CONCURRENCY AND COMPUTATION: PRACTICE AND EXPERIENCE
Concurrency Computat.: Pract. Exper. (2014)
DOI: 10.1002/cpe.3325

SPECIAL ISSUE PAPER

Reporting an experience on design and implementation of e-Health systems on Azure cloud

Shilin Lu[1], Rajiv Ranjan[2,*,†] and Peter Strazdins[1]

[1]*Research School of Computer Science, Australian National University, Australia*
[2]*Information Engineering Laboratory, CSIRO Computational Informatics, Australia*

SUMMARY

Electronic Health (e-Health) technology has brought the world with significant transformation from traditional paper-based medical practice to Information and Communication Technologies (ICT)-based systems for automatic management (storage, processing, and archiving) of information. Traditionally, e-Health systems have been designed to operate within stovepipes on dedicated networks, physical computers, and locally managed software platforms that make it susceptible to many serious limitations including: (1) lack of on-demand scalability during critical situations, (2) high administrative overheads and costs, and (3) inefficient resource utilization and energy consumption due to lack of automation. In this paper, we present an approach to migrate the ICT systems in the e-Health sector from traditional in-house Client/Server (C/S) architecture to the virtualized cloud computing environment. To this end, we developed two cloud-based e-Health applications (Medical Practice Management System and Telemedicine Practice System) for demonstrating how cloud services can be leveraged for developing and deploying such applications. The Windows Azure cloud computing platform is selected as an example public cloud platform for our study. We conducted several performance evaluation experiments to understand the QoS tradeoffs of our applications under variable workload on Azure. Copyright © 2014 John Wiley & Sons, Ltd.

Received 15 January 2014; Revised 2 June 2014; Accepted 2 June 2014

KEY WORDS: cloud computing; e-Health; energy efficiency

1. INTRODUCTION

Providing efficient healthcare services is becoming a challenging problem for governments across the world. On one hand, the increasing health-awareness among people has led to soaring demands for the healthcare services. On the other hand, the governments have limited fund and limited personnel to dedicate to this sector. Recent studies have shown that the healthcare sector consumes a large of proportion of GDP in many countries. Over the past decades, Information and Communication Technologies (ICT) has been widely adopted within the healthcare sector, which has significantly improved the work efficiency [1]. This has led to the highly developed e-Health care service sector worldwide. e-Health is a new term where ICT systems are deployed for better management and coordination of information.

However, the substantial application of ICT systems to health care has led to number of serious concerns [2]. Because large number of computing, storage, and networking equipment are widely deployed for e-Health applications in the hospitals, the equipment consume huge electrical power or

---

*Correspondence to: Rajiv Ranjan, Information Engineering Laboratory, CSIRO Computational Informatics, Australia.
†E-mail: raj.ranjan@csiro.au

CSIRO Computational Informatics: formerly known as CSIRO ICT Centre.
This is the extended version of short paper published at IDCS 2013 Conference held in Hangzhou, China (28–30 Oct, 2013).

energy, which is becoming an issue. According to Chamara [3], a traditional PC Dell 2350 1.8GHz Pentium 4 (only the host unit) consumes 6 Watts in its sleep state and 60–85 Watts when fully powered on. Another study by Lawrence Berkeley National Laboratory suggested that 60% of all desktop PCs in commercial buildings remain fully powered on, 36% were turned off, and 4% were asleep during nights and weekends [4] with existing power management utilities of the computing servers or networking equipment almost always disabled. Further, the research has confirmed that even at a very low load, such as 10% CPU utilization, the power consumed is over 50% of the peak power [5]. Similarly, non-consolidated ICT systems also lead to increased cooling costs.

Recent technological advances in e-Health services, such as Medical Body Area Networks (MBAN), are challenging the existing in-house ICT infrastructures. According to the market intelligence company ABI research [6], over the next 5 years, close to five million disposable wireless MBAN sensors will be shipped. MBANs enable a continuous monitoring of patient’s condition by sensing and transmitting measurements such as heart rate, electrocardiogram, body temperature, respiratory rate, chest sounds, and blood pressure. MBANs will allow (i) real-time and historical monitoring of patient’s health, (ii) infection control, (iii) patient identification and tracking, and (iv) geo-fencing and vertical alarming. However, to manage and analyze such massive MBAN data from millions of patients in real time, healthcare providers will need access to an intelligent and highly scalable ICT infrastructure.

Other classes of e-Health services such as medical imaging [7] produce extremely large and distributed data files, and the modalities used to create them are constantly evolving. Medical image archives are increasing [7] by 20–40% each year. Based on the US Report, there were 1 billion medical images stored by 2012, accounting to one-third of global storage demand. With such increases in image sizes, aging storage archives and space capacity can hinder overall healthcare efficiency. It is clear that medical organizations existing technology – including existing data storage capabilities and the image archiving and communication system used by radiologist – are radically limiting efforts to harness this massive amount of medical imaging data.

Hence, it is clear that there is an immediate need to leverage efficiency and dynamically scalable ICT infrastructure for deploying current and next-generation e-Health applications. We propose to achieve this by leveraging cloud computing systems. Cloud computing assembles large networks of virtualized ICT services such as hardware resources (such as CPU, storage, and network), software resources (such as databases, application servers, and web servers), and applications. In industry, these services are referred to as Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). Cloud computing services are hosted in large data centers, often referred to as data farms, operated by companies such as Amazon, Apple, Google, and Microsoft.

Today, cloud computing presents an immense opportunity for the healthcare sector. First, it can significantly reduce the initial capital investments in the IT infrastructure in hospitals because of the pay-as-you-go pricing models. Second, it can improve the utilization of IT resources and improve the quality of healthcare service delivery among the healthcare sector [2]. In addition, sharing and managing large amounts of distributed medical information including EHR and X-Ray images across the e-Health system through cloud environment is the current trend [8]. The cloud storage services provide the good and scalable solution for such massive data management challenges [9].

We note that optimizing energy efficiency [10] of cloud computing data center has also emerged as one of the important research in the past few years. Discussion on how to optimize the energy efficiency of data centers is beyond the scope of this paper. We assume that cloud data center provider implements number of software and hardware-based approaches to perform energy optimizations. Our argument is based on the fact that cloud computing has better energy efficiency than traditional C/S application hosting approaches, as it does better consolidation of application workload via dynamic system scaling and de-scaling (server shutdown, migration, and the like)

In this paper, we present two e-Health applications, which are programmed as SaaS applications using Azure cloud services at PaaS and IaaS layers. We developed two practical applications (Cloud-based Medical Practice Management System [11] and Cloud-based Telemedicine Practice System [12]) to demonstrate how cloud computing can be applied for e-Health for overcoming those limitations on traditional ICT architectures and improving the scalability and energy efficiency of healthcare applications. The Windows Azure cloud computing platform is carefully selected as an

DOI: 10.1002/cpe

example of public cloud platform for hosting our applications. On the programming level, ASP.NET MVC programming model, SQL Azure Database, and C# programming language are leveraged for developing our applications.

The main contributions of the paper are as follows: (1) we illuminate a concept of migrating the e-Health applications from traditional C/S architecture to cloud computing environment for improved energy efficiency and salability; (2) we present designs and implementations of two e-Health applications and their deployments in a public (Microsoft Azure) cloud computing environment; and (3) we conduct extensive experiments for evaluating the QoS features of our application on Windows Azure.

The rest of the paper is organized as follows. In Section 2, the literature review will be given to show the state-of-the-art e-Health and cloud computing research. In Section 3, we will discuss details in the e-Heath applications and cloud-based ICT architecture deployed in the hospitals. In Section 4, we will demonstrate the outcome of experiments. We end the paper in Section 5 with concluding remarks.

2. LITERATURE REVIEW

Computers have been widely used by health practitioners since the 1990s. Nowadays, most doctors, nurses, and other health practitioners are using personal computers to process the patients' records, prescriptions, and appointments. Some typical computing approaches are widely adopted by the healthcare sector such as EHRs, e-Prescription, e-Pharmacy, and telemedicine. The term Electronic Health Record (EHR) refers to the digital records saved in database to store the patients' personal medical information. The records can contain various types of information, such as patients' personal profile, physiological data, medical history, prescriptions from the medical providers, physiological test results, or even some multimedia data such as digital X-ray films. The EHR data can be used for further verification of patient's condition by the doctors, or provided to the insurance for claim verification. Compared with paper-based medical records used in the past, the EHR system has many advantages, including easy to search and store.

Many countries have initiated high profile EHR programs. For example, in Australia, the government has appointed the National E-Health Transition Authority Limited to research the EHR system since 2004. In China, the EHR system has been developed for many years; it will be deployed by next year. Moreover, in contemporary hospitals and clinics, electronic prescription (e-prescription) has been prevailing as another popular application in e-Health practice, so is the electronic pharmacy (e-Pharmacy). Telemedicine is another contemporary approach for connecting the patient and doctor at distance using high definition video conferencing technologies. It is usually deployed with videoconference device, audio device, scanner, and respective data compression algorithm to transfer the data between two points. The benefit of this approach is obvious.

In addition, the cloud computing technique is good for health data exchange, data mining for health science research. In the traditional way, in order to discover new drugs and new medical treatments, scientists need to analyze vast medical data over years where millions of dollars are invested. With cloud computing, investments and time consumption are significantly reduced [13]. Further, the cloud can be used for body sensor network, for example, the patients' physiological data at remote can be accessed and verified by the doctors over the cloud [9,14] in real time. Obviously, in recent years, more and more sectors including health care are adopting cloud computing to replace their own computing infrastructure. A survey indicates that almost three-quarters of health industry respondents are planning or already using cloud-based services [9]. Figure 1 shows that 32% sectors are acting to move to cloud platform from the traditional computing facilities.

Medical imaging application contributes significantly to the digital data deluge phenomenon. For data processing and storage management point of view, digital medical images represent a particular challenge. High-level steps (1–5) in medical imaging process as shown in Figure 2 are described as follows:

1. Imaging devices produce large number of files (slices).
2. Raw files are converted to three-dimensional (3D) images, which require massive computational resources.

DOI: 10.1002/cpe

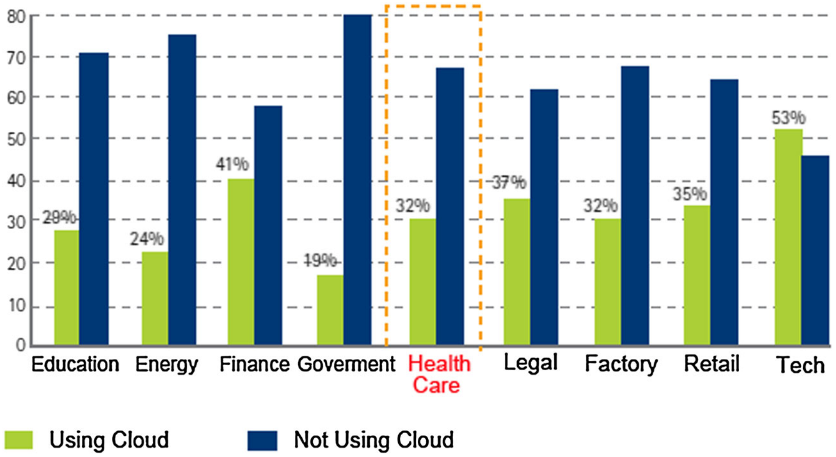


Figure 1. Cloud computing adoption across different sectors [9].

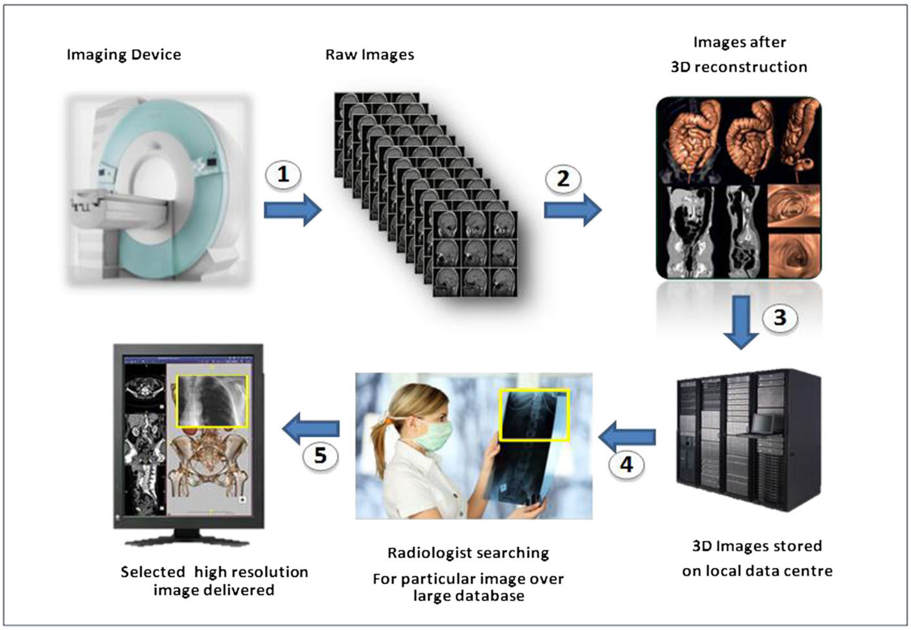


Figure 2. Medical imaging use case.

3. Three-dimensional models of images are much bigger in size than their raw counterparts, which are needed to be archived for future usage. The images are tagged by standard DICOM codes, which assist radiologists and physicians in search.
4. The radiologist searches for the image related to a patient on the storage server (in-house server). The server sends a low resolution preview of the image(s).
5. The radiologist selects the area of interest, following that the server sends the full resolution images, starting from the selected area. These images can be delivered to any kind of mobile devices or PCs.

In health care (medical imaging), the exponential size growth of diagnostic studies has necessitated a continued increase in computing power. The diffusion of teleradiology requires an ever greater efficiency in data transmission even in areas with limited network bandwidth. The evolution of technologies in diagnostic imaging has created an increasing need of resources, especially for the execution of tests based on 3D images, such as those regarding gastroenterology or neuroradiology. With such increases in image sizes, aging storage archives and space capacity can hinder overall healthcare efficiency. Medical practitioner needs to archive these images for a long time for protecting themselves against malpractice lawsuits. Further, as patient moves from one location to another, multiple imaging of the same organs are carried out again and again because of lack of technical solutions available for image sharing across health organizations.

It is clear that the aforementioned factors are stressing the IT resources of health organizations, who have historically underinvested in IT compared with other information-intensive industries. At this rate, many healthcare organizations and industries will have adequate computing and storage resources to manage growing amount of imaging data. Hence, it is necessary for health organizations and industries to consider the accessibility and ‘share ability’ of medical images, as well issues of data migration, 3D image construction to deal with future tsunami of data. The cloud-powered e-Health application can significantly boost the economy productivity in the healthcare sector [15]. However, the opportunity and challenge are coexisting the current cloud context [16].

3. CLOUD-BASED E-HEALTH APPLICATION ARCHITECTURE

In order to demonstrate the advantages of hosting the health applications in cloud computing environments, we developed two e-Health applications and deployed them on the Windows Azure cloud platform, although there are several vendors who provide cloud computing services, including Amazon, IBM, Google, and Microsoft. Compared with other cloud platform, Windows Azure has a few unique advantages. The first advantage is that the Visual Studio. Net Development Platform has close integration Windows Azure cloud platform leading to seamless application programming and deployment experience. Therefore, one can develop and debug cloud-based applications within Visual Studio. Microsoft also provides a tool called ‘Publish to Windows Azure’ for developer to deploy the application to Azure. Another advantage of Windows Azure is that it directly integrates the ‘SQL Azure’ as the database system into the cloud platform. Developers can move their SQL server database from existing in-house database systems to Azure cloud with minimal programming. The third advantage is that Windows Azure provides very high performance backup mechanism for database, web service, virtual machine, and virtual network.

Our first application is called ‘Cloud-based Medical Practice Management System’, and the second is called ‘Cloud-based Telemedicine Practice System’. Figure 3 shows the Windows Azure-based system architecture for deploying the proposed e-Health applications. From the figure, we can see that there are three layers in our cloud-based e-Health application architecture: IaaS, PaaS, and SaaS. At the IaaS layer, Windows Azure provides the infrastructure services such as virtual machines, storage unit, and high speed network.

Our application components are deployed on the virtual machines to provide web services and to store the huge health data on the Azure’s Blob storage, which is a service for storing large amounts of unstructured data that can be accessed via HTTP or HTTPS. A single blob can be very big in size (Gigabytes), and a single storage account can contain up to 100 TB of blobs, which can be used for distributed access [17]. Windows Azure provides two different kinds of blobs: the first one is block blob and the second one is page blob. Hence, Azure can support different data formats based on type and mix of e-Health applications. Our applications leverage blob storage to save the patients’ image files, X-ray data, EHR documents, video, and audio data. Assuring security [18] and privacy [19] of e-Health data on public cloud storage services is beyond the scope of this paper. However, in future, we intend to integrate our e-Health applications with TrustStore system [18] developed by CSIRO. TrustStore is a service-oriented solution for provisioning hybrid (including both private and public) data center resources with strong guarantees on data security and privacy.

On the user side or client side based on the IaaS layer, all the typical desktop computers in the hospital can be replaced with the thin cloud terminals. In this case, all the healthcare staff can directly access the cloud-hosted applications via remote desktop Utility.

At the PaaS layer, our applications rely on the web services to provide online services, the SQL Azure server to provide SQL queries service, and the media server to provide live streaming service for the videoconference communication. Our two e-Health applications operate at SaaS layer for providing the software functionalities for the users or healthcare staff (doctors, nurses, pharmacists,

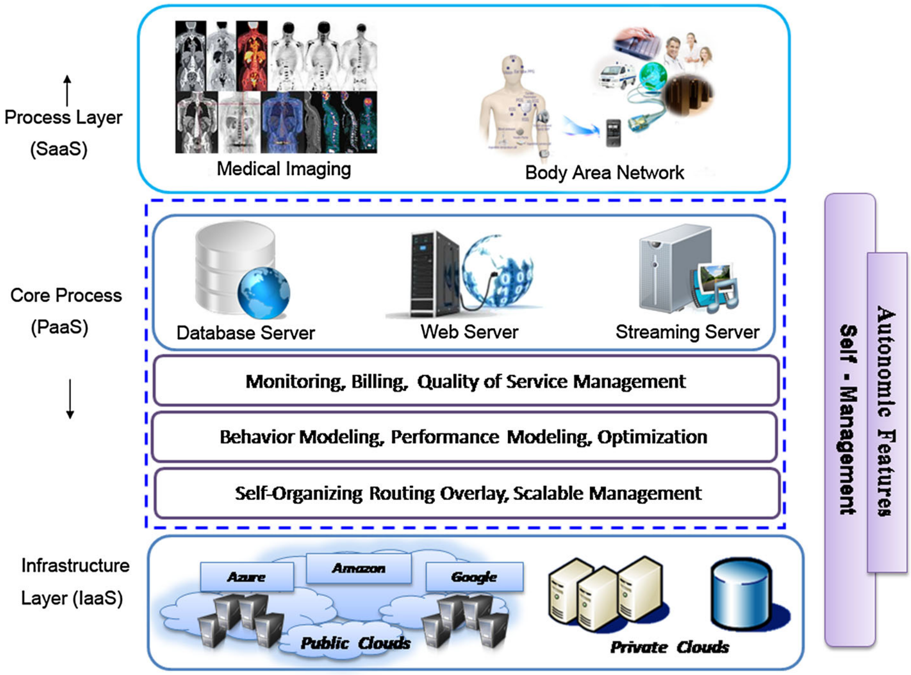


Figure 3. Windows Azure Cloud-based e-Health application architecture.

etc.). Our application can be scaled based on the workload demands (e.g., number of users and data size). Discussion on how our applications can be automatically scaled dynamically based on workload demands is beyond scope of this paper.

3.1. Cloud-based Medical Practice Management System

The first e-Health application is called 'Cloud-based Medical Practice Management System', which is shown in Figure 4. The application is integrated with the typical health management systems, which can be used for the hospitals, clinics, and other medical organizations. In this system, most useful medical relevant business processes and data are efficiently managed including EHR, e-Prescription, Personal Health Archives, X-Ray data, e-Pharmacy Management, e-Appointment, Billing, Accounting, and Finance management systems.

In this application, we developed the software components using C# language on the Visual Studio 2012 development platform. We adopt the MVC programming model and SQL Server 2008 as the database. Figure 5 shows a UML flow diagram of the Cloud-based Medical Practice Management System. In this flow diagram, the main business processes are described as four models: patient module, doctor module, system administrator module, and pharmacy module.

Because the application is designed using MVC model, there are several core classes defined in the Controller component. These six-core classes are shown in Figure 6. Each class implements a service. In each class, few methods are defined as well based on their relative functionalities.

In the pharmacy service, the three-core sub-module is defined as DrugInventory, DrugPurchase, and DrupSales. For example, in the DrugInventory class, six methods are created as Figure 7: (1) DrugInventoryCreate, (2) DrugInventoryDetails, (3) DrugInventoryIndex, (4) DrugStockCreate, (5) DrugStockDetails, and (6) DrugStockIndex.

In this application, the database is MS SQL and deployed on the SQL Azure database system of Windows Azure platform. After an SQL database instance on Azure was created, users can run the SQL Server scripts, which is developed on local machine. The database will be replicated on one SQL Azure instance. Application can connect to the database instance on Azure SQL server through the ADO.NET or ODBC connection strings. In this application, several tables are designed. Figure 8 shows the UML database diagram of Cloud-based Medical Practice Management System. There are

DOI: 10.1002/cpe

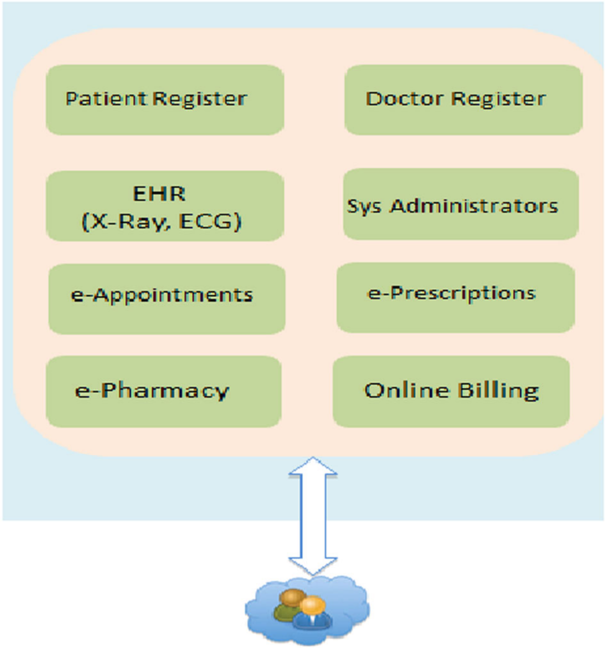


Figure 4. Cloud-based Medical Practice Management System.

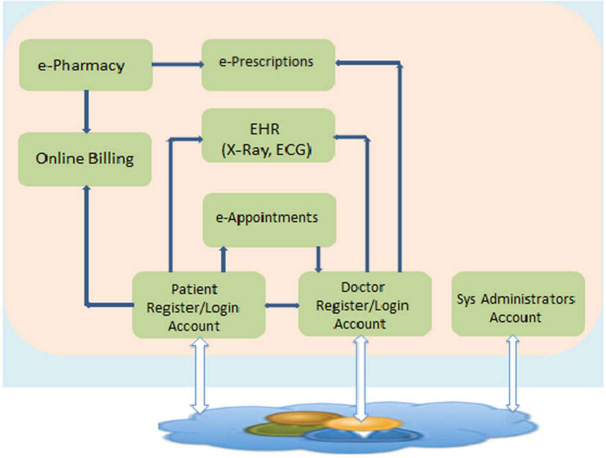


Figure 5. UML of Cloud-based Medical Practice Management System.

four main database tables that are designed to support the most functionalities in the e-Health system including ‘Patients’, ‘eAppointments’, ‘Billings’, and ‘EHR’ database.

3.2. *Cloud-based Telemedicine Practice System*

Another e-Health application applied on the cloud architecture is called ‘Cloud-based Telemedicine Practice System’. It is integrated with multi-functions such as e-Appointment, e-Consulting, Telemedicine, and e-Prescription. Based on the Azure cloud platform, the patients can see the doctors by remote through internet and consult any health problems. The doctor can check the health records, X-Ray graphics, and so on for the patient and even check the patient’s live physiologic data by real time with some body sensor network.

Telemedicine application is a hybrid system. It combines diverse communication techniques and hardware. In this experiment, we adopt web camera as the user front device and Microsoft

DOI: 10.1002/cpe

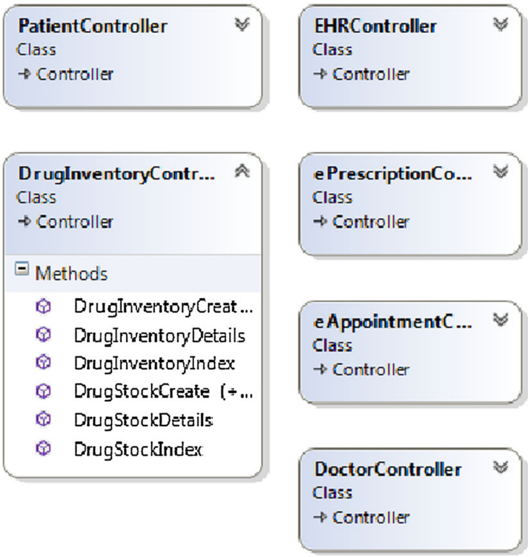


Figure 6. Classes defined in Controller component.

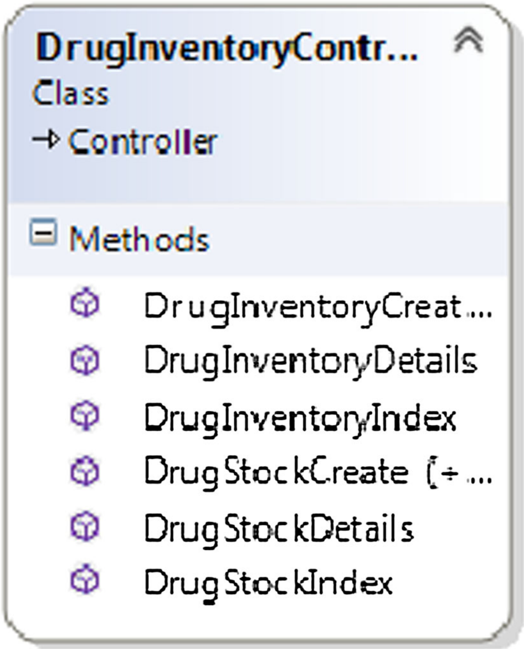


Figure 7. Methods defined in DrugInventory Class.

Expression Encoder 4 as the video compression technique, Windows Azure virtual machine as the live video stream server. In the Azure cloud platform, the live streaming media server is deployed for video/audio processing. Figure 9 shows the diagram of main modules provided in the Cloud-based Telemedicine Practice System. Window Azure offers the scalable video streaming service through the web-role media service running in the virtual machine.

In the up streaming process of Figure 10, the Expression Encoder 4 will be used to collect the raw data from the camera on the client (either a patient or a doctor) and encoder the raw video streaming to Silverlight format; meanwhile, the streaming will be pushed to a Windows Azure web role, which is a virtual machine. The web role is an IIS media service, which can receive the video streaming through a push point, for instance, domain.com/push.isml/mainifest. In the down streaming process, a Windows

DOI: 10.1002/cpe

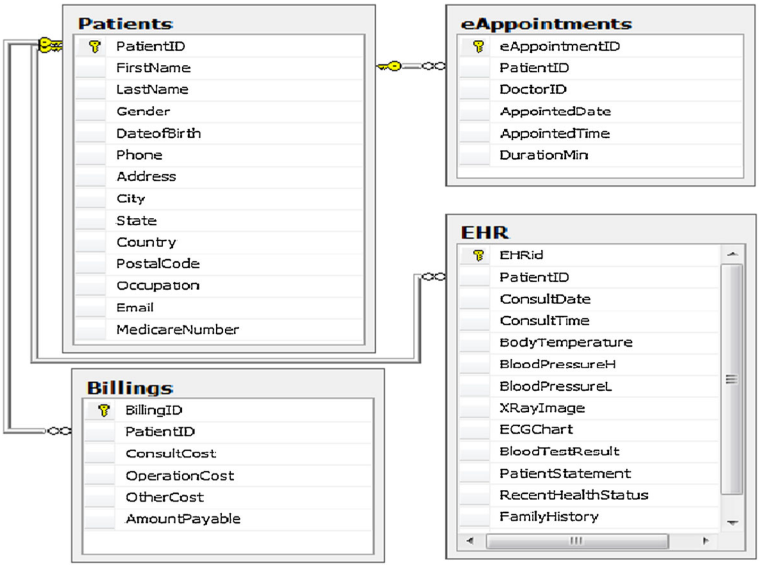


Figure 8. UML database diagram of Cloud-based Medical Practice Management System.

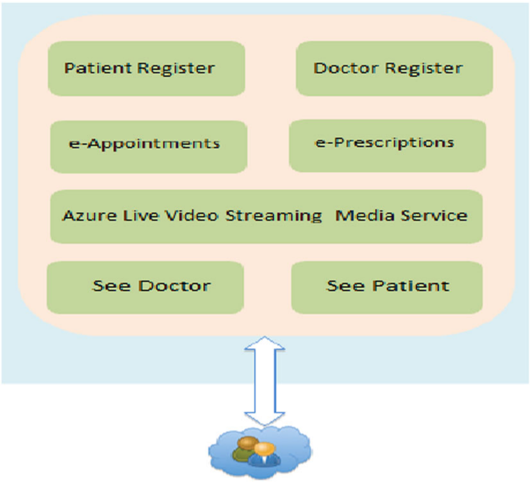


Figure 9. Cloud-based Telemedicine Practice System.

Azure Web Role loads the video streaming by balance and publishes it on the pull point, for example, domain.com/pull.isml/manifest. This process is executed by the Media Server on the Windows Azure Web Role. This publish point enables the video player to pull video stream from the Media Server. On the client end, the Silverlight player should be installed with web browser, either Internet Explorer or Firefox. The Silverlight-formatted video stream will be decoded and shown by the web browser.

In the telemedicine system, a patient can register and then login to search the appropriate doctor at remote for him or her and then make appointment with the remote doctor on the available date and time. Then at the appointed date and time, the patient will login the system to meet with the appointed doctor. The patient is able to see the doctor on the system interface by video and audio and then talk to the doctor with his or her statement. In addition, the patient can present his or her other physiological data to the doctor, such as his or her recent blood test report, X-ray image, and EGG chart or other multimedia data or text descriptions. At the end of consultation, the doctor can give the conclusion and solution or prescription. The prescription will be presented to the patient on his or her system. The patient will follow the advice. Then the consultation ends.

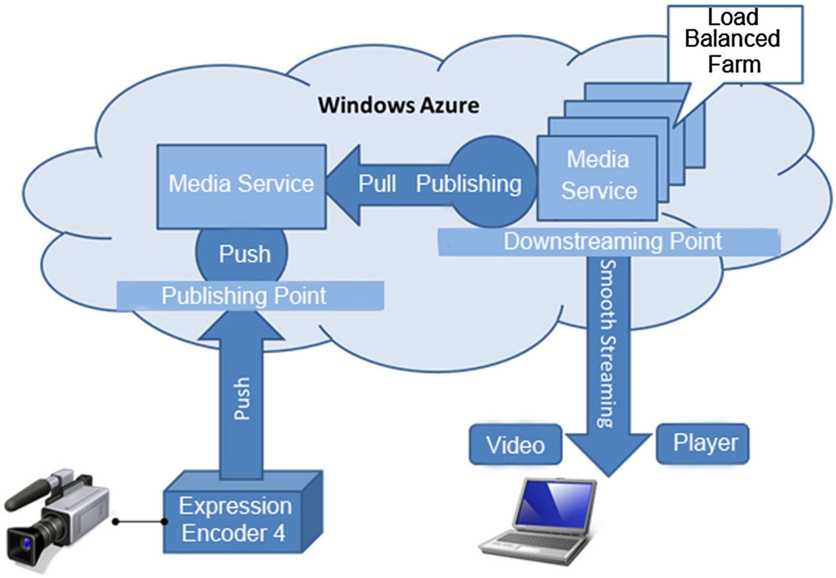


Figure 10. Windows Azure Live Smooth Streaming.

4. EXPERIMENTAL RESULTS

In our experiments, we deploy the aforementioned e-Health applications on Windows Azure cloud [20]. The following services on Windows Azure are leveraged for this deployment: Cloud Web Services, Azure SQL Databases, Virtual Machine, IIS, and Live Smooth Streaming Media Services. We assumed unsaturated server availability for these experiments, so that enough capacity could always be allocated to a virtualized web service or SQL database for any service request. At user-end, we simulate large number of users in the hospital, who access the services of two e-Health applications using different workload generation tools. First, we use JMeter [21] for simulating 20 groups of concurrent users to evaluate the scalability of our applications hosted on Windows Azure cloud. In particular, we quantify the Average Response Time of HTTP Request (ARTHR) of the following components related to the Cloud-based Medical Practice Management System: (i) web service and (ii) SQL database.

Figure 11 shows the measurement for the ARTHR under different-sized groups of concurrent users. As expected, from the initial results, it is clear that the ARTHR degrades as the number of users accessing the service increase. We observed that the ARTHR stayed below 200 ms for a user population below 93. However, as the concurrent users' workload was increased to 93 or above, the

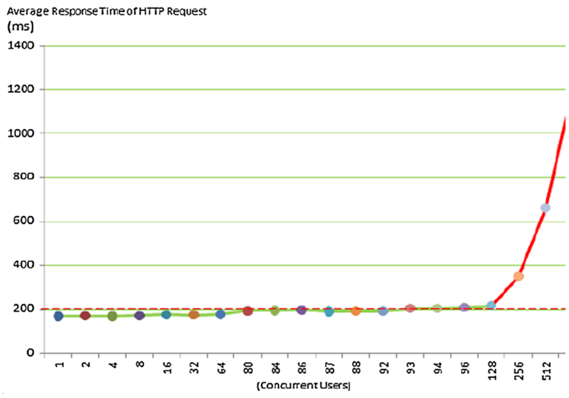


Figure 11. Average Response Time of HTTP Request to concurrent users.

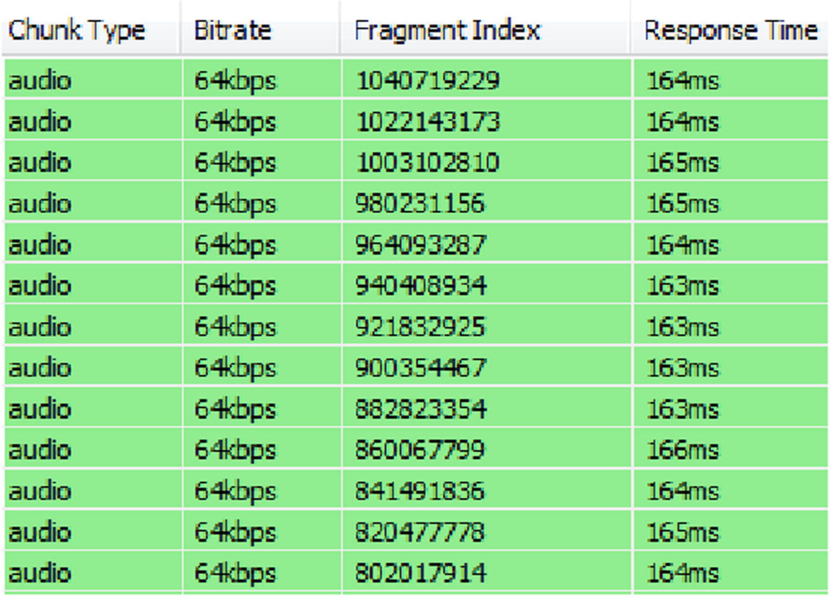
DOI: 10.1002/cpe

ARTHR grows beyond 200 ms. For example, as we increased the concurrent user population to 1024, the ARTHR rises significantly and, finally, it soars to 1205 ms. The red line on the graph shows the elevated HTTP response latency. A red horizontal line at 200 ms shows the threshold of the HTTP response latency of web service on Azure cloud. That means our e-Health applications with its current Azure configuration (single instance) provide the best QoS in terms of ARTHR for the web service and database query when we keep the concurrent user below than 93. We believe that our applications can be scaled for much larger population of users via implementation of an autonomic application provisioning technique, which will adapt to the increase or decrease in workload by dynamically scaling the number of instances of the application components. We intend to investigate this aspect in our future work.

In the second experiment, we evaluate the scalability and QoS of the live video streaming service hosted on the virtual machine (an IaaS layer service) of Windows Azure. In the Cloud-based Telemedicine Practice System, we deploy the Live Smooth Streaming Media Services on the virtual machine to enable the patient and doctor to implement an easy-to-use online medical consultation via the video conferencing system. In this experiment, we use Smooth Stream Performance Testing Tool [22] that generates simulated workload for the streaming media services. This tool simulates the real users, who try to connect to the media stream available from the streaming service. Here, we analyze the average video/audio chunk retrieval time for assessing the media streaming QoS of the virtualized media service.

In this experiment, we selected a medium size virtual machine with two cores, 3.5 GB memory, and located at the datacenter in West US for hosting the media service. In our system, the video conferencing involves two users, that is, one patient and the other healthcare provider. Our early results show that the performance of audio stream remains constant and stable around 164 ms at 64 kbps over different chunks or files. This is understandable as the audio files are not generally network communication heavy if compressed using an efficient encoding technique. However, the audio and video stream shows uncertain QoS in terms of response time for different chunks or file fragments, as shown in Figures 12 and 13, respectively. We believe that uncertain video QoS is due to the variability of network bandwidth between the two users. In future work, we will work on developing network QoS profiling technique for dynamically learning the congestion and bandwidth between users and cloud-hosted applications. Such a technique will help us in dynamic migration of video content across data centers for improving user's QoS.

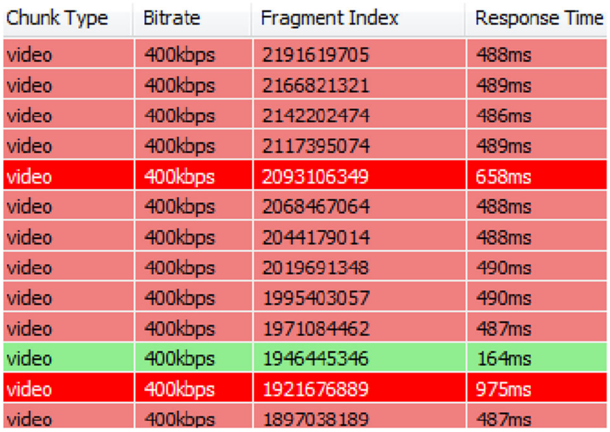
Figures 14 and 15 show the media stream service's performance with four cameras and two cameras, respectively. We can see that the average video chunk response time is 497 ms at the



Chunk Type	Bitrate	Fragment Index	Response Time
audio	64kbps	1040719229	164ms
audio	64kbps	1022143173	164ms
audio	64kbps	1003102810	165ms
audio	64kbps	980231156	165ms
audio	64kbps	964093287	164ms
audio	64kbps	940408934	163ms
audio	64kbps	921832925	163ms
audio	64kbps	900354467	163ms
audio	64kbps	882823354	163ms
audio	64kbps	860067799	166ms
audio	64kbps	841491836	164ms
audio	64kbps	820477778	165ms
audio	64kbps	802017914	164ms

Figure 12. Average audio chunk response time.

DOI: 10.1002/cpe



Chunk Type	Bitrate	Fragment Index	Response Time
video	400kbps	2191619705	488ms
video	400kbps	2166821321	489ms
video	400kbps	2142202474	486ms
video	400kbps	2117395074	489ms
video	400kbps	2093106349	658ms
video	400kbps	2068467064	488ms
video	400kbps	2044179014	488ms
video	400kbps	2019691348	490ms
video	400kbps	1995403057	490ms
video	400kbps	1971084462	487ms
video	400kbps	1946445346	164ms
video	400kbps	1921676889	975ms
video	400kbps	1897038189	487ms

Figure 13. Average video chunk response time.

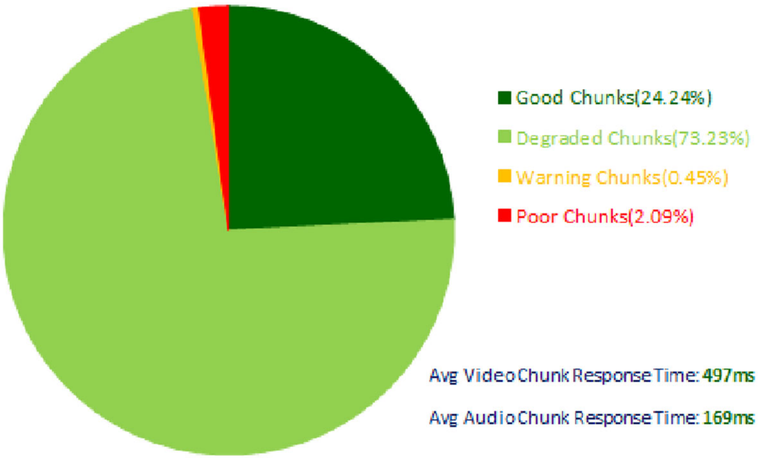


Figure 14. Media stream services performance with four cameras.

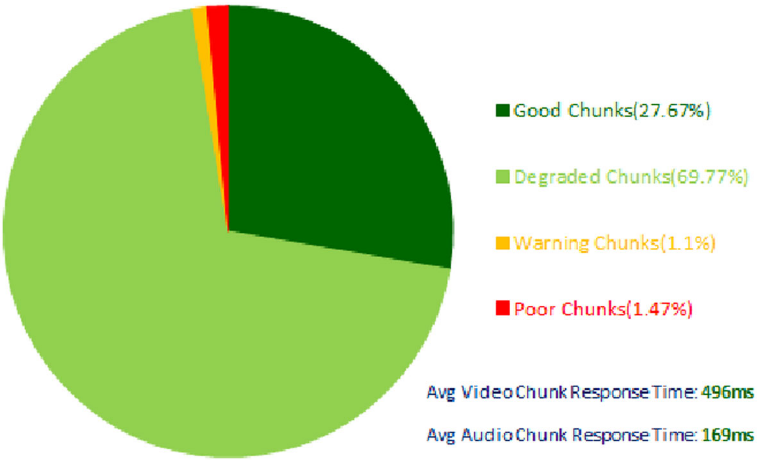


Figure 15. Media stream services performance with two cameras.

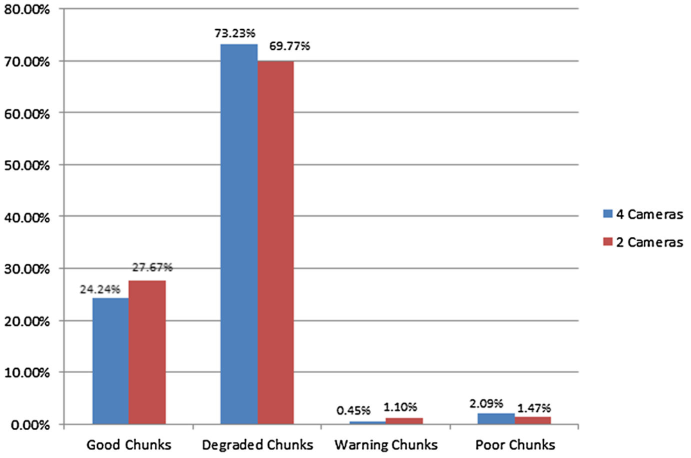


Figure 16. Comparison of the media stream services performance.

scenario of four cameras compared with 496 ms at the scenario of two cameras, while the audio performance is the same 169 ms during the two scenarios.

In Figure 16, we compare the overall performance of media stream services for two scenarios. We can see that there is no significant difference between the two situations because of different video content delivery workload generated by cameras. As we expected in the four-camera setting, the performance of the media stream service degraded according to increasing computing and network traffic overload. Overall, we conclude that it is feasible to engineer e-Health applications using public cloud services. However, to guarantee QoS of applications, one needs to develop intelligent cloud service and network provisioning technique. Further, one also needs to develop data security and privacy preserving techniques for protecting confidential e-Health data.

5. CONCLUSION AND FUTURE WORK

In this paper, we presented our experience on designing and implementing two e-Health application systems by leveraging Azure cloud platform. We started by analyzing challenges (lack of scalability, energy in-efficiency, and the like) healthcare sector faces when using traditional C/S architecture for delivering e-Health services. Our proposed approach addresses these challenges by leveraging cloud computing services. We have implemented the prototype of our e-Health application systems and successfully evaluated its QoS performance on Azure cloud under variable workload settings. The benefits of our approach include (i) faster search of medical databases, (ii) elastic storage capacity for archiving images, (iii) elastic computing capacity for creating complex 3D model from raw images, (iv) massive cost-savings for health organizations, which are often subjected to budget cuts, and (v) consolidated access to the image database from any point on the Internet via any device type.

However, migrating e-Health application to cloud environment challenged our abilities in several aspects. It required novel cloud computing methodology and theoretical underpinnings that ensures the following: (i) security, privacy, and integrity of confidential medical data; (ii) QoS (e.g., 3D model reconstruction delay, image transmission delay, and indexing delay over large databases) when running medical experiments; (iii) easy integration with organizations existing imaging access and storage infrastructure; and (iv) interface with other health information systems. As part of our ongoing work, we are working on an intelligent elastic framework for autonomic provisioning of e-Health applications in private or public cloud environments. This framework will allow knowledge-driven optimized resource provisioning where it adapts to uncertain data streams/volumes, the number of users and varying resource, and workload unpredictability. In addition, with the fast development of cloud technologies, we can improve the performance of cloud-based e-Health applications from many new means, such as building the private cloud platform using OpenStack to enhance the privacy and security, adopting live migration cloud technology to balance the performance of vital tasks over the cloud, and reducing energy consumption over the private cloud by energy efficient cloud technologies.

REFERENCES

1. Hansen DP, Gurney P, Morgan G, Barraclough B. The Australian e-Health Research Centre: enabling the health care information and communication technology revolution. *Medical Journal of Australia* 2011; **194**(4):S5.
2. Maria AF, Fenu G, Surcis S. An approach to cloud computing network. *Proceedings of the 3rd International Conference on Theory and Practice of Electronic Governance*, Bogota, Colombia, 10–13 November 2009; 409–410.
3. Chamara G, Christensen K, Nordman B. Managing energy consumption costs in desktop PCs and LAN switches with proxying, split TCP connections, and scaling of link speed. *International Journal of Network Management* 2005; **15**(5):297–310.
4. Roberson J, Webber C, McWhinney M, Brown R, Pinckard M, Busch J. After-hours power status of office equipment and inventory of miscellaneous plug-load equipment. *Technical Report LBNL-53729*, Lawrence Berkeley National Laboratory, January 2004.
5. Barroso LA, Holzle U. The case for energy-proportional computing. *IEEE Computer* 2007; **40**(12):33–37.
6. ABI report on medical body area networks. Available from: http://www.abiresearch.com/press/disposable-wireless-sensor-market-shows-signs-of-l.
7. Medical imaging in the cloud. AT&T Tecnical Report. Available from: www.corp.att.com/healthcare/docs/medical_imaging_cloud.pdf.
8. Sukanta G. Sharing information and data across heterogeneous e-health systems. *Telemedicine and e-Health* 2009; **15**(5):454–464.
9. Wan D, Greenway A, Harris JG, Alter AE. Six questions every health industry executive should ask about cloud computing. Available from: http://newsroom.accenture.com/images/20020/HealthcareCloud.pdf.
10. Beloglazov A, Buyya R, Lee YC, Zomaya A. A Taxonomy and Survey of Energy-Efficient Data Centers and Cloud Computing Systems. Advances in Computers, vol. **82**, Zelkowitz M (ed.), Elsevier: Amsterdam; 47–111. ISBN: 978-0-12-385512-1
11. Lu S, Ranjan R, Strazdins P. Cloud-based Telemedicine Practice System. Available from: http://telemedicine.cloudapp.net May 2013.
12. Lu S, Ranjan R, Strazdins P. Cloud-based Medical Practice Management System. Available from: http://mhealth.cloudapp.net May 2013.
13. Kaufman W. Cloud computing saves health care industry time and money. Available from: http://www.npr.org/blogs/alltechconsidered/2012/10/01/162080613/cloud-computing-saves-health-care-industry-time-and-money accessed on 12 May 2013.
14. Eman A, Mohamed N, Al-Jaroodi J. e-Health cloud: opportunities and challenges. *Future Internet* 2012; **4**(3):621–645.
15. Banica L. Cloud-powered e-Health. *Buletin Stiin ific, Seria tiin e Economice* 2013; **12**(1):26–38.
16. Eman A. e-Health cloud: opportunities and challenges. *Future Internet* 2012; **4**(3):621–645.
17. Microsoft. Available from: http://www.windowsazure.com/en-us/develop/net/fundamentals/cloud-storage/ accessed 10 May 2013.
18. Nepal S, Friedrich C, Henry L, Chen S. A secure storage service in the hybrid cloud. *Proceedings of the International Conference on Utility and Cloud Computing (UCC 2011)*, IEEE Computer Society, Washington, DC, USA; 334–335.
19. Fan L, Lo O, Buchanan W, Ekonomou E, Sharif T, Sheridan C. SPoC: protecting patient privacy for e-Health services in the cloud. Available from: http://www.flexiant.com/wp-content/uploads/2012/09/E-Health-FP7.pdf.
20. Microsoft Azure Cloud Services. Available from: http://www.windows.azure.com.
21. Apache JMeter. Available from: http://jmeter.apache.org/ accessed 15, June. 2013.
22. Smooth streaming performance testing tool. Available from: http://ssperf.codeplex.com.

DOI: 10.1002/cpe