Cloud Computing in Healthcare – a Literature Review on Current State of Research

Completed Research Paper

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ABSTRACT

Nowadays, IT resources are increasingly being used in all areas of the health sector. Cloud computing offers a promising approach to satisfy the IT needs in a favorable way. Despite numerous publications in the context of cloud computing in healthcare, there is no systematic review on current research so far. This paper addresses the gap and is aimed to identify the state of research and determine the potential areas of future research in the domain. We conduct a structured literature search based on an established framework. Through clustering of the research goals of the found papers we derive research topics including developing cloud-based applications, platforms or brokers, security and privacy mechanisms, and benefit assessments for the use of cloud computing in healthcare. We hence analyze current research results across the topics and deduce areas for future research, e.g., development, validation and improvement of proposed solutions, an evaluation framework.

Keywords

Cloud Computing, Healthcare, Literature Review.

INTRODUCTION

Nowadays, IT resources are increasingly being applied in all health sector areas. They contribute to improving healthcare services, medical education and research (Nordin and Hassan, 2011; Nordin et al., 2012; Delgado, 2011). The new cloud computing technology promises to satisfy the IT needs in a more favorable way. Besides the many benefits cloud computing is known for (e.g., Mell and Grance, 2012), it is believed to open new healthcare specific perspectives (e.g., Chang et al., 2009; Chowdhary et al., 2011; Delgado, 2011; Loehr et al., 2010).

The literature covers the topic of cloud computing in healthcare from a variety of perspectives. Though there are numerous publications in the domain, we found no systematic review on current research so far. Based on these observations, we address this gap and derive the following research questions for our research:

(1) What are the main research topics in the context of cloud computing in healthcare?

(2) What are the current research findings on the identified research topics?

(3) What are potential areas of future research?

This research is aimed to support the TRESOR (TRusted Ecosystem for Standardized and Open cloud-based Resources) project (TRESOR, 2013) and conducted in accordance with the literature review frameworks proposed by vom Brocke et al. (2009), Webster and Watson (2002), and Cooper (1988). We systematically research articles published up to year 2012 in the context of cloud computing for healthcare and derive research topics by clustering the identified research goals. We present and discuss the current research results in accordance with the background of the papers, benefits and critical success factors seen by the authors for applying of cloud computing in healthcare, type of proposal, application area where applies and formulate the main ideas presented in the works. Finally, we summarize research potentials mentioned in the publications and conclude by our recommendations based on the literature review results and our interviews with multiple experts from the German healthcare industry.

The paper is structured as follows: We first define the scope of the review and conceptualize the topic. Next, we discuss the literature search process. We then analyze and synthesize the collected literature, present the current research issues and findings and derive a research agenda. Finally, we conclude by summarizing our results.

STATE OF THE ART REVIEW ON CLOUD COMPUTING IN HEALTHCARE

Definition of Review Scope

Defining the scope of the review we draw on an established taxonomy for literature reviews presented by Cooper (1988).

Characteristic		Categories			
(1)	Focus	Research outcomes	Research methods	Theories	Applications
(2)	Goal	Integration	Criticism	Identification of central issues	
(3)	Organization	Historical	Conceptual	Methodological	
(4)	Perspective	Neutral representation		Espousal of position	
(5)	Audience	Specialized scholars	General scholars	Practitioners	General public
(6)	Coverage	Exhaustive	Exhaustive and selective	Representative	Central / Pivotal

Table 1. Taxonomy of literature reviews (following Cooper (1988))

Table 1 highlights the categories characterizing the present literature review. We focus (1) on research outcomes, research methods, theories, and applications. The goals (2) of our review include identifying central issues and integrating findings. For organizing (3) the review we apply a mix of historical, conceptual and methodological organizational formats. We take a neutral perspective (4) and hope to achieve results of value to general scholars as well as practitioners (5). We consider all the relevant sources, but describe only a meaningful sample (6).

Conceptualization of the Topic

Cloud computing with its Software (SaaS), Infrastructure (IaaS) and Platform (PaaS) as a Service delivery models represents a model providing on-demand access to a network-based cluster of shared computing resources and storage units (e.g., Mell and Grance, 2012; Foster et al., 2008) and promises numerous advantages over conventional in-house solutions (e.g., Tak et al., 2011). According to our analysis, most authors follow the definition of cloud computing proposed by Mell and Grance (2012) (Abbadi et al., 2011; Chen et al., 2012b; Delgado, 2011; Chen et al., 2012a). The second most often cited definition is proposed by Foster et al. (2008) (Chen et al., 2011; Nordin et al., 2011; Rolim et al., 2010).

Literature Search

We conduct the literature search process in accordance with the approach proposed by vom Brocke et al. (2009) in four phases, namely journal search, database search, keyword search and backward/forward search. We base on the AIS World MIS Journal Ranking for IS and Management literature to select journals and conferences. Aiming to ensure that all the journals and conferences are included we identify the EBSCOhost, IEEE Xplore, Emerald, ScienceDirect, AISeL, Springer, ACM Digital Library and Proquest databases. We derive the keywords from the key variables in the given context as well as

their main synonyms, i.e. cloud, IaaS, SaaS, PaaS, and health, hospital, medical, and formulate the search phrases as all possible combinations of them. The results of the keyword search are shown in Table 2. A further combined backward and forward search leads us to 12 additional documents dealing with the topic.

Keywords / Database	cloud +			IaaS +			SaaS +			PaaS +			Sum Hits
	health	hospital	medical	health	hospital	medical	health	hospital	medical	health	hospital	medical	
EBSCOhost	**924** (2)	**288** (1)	**626** (0)	**17** (0)	**2** (0)	**10** (0)	**109** (0)	**37** (0)	**48** (0)	**18** (0)	**5** (0)	**21** (0)	**2105** (3)
IEEE Xplore	**250** (13)	**67** (1)	**436** (2)	**7** (1)	**2** (0)	**7** (0)	**16** (1)	**8** (0)	**21** (0)	**5** (0)	**3** (0)	**6** (0)	**828** (18)
Emerald	**3** (0)	**0** (0)	**2** (0)	**0** (0)	**0** (0)	**0** (0)	**0** (0)	**0** (0)	**0** (0)	**0** (0)	**0** (0)	**0** (0)	**5** (0)
ScienceDirect	**161** (0)	**22** (0)	**60** (1)	**2** (0)	**3** (0)	**4** (0)	**3** (0)	**5** (0)	**8** (0)	**4** (0)	**5** (0)	**1** (0)	**278** (1)
AISeL	**27** (2)	**1** (0)	**12** (0)	**0** (0)	**0** (0)	**0** (0)	**2** (0)	**0** (0)	**0** (0)	**0** (0)	**0** (0)	**0** (0)	**42** (2)
Springer	**96** (4)	**15** (0)	**61** (2)	**3** (0)	**3** (0)	**1** (0)	**3** (0)	**1** (0)	**1** (0)	**1** (0)	**0** (0)	**0** (0)	**185** (6)
ACM	**30** (3)	**4** (0)	**22** (3)	**1** (0)	**14** (0)	**0** (0)	**0** (0)	**0** (0)	**0** (0)	**0** (0)	**0** (0)	**0** (0)	**71** (6)
Proquest	**381** (0)	**129** (0)	**165** (0)	**0** (0)	**0** (0)	**0** (0)	**5** (0)	**3** (0)	**6** (0)	**6** (0)	**2** (0)	**5** (0)	**702** (0)
Sum Hits	**1872** (24)	**526** (2)	**1384** (8)	**30** (1)	**24** (0)	**22** (0)	**138** (1)	**54** (0)	**84** (0)	**34** (0)	**15** (0)	**33** (0)	**4216** (36)

Table 2. Number of Found (and Relevant) Hits in the Keyword Search

Literature Analysis and Synthesis

Clustering the research goals of the found papers we derive the five main research areas, namely developing cloud-based applications, platforms or brokers, and security and privacy mechanisms, as well as assessing the benefits for the use of cloud computing in healthcare. We categorize the papers in accordance with the derived framework. We further evaluate the papers with respect to the background of the paper, benefits and critical success factors seen by the authors for applying of cloud computing in healthcare, kind of proposal, application area or methods used where applies and formulate the main ideas presented in the works. Here, we mostly rely on the description provided in the abstracts. To formulate the research agenda, we analyze the concluding parts of all papers with respect to the authors' suggestions for future research. We finally provide our own recommendations based on the literature review results and our interviews with the heads of IT departments, project managers and medical workers from different German hospitals.

Findings

Development of cloud-based applications in healthcare

The authors coming up with design proposals of cloud-based applications in healthcare refer to the limited access to patients' health data during medical service delivery (Poulymenopoulou et al., 2011; Kanagaraj and Sumathi, 2011; Karthikeyan and Sukanesh, 2012; Koufi et al., 2010; Rolim et al., 2010), the challenge of management and analysis of large data amounts (Huang et al., 2011), as well as high costs and waste of resources for constructing an independent information system (He et al., 2010; Kanagaraj and Sumathi, 2011). Cloud computing is expected to create a much more connecting environment for healthcare providers (Ratnam and Dominic, 2012), enable easy, immediate and ubiquitous access to health data (Poulymenopoulou et al., 2011; Koufi et al., 2010; Hoang and Chen, 2010), bring IT-related resources as services on demand (Karthikeyan and Sukanesh, 2012), while reducing costs (Deng et al., 2011; Hoang and Chen, 2010), providing scalability, high performance (Deng et al., 2011; Hoang and Chen, 2010), and being increasingly adopted among users (Hoang and Chen, 2010). The main barriers to the acceptance of cloud computing are seen in insufficient security and privacy protection (Deng et al., 2011; Hoang and Chen, 2010).

The contribution made by Rolim et al. (2010) delivers a telemedicine solution which integrates wireless sensor networks at a patient's bedside to automated data gathering and transmitting to an exchange service for further storage, processing and distribution to cloud services. Similar ideas are followed by Hoang and Chen (2010), Sharieh et al. (2012), and by Berndt et al. (2012) in the FEARLESS and eHealth-MV projects. In the model by Sharieh et al. (2012), the sensors are attached to the body to monitor oxygenated and deoxygenated hemoglobin concentration changes in the brain and tissues. In the MoCAsH (Mobile Cloud for Assistive Healthcare) infrastructure introduced by Hoang and Chen (2010), the collected data are further transmitted to the intelligent context-aware mobile cloud middleware. The authors additionally address scalability, load balancing, security and privacy in a federate cloud layer scheduling distributed clouds with respect to user security and resource requirements and guarantee the ease of service usage via a cloud portal.

The works presented by Koufi et al. (2010) and Poulymenopoulou et al. (2011) build an emergency medical system in a cloud environment on the basis of personal health records (PHRs) and other external systems. A further cloud-based emergency healthcare application proposed by Karthikeyan and Sukanesh (2012) uses palm vein pattern recognition technology for patient's identification and distributes an image processing tool, i.e. a DICOM (Digital Imaging and Communications in Medicine) viewer.

Deng et al. (2011) focus on home healthcare applications, particularly to support depressed patients, and introduce a cloud-based system design for home healthcare providing drug therapies, sleep and light, and physical activity management and other services. The authors derive security and privacy requirements applying business logic and architecture driven approaches, sketch out a plan to integrate the proposed architecture into a cloud, and give preliminary recommendations for health data protection. Home healthcare application scenarios can be also found in other works, e.g., by Abbadi et al. (2011), Deng et al. (2012), and Berndt et al. (2012). Deng et al. (2012) illustrate the home monitoring and wellbeing portal applications monitoring the patient's data uploaded via a mobile device to the cloud and sharing it with medical workers for further instructions on need or demand. Berndt et al. (2012) present the FEARLESS (Fear Elimination as Resolution for Loosing Elderly's Substantial Sorrows) project to support elderly people in their self-serve activities by detecting a wide range of risks with a sensor (e.g., fall); the mobile diabetes (M-Diab) and mobile skin (M-Skin) systems to support the therapy and aftercare of patients suffering from diabetes and skin diseases, respectively; and the eHealth-MV (eHealth-Mecklenburg Vorpommern) project to estimate and monitor the stress and fitness level based on physiological signals gathered via wireless sensors.

He et al. (2010), Kanagaraj and Sumathi (2011) and Huang et al. (2011) propose cloud-based PACS (Picture Archiving and Communication System) to simplify the exchange of DICOM images between healthcare providers. Vazhenin (2012) presents the architecture of a cloud-based information retrieval service (e.g., DICOM) for a wide range of devices and provides performance measures of the implemented solution. The practical principles of constructing a cloud service can be found in the works by Zhang and Lu (2010), Chiang et al. (2011), and Ratnam and Dominic (2012).

Development of cloud-based platforms in healthcare

The authors of cloud-based platform designs for healthcare remark cloud computing as facilitating coordination among healthcare providers (Basu et al., 2012; Guo et al., 2010) and efficient use of medical resources (Guo et al., 2010), and

enabling a broad set of healthcare scenarios (Chang et al., 2009). However, security and privacy are to be paid more attention to (Berndt et al., 2012; Ekonomou et al., 2011) as well as the related concerns of healthcare providers (Deng et al., 2012).

Chang et al. (2009) analyze cloud healthcare services based on the principles of sustainable ecological systems, deduce high-level requirements and provide an ecosystem analysis of several emerging healthcare ecosystems, e.g., radiology image data network, electronic medical/health record (EMR/EHR) and PHR ecosystems. Wang and Tan (2010) and Guo et al. (2010) consider a cloud-based platform to provide healthcare organizations with software services, a program development environment and hardware and computational resources. Ekonomou et al. (2011) elaborate on EHR and PHR integration in a cloud-based healthcare infrastructure. Berndt et al. (2012) derive basic functions of a SaaS platform. Basu et al. (2012) present a cloud-based Fusion platform sharing EHRs securely and aggregating de-identified data to support analytics applications, whereas Deng et al. (2012) introduce a trustworthy cloud platform provisioning healthcare services.

Development of brokers for the use of cloud computing in healthcare

The proposals on the broker component are motivated by huge amount of medical resources to be handled (Nordin et al., 2011; Nordin and Hassan, 2011; Nordin et al., 2012). A broker is supposed to minimize user involvement in resources discovery (Nordin and Hassan, 2011) and composition (Wu and Khoury, 2012) ensuring the quality of services and the satisfaction of a user's need (Nordin et al., 2012). It is expected to particularly forward the exchange of medical records between different healthcare providers (Wu and Khoury, 2012; Nordin et al., 2012; Nordin et al., 2011; Nordin and Hassan, 2011) by discovering and selecting correct (Nordin et al., 2012; Nordin et al., 2011; Nordin and Hassan, 2011) as well as complete and unique (Wu and Khoury, 2012) medical records and optimizing the response time when retrieving the data from the distributed database repository (Nordin and Hassan, 2011). In general, the authors believe to minimize the treatment delay (Nordin et al., 2012; Nordin and Hassan, 2011) and reduce medical errors and cost (Wu and Khoury, 2012). The studies on the broker cover goal-based (Nordin and Hassan, 2011; Nordin et al., 2011), agent-based (Nordin et al., 2012) and workflow- and QoS-based brokers (Wu and Khoury, 2012).

Development of security and privacy mechanisms for the use of cloud computing in healthcare

The well-known benefits of cloud computing as cost reduction (Loehr et al., 2010, Chen et al., 2012a), metered and flexible utilization of its resources (Chen and Hoang, 2011, Chen et al., 2012a, Li et al., 2011a, Li et al., 2010) are also being seen as advantages with respect to health information systems. Receiving increasing adoption among users (Chen and Hoang, 2011), cloud computing is characterized here as enabling one storage center for health data (Li et al., 2011b; Shini et al., 2012) and increased-volume and open collaboration between physicians (Shini et al., 2012), enhancing the availability, recovery and transfer of health records (Nematzadeh and Camp, 2010), providing easy and ubiquitous access to health data (Loehr et al., 2010, Chen and Hoang, 2011, Chen et al., 2012a) and massive storage space (Shini et al., 2012), improving and enhancing medical services and creating new business models opportunities in healthcare (Loehr et al., 2010).

Nevertheless, cloud computing also faces many security and privacy challenges, which raise wide concerns among patients and medical workers (Li et al., 2011b, Li et al., 2012, Chen et al., 2012a; Deng et al., 2012; Shini et al., 2012; Abbadi et al., 2011), in particular the risk of losing control over data (Chen and Hoang, 2011, Li et al., 2010).

Zhang and Liu (2010), Abbadi et al. (2011), and Shini et al. (2012) derive security and privacy requirements and techniques for sharing of medical data in the cloud. Similarly, security and privacy challenges are identified and addressed by Loehr et al. (2010) introducing a security e-health infrastructure based on Trusted Virtual Domains, Nematzadeh and Camp (2010) designing a traitor-tracing algorithm, Deng et al. (2011) establishing trustworthy middleware services, Li et al. (2011a) elaborating on unlinkability between the patient and the electronic health record, Li et al. (2011b) defining a keyword search framework over encrypted records, and Li et al. (2010), Yu et al. (2010), Chen and Hoang (2011), Basu et al. (2012), Chen et al. (2012a), Chen et al. (2012b), Li et al. (2012) proposing novel access control mechanisms.

Potentials and challenges for the use of cloud computing in healthcare

Though being in the very early development phase (Chowdhary et al., 2011), cloud computing is seen as increasing existing capacities or adding new ones without additional resource expenditures (Chowdhary et al., 2011; Delgado, 2011). In particular, it delivers ubiquitous access to platforms and services (Chowdhary et al., 2011; Fernández-Cardeñosa et al., 2012).

Osterhaus (2010) and Sarnikar (2011) elaborate on the potential usage of cloud computing in healthcare and provide guidelines for decision making. Mohammed und Fiaidhi (2010) discuss the ubiquity notion in sharing EHRs through the cloud computing paradigm and related security concerns, being also addressed by Delgado (2011). Chowdhary et al. (2011)

examine the application of cloud computing for e-health and deduce capacity building, observatory on the latest research information and tools, and interoperability using universal standards as future prospects. Fernández-Cardeñosa et al. (2012) analyze the usage of an EHR management system for a large hospital and a network of primary healthcare centers and derive the feasibility of a hybrid solution implying the storage of the EHRs with images in hospital servers and the rest in the cloud. The experiments by Huang et al. (2011) show a six time improvement of the throughput of the initial model through the usage of cloud computing.

Research Agenda

Many authors express the intention to extend their current work further (Abbadi et al., 2011; Berndt et al., 2012; Chowdhary et al. 2011; Hoang and Chen, 2010; Huang et al., 2011; Nordin et al., 2011; Nordin et al., 2012; Karthikeyan and Sukanesh, 2012; Li et al., 2010; Loehr et al., 2010; Poulymenopoulou et al., 2011).

In the security and privacy area, the future research potential is observed in further development and improvement of the existing mechanisms (Abbadi et al., 2011; Deng et al., 2011; Shini et al., 2012; Loehr et al., 2010) and establishing human trust through campaigns (Ekonomou et al., 2011).

Furthermore, the research findings are going to be deployed in real world settings (Abbadi et al., 2011; Deng et al., 2011; Ekonomou et al., 2011; Hoang and Chen, 2010; Nematzadeh and Camp, 2010; Poulymenopoulou et al., 2011; Rolim et al., 2010), to be simulated (Nordin and Hassan, 2011) or extended to mobile cloud (Karthikeyan and Sukanesh, 2012).

Following Rolim et al. (2010), there is a research potential in the validation of the proposed solutions in the real word settings with respect to scale and security enhancement. Koufi et al. (2010) point out the usability criterion for system evaluation. Sharieh et al. (2012) are interested in the performance and data integrity results in the case of transmission of different data types.

From our perspective, there is also a lack of a measurement framework to evaluate the proposals (e.g., performance (Nordin et al., 2012; Sharieh et al., 2012), efficiency, users' acceptance, etc.) and, following the expert interviews, an overview of potential application scenarios and typical requirement patterns systematically derived, business and actor models for an ecosystem.

CONCLUSION

The literature review shows that the application of the cloud computing paradigm in healthcare is heavily discussed. The literature search process reveals 36 articles in this area across the main databases covering top-ranked IS and Management journals and conference proceedings and 12 additional ones through the backward/forward search.

We observe research proposals for various application fields including emergency healthcare, home healthcare, assistive healthcare, and telemedicine, as well as storage, sharing and processing of large medical resources (e.g., images) in general. Gaining popularity among users, cloud computing is believed to improve accessibility of health data, ensure efficient management and usage of medical resources, facilitate collaboration among healthcare organizations, and open new possibilities for healthcare. However, security and privacy still remain the main concerns. Further research potential is observed in the security and privacy area, the proposals' development, simulation in the real world settings and extension to mobile computing. We observe research needs in a measurement framework to evaluate the proposals, and, based on the interviews with German healthcare experts, an overview of potential application scenarios, typical requirement patterns systematically derived, business and actor models for an ecosystem.

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