An Introduction to Cloud-Based Pervasive Healthcare Systems

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ABSTRACT

The healthcare system is important due to its focus on human care and its interference with human lives. In recent years, we have witnessed a rapid rise in e-healthcare technologies such as Electronic Health Records (EHRs) and the importance of emergency detection and response. Cloud computing is one of the new approaches that can handle some of the challenges of smart healthcare in terms of security, sharing, integration and management. In this study, we review the significance and opportunities of using cloud computing in pervasive healthcare, and then look at the current as well as the future challenges it faces.

Keywords

Cloud Computing, Pervasive Computing, Pervasive Healthcare, e-health

1. INTRODUCTION

Information technology can play a vital role in healthcare services in terms of electronic health. Recent advances in e-health can be broadly defined as the application of information and communication technologies in healthcare systems [1]. This includes a range of information such as patient Electronic medical records (EMR), billing and payment information, employees and hospital information, which results in new ideas including e-billing, e-payment, e-prescription, e-supply, and e-records.

Making use of internet for storing, accessing and modifying healthcare information and digitizing many processes and tasks are necessary steps for realizing e-health. In this case, we have the advantages of e-health such as a rise in the quality of services in aging societies, reduction in cost and in medical errors and the ease at which the data can be moved to the right place. However, digitizing paper-based records, collecting and storing medical information as well as lack of suitable technology for preventive care can become rather challenging.

After emergence of pervasive computing paradigm, pervasive healthcare technology is proposed to support a wide range of applications and services including patient monitoring and emergency response. However, at the same time they introduce several challenges including data storage and management, interoperability, availability of resources and ubiquitous access issues [2].

Cloud computing has been emerged as an important trend in the information technology industry, due to its prominent features of reliability and cost effectiveness. Cloud is defined by the National Institute of Standards and Technology (NIST) as "a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources that can rapidly provisioned and released with minimal management effort or service providers interaction" [3]. This paradigm can support existing electronic healthcare and use latest technologies including smart mobile phones, smart cards, robots, sensors and Tele-health systems via internet. The essential need for pervasive and ubiquitous real-time access to patient's data from anywhere and from any digital device is necessary for proper diagnosis and treatment procedure that results in high quality medical services. This motivates current research to study cloud-based pervasive healthcare systems.

Rest of the paper is organized as follows: After this introduction section II discusses current healthcare systems. Section III defines pervasive healthcare. Section IV describes the critical role that cloud computing could play in healthcare. Section V reviews some healthcare projects in details. Section VI explores cloud-based pervasive healthcare projects and finally, Section VII states open research directions and concludes the paper.

2. CURRENT HEALTHCARE SYSTEMS

Nowadays, the current situation of healthcare systems is fairly complex in many countries. One of the main problems of this context is high amount of money per person that the government has to spend. Large number of uninsured people is another problem that increases the healthcare expenses. The lack of focus on preventive care, widespread obesity, multiple chronic diseases, shortage of healthcare professionals, inefficiency in healthcare delivery, overpriced medications, large number of medical mistakes, and lack of technologies and access to information are common problems that lead researchers to bring IT solutions in healthcare systems. The accelerating innovations of smart electronic devices have facilitated the dynamic nature of healthcare systems by solving issues of human errors and providing an active way of accessing and processing large volume of patient's information. However, these developments and deployments of e-health introduce several challenges including data storage and management, interoperability and availability of heterogeneous resources, security and privacy, and ubiquitous access.

There are two main healthcare domains: (1) formal care referring to institutionalized and centralized health services like hospitals and clinics. (2) Informal care referring to de-centralized care, mainly for chronic conditions and elderly population [4]. Many technology innovations have introduced the concept of centralized Electronic Health Records (EHRs) and patient-centric Personal Health Records (PHR). PHR provides freedom of capturing, storing and sharing to the patient and is more consistent with modern technological trends. The current technologies such as distributed and grid computing are not sufficient enough to handle the existing and new healthcare applications in terms of dynamicity, scalability and low cost. There is a huge amount of data in healthcare

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domain that is increasing in its volume, velocity, and variety and makes major problems for healthcare organizations [5].
Therefore, it is necessary to bring a new technical paradigm for solving current healthcare problems and improving the quality of healthcare services. In this study, we review some new technologies that can help to reduce systemic inadequacies in healthcare systems.

3. PERVASIVE COMPUTING IN HEALTHCARE

Ubiquitous or pervasive computing (the latter term was coined by Mark Weiser in 1988) is fundamentally a post-desktop model of human-computer interaction. In a pervasive environment, information processing has been thoroughly integrated into everyday objects and activities [6]. Ubiquitous computing refers to building a global computing environment, where seamless and invisible access to computing resources is provided to users, and pervasive computing deals with acquiring context knowledge from the environment, and providing dynamic, proactive and context-aware services to the users [7]. Therefore, a confluence of developments has led to the possibility of realizing a vision of pervasive healthcare [6].

Within the last decade a variety of new healthcare concepts for supporting and assisting users in technology-enhanced environments has been emerged. In addition, the so-called pervasive healthcare applications open up a new paradigm that has enabled the awareness towards the elderly and the need for constant medical supervision of chronic patients or habitants at remote, isolated and underserved locations. For patients with chronic diseases, like chronic heart failures or diabetes, pervasive healthcare systems help to minimize hospital stays and in doing so, enable an independent life in a domestic environment [2].

Pervasive healthcare systems are designed to enhance several issues and to provide different types of medical services and to support users individually (according to user profiles), adaptively (according to the course of disease) and sensitively (according to living conditions) [2]. In the most of the systems the general goals are the same, but the technical approaches that achieve these goals vary widely. Looking at the state-of-the-art research prototypes reveals three basic realization concepts. To continue, we will look into each concept in more detail.

3.1 Smart Mobile Devices

Nowadays, most smart phones are equipped with various sensors including accelerometer, gyroscope, proximity sensor, and global positioning system (GPS), which can be used for detecting user activity and mobility [8]. These systems are able to capture information about their surroundings, communicate with each other, and react according to previously defined rules.

3.2 Wearable Sensors

Recent advances in epidermal electronics technology promise a new era of health-related sensor technology. Researchers have already developed different kinds of sensors in form of patches, smart cloths and body-worn devices to monitor health signals [8]. Sensors generally rely on a network architecture known as the body area network (BAN) that enables wireless communication in or around a human body.

3.3 Smart Environment

Current research activities mainly focus on intelligent home environments for assisting elderly and ill people. A smart or intelligent home is a typical home that has been augmented with various types of sensors and actuators, which act and communicate automatically [8]. It uses basic devices to build an environment in which many features are automated and devices can communicate with each other. Enabling devices to communicate efficiently means that one device can then instruct other devices to perform functions if certain conditions are met. There are several smart home projects aimed at assisted living. For example, one of the projects at Washington State University that provides an assistive environment for dementia patients at home, is CASAS [9] project. The "Aging in Place" project at the University of Missouri aims at providing a long-term care model for seniors in terms of supportive health [10]. In Europe, also some smart home projects have been developed, such as the *iDorm* [11], Grenoble Health Smart Home [12]. "Welfare Techno House" is another smart home project that has been developed in Asia[13]. It measures indicators such as body weight, and urinary volume using sensors placed in the bathroom and bathtub for monitoring the older adults.

4. CLOUD-BASED HEALTHCARE SYSTEMS

The pervasive and ubiquitous technologies for delivering medical assistive services through mobile devices introduce several challenges including 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.), and unified and ubiquitous access [14]. Cloud computing is a new paradigm that has many potential benefits for improving healthcare services and is a useful solution for addressing all aforementioned issues in electronic healthcare systems. Cloud computing is a new economic computing model which evolves over time. Figure 1 illustrates cloud computing concept.

Figure 1. An illustration of cloud computing. All kinds of computing and communication devices are able to interact with the cloud and share the same data resources.

There are many definitions for cloud computing. Based on the study of Alex Mu-Hsing Kuo [15] "clouds are a large pool of easily usable and accessible virtualized resources (such as hardware, development platforms and/or services). These resources can be dynamically reconfigured to adjust to a variable load (scale), allowing also for an optimum resource utilization. This pool of resources is typically exploited by a pay-per-use model in which guarantees are offered by the Infrastructure Provider by means of customized Service-Level Agreements". From a service point of view, cloud computing provides the facility to access shared resources and common infrastructure in a ubiquitous and pervasive manner, offers services in an on-demand manner, reduces the cost of EHR in terms of ownership and maintenance, and provides pay-per-use feature.

As a new technological innovation, the impact of cloud computing on some contexts, specifically in e-Health, is worthwhile. Beside obvious opportunities that cloud computing creates in healthcare sector, there are some challenges that need to be addressed in future, too. To continue, we evaluate some of these opportunities and challenges from different aspects in more details (see Table 1). Cost-effective IT solution, rapid elasticity and ubiquitous access are some of the occasions for managing efficiently, but there can be some problems like lack of trust in data security and privacy by users, cultural resistance, and loss of data governance that are challengeable. From the technology point of view, increasing the scalability, flexibility, and cost effectiveness of infrastructure and promoting energy saving, are some useful characteristics of cloud computing in health technology. Resource exhaustion, unpredictability of performance, data lock-in, data bottlenecks and bugs are some technology failures. We also look at security aspect due to its significance in this context. Improving all kinds of security measures, such as hardware, software, human resources, and management costs are some of these issues that are reachable by cloud-based systems. There are some specific risks like separation failure, public management interface, poor encryption key management, and privilege abuse in security part. Commitments of providers for developing best policies and practices to protect customer's data is a practical feature of using cloud computing in healthcare sector from legal aspect. Legal issues such as contract law, intellectual property rights, data jurisdiction, and privacy are still challengeable.

Some of the previous studies have reported the potential of cloud computing and proposed different models or frameworks in an attempt to improve healthcare services. A system that automates the process of collecting patient's vital data via a network of sensors connected to medical devices, and then delivers the data to medical cloud center for storage, processing, and distribution in real-time, is called a cloud-based system [16], [17]. Furthermore, it allows healthcare professionals to monitor patients remotely and pervasively which saves transportation and in-hospital cost besides considering patients comfort for a better care. It can reduce electronic health record startup expenses, such as hardware, software, networking, personnel, and license purchasing cost [5], [8], [16]. Cloud offers backup data redundancy and disaster recovery capabilities which are significant for healthcare organizations since it replicates the data in various locations for more availability and robustness. The practical application of Cloud Computing in healthcare systems has emerged due to its functionality for managing data in distributed, ubiquitous and pervasive methods by supporting several platforms, systems and applications at independent locations.

Table 1. Evaluating the opportunities and challenges of cloud computing

Aspects	Opportunities	Challenges
Management	Cost-effective IT solution, rapid elasticity and ubiquitous access.	Lack of trust in data security and privacy by users, cultural resistance, and loss of data governance.
Technology	Increasing the scalability, flexibility, and cost effectiveness of the infrastructure and promoting energy saving.	Resource exhaustion, unpredictability of performance, data lock-in, data bottlenecks and bugs.
Security	Improving all kinds of security measures, such as hardware, software, human resources, and management costs.	Specific risks like separation failure, public management interface, poor encryption key management, and privilege abuse.
Legal	Commitments of providers for developing best policies and practices to protect customer's data.	Legal issues such as contract law, intellectual property rights, data jurisdiction, and privacy.

It also creates a new era of healthcare for treating old people or chronic patients that need constant medical supervision, like diabete patients [18]. Many studies introduce diabetes as one of the major chronic diseases and growing health problems in the world. This disease increases a patient's risk of developing multiple health complications such as heart and kidney failure [19], [20]. With pervasive computing and cloud infrastructure, patients can be monitored remotely and professionals are able to response effectively in dangerous situations, and the quality of service will increase in terms of early detection and emergency response.

5. GENERAL OVERVIEW OF PROJECTS

Today, there is a great amount of research work in the field of pervasive healthcare to improve e-health services; however, only a few of which use cloud infrastructure as a new IT paradigm, which are surveyed as below.

"The Integrated Cloud-based Healthcare Infrastructure" project, ICHI, has been developed in Edinburgh Napier University of United Kingdom and presents a system that integrates a formal care system (DACAR) with an informal care system (Microsoft Health Vault) that enables not only sharing and access of health records right along the patient pathway, but also provides high level of security and privacy within a cloud environment [4].

Another project in the University of Central Greece, "Bringing IoT and Cloud Computing towards Pervasive Healthcare", IoTC, proposes a platform based on cloud computing for management of mobile and wearable healthcare sensors [14]. Further, we have scrutinized two more articles that introduce a personal health system (PHS) to manage diabetic patients. One of these projects in University of London, is "COMMODITY: A Smart e-Health Environment for Diabetes Management" that emphasizes on designing the PHS to address major problems of both diabetic patients and doctors who treat diabetes [19].

In the University of Murcia, another healthcare study for diabetes is developed, "An Internet of Things-based Personal device for Diabetes Therapy Management in Ambient Assisted Living (AAL)", PDIT, which presents a personal diabetes management

device based on Internet of Things - so as to support a patient's insulin therapy to decrease hyperglycemia count and the risks involved [20].

In another research in the University of Greece, namely "Managing Wearable Sensor Data through Cloud Computing", MWSC, a wearable textile platform that collects motion and heartbeat data and stores them wirelessly on an open cloud infrastructure for monitoring and further processing is studied [21]. "Cloud-Enabled Wireless Body Area Networks for Pervasive Healthcare" is another article in the same context that focuses on a cloud-enabled WBAN architecture and its applications in pervasive healthcare systems and develops WBANs with MCC (Mobile Cloud Computing) capability, Cloud-Enabled WBAN, [22]. This project has also been developed in different universities including South China University of Technology, King Saud University, and the University of British Columbia. Another article namely "An Auto-Scaling Mechanism for Virtual Resources to Support Mobile, Pervasive, and Real-Time Healthcare Applications in Cloud Computing", RTHA, proposes a novel server-side auto-scaling mechanism through cloud computing with virtualization technologies in University of Houston and Korea University [23]. All these studies are surveyed in Table 2.

Table 2. Surveying cloud-based projects

Project Name	Organization	Year	Paper type	Ref.
ICHI	Edinburgh Napier University	2011	Conference	[4]
IoTC	University of Central Greece	2012	Conference	[14]
COMMODITY	European Commission Information Society and Media	2013	Journal	[19]
PDIT	University of Murcia	2011	Journal	[20]
MWSC	University of Central Greece	2011	Conference	[21]
Cloud-Enabled WBAN	National Natural Science Foundation of China	2013	Journal	[22]
RTHA	University of Houston	2013	Journal	[23]

6. A SURVEY ON CLOUD-BASED PERVASIVE HEALTHCARE PROJECTS

The concept of cloud-based pervasive healthcare system is a new paradigm for the healthcare sector that uses cloud computing to treat, manage and control patients pervasively. The systems are supported by different algorithms, cloud infrastructures, smart homes, devices, and sensors and create several service types according to their context and environment.

In the following sections, we propose the most important parameters in more detail and make use of them to explore successful case studies.

6.1 Service type

Service type demonstrates the kind of service that is provided by the healthcare system. Through the augmentation of beneficial service areas in healthcare, the quality of a patient's life increases automatically. Different service types are provided by various studies in different situations for several purposes like treating, managing, and providing high level of security and privacy for patients and professionals. After investigating several projects, we propose a categorization for service type, which consists of 6 different groups as follows (see also Table 3):

6.1.1 Monitoring

The continuous act of observing vital signs (body temperature, blood pressure, heart rate, etc.), conditions and daily activities is called monitoring. Patients need to be monitored or checked anywhere whether in the hospital, home or outdoor, and anytime by specialists or caregivers, especially patients with chronic diseases or disabilities.

Today, most studies are focused on monitoring and treating patients at home as there is a growing need of continuous medical attendance and checking of high risk conditions. Two subsystems, an EHR system and a PHR system on a cloud-based infrastructure, originally meant to operate in different health domains - home and hospital - have been integrated in ICHI project. Monitoring patients through smart tools like various wearable sensors is another way of checking patients remotely that has been used in IoTC, MWSC and Cloud-Enabled WBAN projects.

Body area networks consisting of different types of sensors for monitoring patients are also used as a platform in COMMODITY. In RTHA project, some kinds of infrastructures provide a mechanism in which a local controller periodically collects sampled data in client node, and then the server side processes the collected data sent by client nodes and transmits the results to remote client nodes if necessary.

6.1.2 Daily life assistance

In recent years, researchers have developed a variety of assistive technologies and ambient-assisted living tools for empowering people's capabilities [8]. Some AAL technologies, that have been developed in COMMODITY, PDIT and Cloud-Enabled WBAN projects, help people to perform daily activities more comfortably, to facilitate the lifestyle of the elderly and the people living alone or patients in general. For example, some AAL technologies are like reminding older adults of location of objects or tasks such as taking medication.

6.1.3 Medical assistance

Medical assistance helps patients during their treatment process through AAL, such as Personal Health Systems (PHS) that provide continuous and personalized health services to diabetic patients, like COMMODITY. In PDIT study, a medication management via a personal device has been proposed for assisting insulin therapy in diabetics and for anomaly detection and wandering prevention in other patients.

6.1.4 Pervasive access to healthcare information

Accessing a patient's medical and background information ubiquitously by legal users like professionals, nurses and relatives becomes possible. In ICHI study, a cloud-based e-Health platform allows patients to create and share health data. Utilizing ambient devices like PHS creates remote access to patient's health records for health professionals in COMMODITY and PDIT projects. In cloud-Enabled WBAN study, mobile Cloud Computing (MCC) platforms forward collected patient's data to a medical server which patients and physicians can have pervasive access.

6.1.5 Emergency management

From a technical point of view, emergency response can be defined as controlling high risk conditions and managing emergency situations. As an instance, COMMODITY manages hypoglycemia and hyperglycemia (very low and high blood glucose), which are life-threatening. It is necessary to react to these conditions imme-

diately through a PHS that monitors and interprets blood-glucose level.

PDIT, proposes a personal diabetes management device based on Internet of Things in order to prepare mobile assistance services for Insulin therapy and for consequently decreasing the amount of risk in diabetic patients. By using different kinds of sensors and technologies such as wearable sensors and WBANs through a cloud-based system, researchers are able to monitor and response emergency conditions like MWSC and Cloud-Enabled WBAN studies.

6.1.6 Smart hospital

Provision of different facilities for patients and better communication among the patients, doctors and families is possible in a smart hospital. For example, the ICHI project utilizes a cloud-based e-Health platform for providing clinical services to clinicians and patients. The Cloud-Enabled WBAN is a project that uses geographical information system (GIS) for hospitals with a local private cloud, so doctors and caregivers can quickly acquire location information and physiological data.

Table 3. Different service types in healthcare projects

Project Name	Service Type					
	Monitoring	**Daily Life Assistance**	**Medical Assistance**	**Pervasive Access**	**Emergency Management**	**Smart Hospital**
ICHI	✓			✓		✓
IoTC	✓					
COMMODITY	✓	✓	✓	✓	✓	
PDIT	✓	✓	✓	✓	✓	
MWSC	✓				✓	
Cloud-Enabled WBAN	✓	✓		✓	✓	
RTHA	✓					✓

6.2 Context Type

A classification of any context type helps application program designers to use practical context information in their programs. Up to now various classifications of context has been proposed. According to Dey's classification, location, time, identity and activity are the most important contexts and have been termed "primary context". He believes that through primary context we can obtain other context information which is called "secondary context" [28].

Context in the healthcare sector can be any kind of information about different entities such as patients, caregivers, medical places, homes and others that are considered relevant to the system [29]. Different projects have used various context types in healthcare systems which can be categorized as follows (see Table 4).

6.2.1 Medical information

All medical information about a patient like vital signs, blood glucose, health condition, type of illness, emergence of disease and treatment plans are necessary for a suitable and complete cure. Different kinds of medical information are used in different studies including ICHI, IoTC, MWSC, Cloud-Enabled WBAN, and RTHA. They utilize various medical contextual information; like biosignals, in a cloud-based healthcare infrastructure for better treatment. COMMODITY and PDIT projects focus more on diabetics' medical information like blood glucose or health conditions to address high risk situations.

6.2.2 Non-medical information

Besides medical information, non-medical personal information is also functional in a healthcare system. Such information can be referred to as contextual data like location, time, activity, and etc. that are used in some studies including IoTC and MWSC to increase the quality of health services.

6.2.3 Environmental information

It involves all information about the surroundings, like temperature, light, moisture and the place that patient lives. These information are collected by sensors for managing data and for making a true medical assessment and an accurate medical decision, like IoTC and Cloud-Enabled WBAN studies.

7. OPEN RESEARCH DIRECTION AND CONCLUSION

The evolution of technology allows introduction of new advanced systems that reach more accurate and convenient solutions. Among such new technologies is cloud computing which is a new trend in pervasive systems. Cloud computing is a new model of computing that assists healthcare organizations to focus more on increasing the quality of delivered healthcare services.

In this context, we have reviewed the opportunities and challenges of using cloud computing in healthcare sector and proposed important parameters in a cloud-based pervasive healthcare system in more detail. In addition, a classification of different services and context types have been suggested. Cloud computing offers potential opportunities for improving EHR adoption and provides an altogether new generation of healthcare services. It also provides more flexibility, less expense, and more efficiency in IT services. Cloud-based healthcare systems can create more vital solutions for preventive or emergency care in cases such as chronic diseases like diabetes.

Related studies show a lack of research on the various issues of this area. Generally speaking, cloud-based pervasive healthcare is a new paradigm in healthcare sector and has many potential and beneficial features, but there are still several problems and challenges that need to be addressed by researchers in the future. These can be summarized into the following open research directions that should be focused upon in the future:

- As we described above, there are various service types in healthcare sector, such as monitoring, daily life assistance, medical assistance, pervasive access, emergency management and smart hospital. Designing a functional healthcare system for managing

emergency situations or assisting medical cares is very important.

- Access to private context types like patient medical information by illegal persons should be banned. Security and privacy for sharing health records and access rights for both patients and professionals are other essential issues.

Table 4. Different context types in healthcare projects

Project Name	Context Type		
	Medical Info.	Non-medical Info.	Environmental Info.
ICHI	✓		
IoTC	✓	✓	✓
COMMODITY	✓		
PDIT	✓		
MWSC	✓	✓	
Cloud-Enabled WBAN	✓		✓
RTHA	✓		

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