power supply to power all the devices. In contrast to conventional personal computers, this infrastructure should be very robust, since a single failure would crash the whole system. With all the restrictions, the total cost is extraordinarily high. Human resource refers to the experts and administrators who execute regular maintenances to the infrastructure and resolve problems in a timely fashion. In order to address these two fundamental problems and achieve the ultimate goal of offering computing power like public utilities (i.e. electricity, water, transportation, etc.) to mankind, concept of cloud computing has been developed.

In [7] cloud computing has been defined as:

A type of parallel and distributed computing system consisting of a collection of interconnected and high performance servers with virtualization techniques , offers service-flow and work-flow orchestrations based on service-level agreements established through contracts between service provider and clients.

Given the definition, there are clearly two key features worth noting about cloud computing system. One is virtualization, and the other is flow orchestration. Virtualization broadly means abstraction of physical IT resources from people and applications using them, such as CPUs, RAMs and hard-disk storage. It can be regarded as a multiplexing technique for hardware resources, thus making all the hardware facilities as an integrated pool of resources rather than discrete systems. Inside virtualization, there are two sub-items: paravirtualization which allows one single server to be treated as multiple virtual servers with heterogeneous operating systems, and clustering which allows multiple physical servers to be treated as one virtual server. With virtualization techniques, cloud is able to provide flexible and scalable platforms for various types of applications.

Secondly, flow orchestration capability means that system is provided with inherent intelligence or even implicitly autonomic control. The system is able to arrange, coordinate, and manage the virtualized IT resource based on the contracts, without human intervention [8]. As a final result, a service image or a complete set of service images could be offered on-demand.

V. SWOT ANALYSIS OF CLOUD

In this section, cloud computing will be evaluated using the classical strategic planning model SWOT (Strengths, Weaknesses, Opportunities, and Threats). Although SWOT analysis is most often used for analyzing businesses it is also well suited for evaluating and weighting the success factors of a product or, in this case, technology (see e.g. [9]). Only through an understanding of the technical and economic impact of cloud computing is it possible to evaluate and analyze the success factors of the medical cloud discussed in Chapter VI.

In the following the four main components of SWOT analysis are discussed. It should be noted, however, that the content of the analysis is not to be considered exhaustive. Instead, it aims to highlight the critical advantages and drawbacks of the technology from multiple viewpoints.

A. Strengths

As mentioned in Section IV, the main strength of cloud computing lies in its ability to reduce needed IT infrastructure, facilitate maintenance and cut down on personnel. While the traditional IT management ranges from purely resident and self-sufficient solutions (i.e. own IT department) to various forms and levels of outsourcing, cloud computing offers yet increased flexibility where the whole IT infrastructure as well as service is located in the cloud provider's premises. The fundamental economic rationale behind cloud computing, thus, mostly lies in the elimination of the fixed (or capital) costs related to the early IT investment leaving only variable costs (i.e. usage payments) to be carried out by the organization. Furthermore, the cloud provider is assumed to be able to gain from economies of scale in providing such service.

In addition to economies of scale, the organization running the cloud should also possess knowledge and capabilities to run the system more efficiently compared to a self-sufficient solution. In a study presented in Table 1 the traditional deployments of eight IT management tasks were compared to times for IBM's cloud computing automated deployments. The study showed a total reduction from 14-24 days to less than six hours.

IT management task	**Traditional**	**Cloud**
Assign servers	3 days	<1 hour
Install software	5-10 days	<1 hour
Configure network and security parameters	5-10 days	<1 hour
Backup operating system	2 hours	1/2 hour
Recover operating system	2 hours	1 hour
Install Operating system	2 hours	1 hour
Dynamically allocate computing resources	1 hour	2 minutes
Regulate operating system parameters for many services	10 minutes	1 minute
Total	14-24 days	<6 hours

Table 1 Traditional vs. Cloud-based Deployment [10]

It is clear that the major strength of cloud computing lies in its ability to bring about business agility through reduced deployment times, reduced maintenance load for the customer and better control of costs. Due to these immediate strengths, cloud computing should provide a most compelling opportunity for both the medical companies and health application service providers alike.

Looking more directly at the medical sector the benefits of cloud computing come from:

- *Lowering entrance barriers* that make UHS systems affordable to small-scale hospital and health communities, allowing them to create their own UHS system and deploy applications. Customers can have more options to choose their healthcare service provider from.
- *Service oriented architecture (SOA)*, which enables faster and more flexible service development ideally linked to shorter payback period, critical for small-scale care-giving entities.
- Service quality, security and data recovery could be improved through cloud computing. Overall customer satisfaction and retention in health-care would increase over time.

B. Weaknesses

Despite the obvious advantages that cloud computing offers to cloud providers and the users alike there are some weaknesses that are critical to the concept success. Firstly, moving information as critical as general health related data or medical records to be stored and handled by an external cloud provider always invokes the question of privacy. Having the data located in a distant storage facility requires additional security measures to be taken, introduction of adequate certificates and full trust towards the cloud provider. In addition, the juridical terms related to the contract itself, especially handling of the situation where data is lost or compromised is likely to add management overhead and additional costs to the subscribing company.

Secondly, a network connection between the health care and the cloud provider is most certainly needed. If the health related information is to travel over public Internet, again, additional security and encryption are needed. The realized concerns related to security in credit card payments, storage of customer information etc. over the last years are prone to weaken the consumers' trust in solutions such as cloud computing requiring the use of public networks. In addition, the external service provider and the use of Internet as transport medium for data may cause significant service quality (QoS) and availability problems.

Finally, interoperability of clouds is currently not standardized. Despite the efforts towards open and standardized interfaces most of the current cloud providers have their proprietary solutions and thus, fluent transactions can't be guaranteed e.g. for transferring medical data between health care providers that utilize different cloud providers.

C. Opportunities

Since health care related cloud computing is still a fairly new concept it is highly uncertain what form it will eventually take in day-to-day health care. Health care providers will be forced to balance the benefits that cloud computing offers with the weaknesses that are inherent in the model.

Regarding the opportunities, there several clear trends that are likely to support cloud computing. First of all, many governments are pushing health care system modernization throughout the world. Among these is the government of the United States with it initiatives such as "Transforming Healthcare Through IT" and "Enabling Healthcare Reform Using Information Technology", recommendations by the Healthcare Information and Management Systems Society (HIMSS). [11] Initiatives such may help lower the barriers for companies to get involved as well as arouse interest and confidence among consumers.

Alongside the public initiatives, there is a strong industrial push for open standards among manufacturers and vendors of Healthcare Information Technology (HIT). Should the standardization work converge to widely acknowledged standards, the medical information exchange between different cloud providers would be truly enabled. This development would significantly benefit both the users (i.e. doctors, patients etc.) but also the health care providers.

One of the key weaknesses of cloud computing is that of the network connecting the healthcare provider to the cloud. Obviously, this weakness may disappear or even represent a significant opportunity for cloud providers to benefit from in the future. Many efforts are being made to lift the security, QoS and the reliability of the Internet. Should these goals be met, many of the current hindrances would be removed.

D. Threats

Although the evolution towards utilization of cloud computing in health care seems inevitable, some threats still prevail. Firstly, the question about the security of patient data and data privacy in general is already a raising concern among some people. These groups may retain from using cloud based health care services and seek alternative solutions. This may create an opposite trend especially if backed up by misconduct among the involved organizations.

Another key threat that those involved should prepare for is that of insourcing. Should the concerns related e.g. to security and QoS become reality, health care providers may start to insource their once outsourced health care information storage and handling operations. At worst, backup up by the attitudes of consumers, this may launch a trend that is very hard to reverse.

Finally, decisions made by individual governments as well as international health care organizations and firms have a crucial impact on the success of the medical cloud concept. For instance, these decisions may inhibit the exchange of information between involved parties or prevent the transfer of medical data to the clouds.

VI. INTRODUCING MEDICAL CLOUD

In this section, one special design requirement from the Health Information Technology sector is elucidated. In order to provide better functionality focusing on fulfilling this requirement, a dedicated infrastructure with abstract components, will be proposed for medical cloud.

A. Special Requirement: EHR Interoperability

Health and wellbeing sector has fully embraced ICT. At this moment, IT applications have already developed into an indispensable part in most developed countries' and many developing countries' national or region health systems. To cite some ICT systems, which have been deployed extensively: Picture Archiving and Communication System (PACS) for storage, retrieval, distribution and presentation of medical images, Radiology Information System (RIS) dedicates for manipulating and distributing radiological data, Laboratory Information System (LIS) which interfaces with other system to process the medical laboratory data, etc. With vast amount of HIT system varieties, one of the greatest obstacle in this area, is the lack of interoperability among them.

The level of diversity of HIT system is incomparable to telecommunication industry. According to Metcalfe's law, the value of telecommunications network is proportional to the square of the number of connected nodes, it has always been the fundamental incentive to push standardization process in telecom industry. In medical ICT area, however, the effect of Metcalfe's law is extremely weak.

The most basic and essential data that is flawing around HIT systems is called electronic healthcare records (EHR). The EHR of a patient can be defined as digitally stored health care information about individual's lifetime with the purpose of supporting continuity of care, education and research, and ensuring confidentiality at all times [12]. The amount of EHR standards proposed by different task groups is enormous, such as openEHR, HL7 CDA (Health Level 7 Clinical Data Architecture), CEN/TC 251 EHRcom, Continuity of Care Record, ANSI X12, etc. Many HIT experts have acknowledge that, given that large number of standards for this purpose, conforming to a single standard is not feasible and efforts on this will not solve the interoperability problem [13]. Therefore, in this paper, we agree that seamless EHR interoperability should be a special requirement for any kind of cloud computing system which is designed for medical purposes.

B. Proposed Medical Cloud Infrastructure

There are lots of proposed architectures and relevant projects going on. Currently, it is one of the areas under most intensive research. The process of constructing the infrastructure for medical cloud, is based on studying and summarizing literature about state-of-art cloud computing models, additionally taking the special requirement of interoperability mentioned before into consideration. The result is elucidated by figure below.

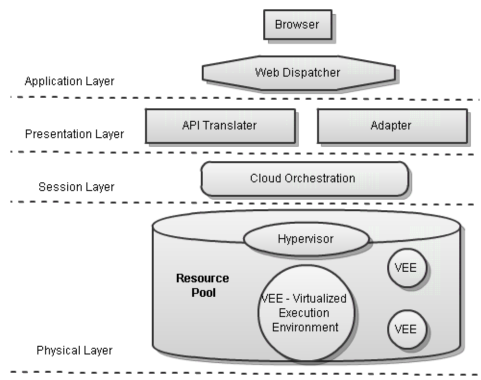

Figure 2. Medical Cloud Infrastructure

The infrastructure is presented in a similarly way as OSI Seven-Layer model for layered communications and computer network protocol design. There are four layers in total, application, presentation, session and physical layer. They will be explained individually, with a top to down approach.

1. **Application Layer:** The element in this layer sees all resources as different applications. The web dispatcher fetches the application, and browser in client side present content to users [7].

2. **Presentation Layer:** The resources used by this layer are different kinds of virtualized operating systems with varied configurations. Two entities presented in this layer, one is API translator which interact with operating systems to offer necessary functions or library files for applications, and another is adapter. The Adapter component is dedicated for solving EHR interoperability problem. It acquires semantic processing capability since it is higher than the OS level i.e. it is OS-independent, thus able to extract the information encoded according to different EHR standards.

3. **Session Layer:** Work flow orchestration is just terminology from cloud computing community. The role of this layer to cloud computing system

is comparable to an OS to a normal workstation. It manipulate the underlying physical IT resources like processors, storage, memory, bandwidth to form and offer operating systems instances to the presentation layer.

4. **Physical Layer:** The bottom-most layer is essentially a pool with infinite resources. A hypervisor is used to create and monitor integrate virtualized execution environments (VEE) [14] with predefined configuration.

VII. CONCLUSION

This paper demonstrates ideas about modeling ubiquitous health system, reviews cloud computing along with explanations of why cloud computing technology is the missing puzzle of the UHS system, and analyses this new computing paradigm utilizing classical SWOT methodology. A theoretic infrastructure for medical cloud is presented, for completing the whole functional model of ubiquitous health system. As part of future work, further technical-economic analysis towards existing commercial cloud computing solutions with real life health care scenarios will be carried out. Another possible research stream is be to build open-source experimental high availability hypervisor utilizing Linux kernel on x86/x86_64 platforms.

REFERENCES

[1] Greenfield, A. (2008). *Everyware: The Dawning Age of Ubiquitous Computing.* AIGA.

[2] Orwat, C., Graefe, A., & Faulwasser, T. (2008). *Towards pervasive computing in health care – A literature review.* BMC Medical Informatics and Decision Making.

[3] Texas Instruments. (2008). *Energy Harvesting.* Retrieved Jun 15th, 2009 from http://www.ti.com/corp/docs/landing/cc430/graphics/slyy018_20081031.pdf.

[4] Jianfeng Wu, Huibin Qin. The design of wireless intelligent home system base on ZigBee.
Communication Technology, 2008. ICCT 2008. 11th IEEE International Conference on
10-12 Nov. 2008 Page(s):73 - 76
Digital Object Identifier 10.1109/ICCT.2008.4716119

[5] Chandler, D. (6. Feb 2008). Smart pillbox could be a lifesaver. Retrieved Jun 15th, 2009 from http://web.mit.edu/newsoffice/2008/itw-india-tt0206.html.

[6] Roy, N.;Quality-of-Inference aware context determination
Pervasive Computing and Communications, 2009. PerCom 2009. IEEE International Conference on
9-13 March 2009 Page(s):1 - 2
Digital Object Identifier 10.1109/PERCOM.2009.4912815

[7] Lizhe W., Jie Tao Kunze, M. Castellanos, A.C. Kramer, D. Karl, W. Scientific Cloud Computing: Early Definition and Experiencen. On 10th IEEE International Conference of HPCC '08. Page(s): 825-830

[8] Haoping Bai; Meina Song; Huiyang Xu; Qian W.; Lingyun Fu; An Optimized Design of Service Orchestration. Pervasive Computing and Applications, 2008. ICPCA 2008. Third International Conference on Volume 2, 6-8 Oct. 2008 Page(s):980 - 984

[9] Un DAFO para el Cloud Computing, Saasmania, http://www.saasmania.com/2008/09/18/un-dafo-para-el-cloud-computing/, Accessed 7. October 2009

[10] Geng Lin; Fu, D.; Jinzy Zhu; Dasmalchi, G.; Cloud Computing: IT as a Service. IT Professional Volume 11, Issue 2, March-April 2009 Page(s):10 - 13

[11] Ofer Shimrat, Cloud Computing and Healthcare, San Diego Physician, April 2009

[12] Towards Personal Health Record: Current situation, obstacles and trends in implementation of Electronic Healthcare Records in Europe," Intern. J. of Medical Informatics, vol 52, No 123, pg. 105 –117

[13] Asuman D.; Tuncay N.; Alper O.; Gokce L.; Ylidiray K.; Marco E.; Key Issues of Technical Interoperability Solutions in eHealth, eHealth 2006 High Level Conference and Exhibition, May 2006, pp. 917-923

[14] B. Rochwerger, D. Breitgand, E. Levy, A. Galis, K. Nagin, I. M. Llorente, R. Montero, Y. Wolfsthal, E. Elmroth, J. Cáceres M. Ben-Yehuda, W. Emmerich, and F. Galán, The Reservoir model and architecture for open federated cloud computing, the European Community's Seventh Framework Programme (FP7/2001-2013)