Application of Mobile Cloud Computing in Care Pathways

Mohd Soperi Mohd Zahid
Faculty of Computing
Universiti Teknologi Malaysia
81310 Johor Bahru, Johor, Malaysia
Email: soperi@utm.my

Abdul Hanan Abdullah
Faculty of Computing
Universiti Teknologi Malaysia
81310 Johor Bahru, Johor, Malaysia
Email: hanan@utm.my

Eko Supriyanto
IJN-UTM Cardiovascular Engineering Center
Universiti Teknologi Malaysia
81310 Johor Bahru, Johor, Malaysia
Email: eko@utm.my

***Abstract*—The advances in cloud computing has resulted in the introduction of several health-care services in the cloud. However, not much work has been done which utilizes Cloud computing for providing pervasive healthcare information management services on mobile devices. This paper focus on the application of Mobile Cloud Computing in Care pathways, a set of tools for managing quality of care provided to patients by medical institutions. Care pathways started in 1980s with paper-based or form-based version. Nowadays, hospitals may use the electronic version which offer greater flexibility and integration with other parts of hospital systems, and helps in reducing medical errors. Mobile cloud computing has a great potential in facilitating Care pathways in this direction. Mobility can be utilized to improve communications between the various levels of Care pathways users, as well as convenient and secured access to medical records and data. In addition, cloud computing allows the offloading of complex resource scheduling or medical processing tasks to be performed remotely reducing computing energy and equipment cost incurred by medical institutions. In this paper, we propose the techniques to develop the Care pathways software based on Mobile cloud computing technologies, the required hardware infrastructure and software components, and propose a design architecture. The objective is to foster and provide systematic guidance on development of advanced Care pathways software.**

I. Introduction

Clinical pathways, or care pathways, are tools that are used to manage the quality of health care where processes are standardized. The objectives are to reduce variations in practice, improve interdisciplinary cooperation, integrate care, and ultimately, improve clinical outcomes [1]. Two main forms of clinical pathways exist which are hard copy and electronic versions. The hard copy version lacks integration with other clinical modules and flexibility. Latest developments on improving efficiency of the electronic versions involve modeling the care pathways into a computer aided workflow management system [9, 10, 11]. In this chapter, the focus is on adopting mobile cloud computing to further upgrade the efficiency of electronic care pathways.

It is important to reduce medical errors and cost the patients have to pay for health-care services. Medical errors could result in unnecessary suffering, use of resources, and even deaths. According to statistics [12], the number of deaths due to preventable medical errors is estimated to be at least 440,000 each year. The cost of health-care has also been increasing each year [13, 14]. Several studies have demonstrated that there are two proximal causes of medical errors in healthcare: 1) limited access to patient-related information during decision-making and 2) the ineffective communication among patient care team members [2, 3]. The cost of health-care services can be reduced by ensuring efficient use of resources and standardizing health-care processes. Mobile cloud computing is a promising technology that can provide good solutions to those issues. The use of mobile devices support convenient access to patient-related information and effective communications between medical team members. The clouds provide platform, infrastructure, and software at low cost and elastically in on-demand fashion. Resource-intensive computing such as scheduling of operation theatre rooms, and processing and interpretation of medical images, scanned data, lab results, and genomics can be performed remotely in the cloud reducing energy of mobile device significantly and the need to have expensive high performance computing facilities in the medical institution.

Recent advances in Cloud computing have inspired many healthcare services in the cloud such as Cloud ECG [4, 5], and secure Electronic Medical Record Exchange [6]. The concept of utilizing Cloud computing for health-care industry is relatively new but is considered to have great potential [15]. Besides the exploded number of people using mobile devices such as smartphones, there is not much work in the literature which utilizes Cloud computing for providing pervasive health-care information management services on mobile devices. Our contribution in this direction is on proposing the Care pathways software based on Mobile cloud computing.

This paper is organized as follows. First, we give an introduction to Care pathways and its essential features. Specifications are produced and inputs, outputs and objects involved are defined. Then we describe the techniques to develop the Care pathways software based on Mobile cloud computing technologies, the required hardware infrastructure and software components, and propose a design architecture. Finally we conclude the chapter with a summary and future works.

II. Care pathways Basics

A Care pathway is a plan of journeys that patients need to take through medical units in health systems for the treatment of one or more disease(s). The plan is based on a standardized healthcare processes that is established by the medical institution. Throughout the journey, patients pass through a sequence of care activities such as surgery, transfer (e.g. from operation

2014 IEEE Canada International Humanitarian Technology Conference - (IHTC)
978-1-4799-3996-1/14/$31.00 ©2014 IEEE

TABLE I. MAIN INPUTS, OUTPUTS AND OBJECTS OF CARE PATHWAYS

Inputs	Outputs	Objects
Repository of Care pathways based on disease	Reports and Screen Displays for:	Patient
Repository of Medical knowledge	– Quality of Care – Cost Analysis	Resources
Models of Medical Institution Workflow	– Variance Analysis – Treatment Timeline	Care Activity
Patients Health Records	– Alerts	Actual Care pathway

theatre to ward), and radiography. Each care activities takes a period of time to complete and require one or more resources such as a physician, a medical team, nurses, porter, operation theatre, or even skills like competency of physicians or lab technicians. The transfer of patients from one care activity to another depends on a set of conditions such as results of patients blood test, and scanned images. Eventually, a patient may exit the Care pathways with being discharged or death.

From actual completion time and type of resources used by each care activity, a cost associated with it can be computed and estimated. Hence, several performance or quality of care indicators can be deduced from Care pathways such as length of stay (LOS) of patients, variations (e.g. the differences between standard and actual completion time or cost of a care activity), number of mortalities and readmissions. Variance analysis may lead to the amendment of care pathways or only the care activity. In Table 1, we propose the main inputs, outputs, and objects of electronic Care pathways.

III. MOBILE CLOUD COMPUTING BASICS

Mobile Cloud Computing (MCC) refers to a new computing paradigm for mobile applications whereby the storage and the data processing are migrated from mobile devices to resources rich and powerful centralized computing data centers in computational clouds [16, 17.]. MCC is being introduced to overcome some obstacles in mobile computing due to constraints of mobile devices such as battery lifetime, processing power, and memory capacity. MCC basically augments energy, storage, processing power, reliablity, and security of mobile devices by:

- Utilizing cloud storage services
- Outsourcing computational intensive components of mobile applications to cloud data centers

IV. UTILIZING CLOUD STORAGE SERVICES

Examples of cloud storage services are Amazon S3 (Simple Storage Services) and DropBox. The challenging issue in this augmentation is to ensure consistency of data on the cloud server nodes and mobile devices.

V. OUTSOURCING COMPUTATIONAL INTENSIVE COMPONENTS OF MOBILE APPLICATIONS

This type of augmentation is based on mobile application offloading frameworks which have been proposed by researchers in the recent years. The frameworks can be divided into three (3) categories: 1) general-purpose mobile cloud computing (GPMCC), 2) application-specific mobile cloud computing (ASMCC) and 3) mobile server cloud computing (MSCC). In Table 2, we provide methods and systems offered under each category to facilitate the development of MCC solutions.

TABLE II. METHODS AND SYSTEMS FOR MCC SOLUTIONS

GPMCC	ASMCC	MSCC
Augmented Execution	Mobile Service Clouds	MapReduce Frameworks
	RESTful Services	
	Elastic Weblets	

A. Augmented Execution

In this approach, virtual clones of mobile device execution are created in the cloud. The execution environment is migrated to the cloud utilizing more powerful computing resources. Users experience the same interface but better system performance (eg. less battery energy consumption and quicker response time). When migrated execution ends, results and states of execution are passed and merged into original process. The CloneCloud [18] is an example that uses this approach. In CloneCloud, the clones are application-level virtual machines such as Java VM, DalvikVM from the Android Platform, and Microsoft's .NET. CloneCloud uses a partitioning mechanism which identifies parts of application execution and state that should be cloned and migrated into the cloud. The identification is done automatically based on execution conditions such as network characteristics, CPU speeds, and energy consumption. While the clones are running, functionality on the mobile device keeps executing but blocked when attempts to access migrated state are made.

B. Mobile service clouds

Mobile service clouds [19] is an extension of service clouds which utilizes context information (e.g. data types, network status, device environments, and user performance) to improve quality of service (QoS). Typically, a mobile service cloud comprises of nodes on single intranet like university campus. A request for a service on the cloud from mobile users will initially goes to a service gateway in the deep service cloud. The gateway then choose an appropriate primary proxy service based on application requirements and current conditions and inform the user about it. The middleware of user's mobile device then make service request to the primary proxy and receive the results. The primary proxy monitors the service path. If failure (eg. high computational load or high RTT due to changes in access point used by client, etc) is detected, the service path is reconfigured.

C. RESTful Services

This approach does not maintain execution state of mobile device application in the cloud. The cloud provides a set of well-defined services. Services are pieces of software available in the cloud which performs resource-intensive computing task. When a mobile device needs a service, it invokes the appropriate function or software residing in the cloud, passing to it input parameters. As an example, the Amazon's Elastic Cloud Compute (EC2) provides image processing service. Following are the sequence of steps involved in using the service:

- Upload a resource such as an image to an S3 location
- Invoke the processing on an EC2 exposed service passing the resource location as a parameter
- Continue processing on-device tasks until the remote processing task is complete and a notification is pushed back to the device
- Transfer the processed output from S3 to local application storage

RESTful web-services [20] is an example of this approach. Web-services may be based on REST or SOAP. However it is simpler to publish and consume service with REST and hence suitable for mobile applications. Service request can be made using http protocol with URL to specify the resource. The remote server may send the response in encoded binary data or XML and parsed by application in mobile client.

D. Elastic Weblets

Applications are partitioned into weblets and integrated dynamically between mobile device and remote cloud server. Weblets are autonomous components of an application which can run on mobile device or on cloud. An elastic application consists of one or more weblets running independently but communicating with each other. Same programming methods used for web applications such as Javascript, AJAX and REST can also be used in weblets due to similarities between client/server partitioning in web applications and more general partitioning of elastic applications. Following are high-level logic in the execution of elastic mobile applications:

if the mobile device running elastic application is in critical condition (eg. insufficient computing resources) **then**
  determine execution point for application partitions
  negotiate with cloud servers to select appropriate server nodes
  migrate partitions of application to remote server node for remote processing
  return results to original application on mobile device
else
  continue execution in mobile device
end if

E. MapReduce Frameworks

The concept of MapReduce [21] is applied in this framework. The cloud is composed of centralized server and worker nodes (smart mobile devices). A large computation is split into a number of smaller tasks which are independent of each other. They can be assigned on different worker nodes to process different pieces of the input data in parallel. MapReduce defines two functional language primitives: map and reduce. The map function is applied in parallel to pieces of input data and produces intermediary <key, values> pairs. The pairs are then partitioned by key and each partition is passed into a reduce function which produce further results. The main idea of this framework is that mobile devices cooperate each other in increasing their computational power.

VI. MCC Care pathways

To apply MCC in Care pathways, we first present a simple workflow of Care pathways and then identify some computational tasks that can be initiated from smart mobile devices. Next, we describe possible ways of how each of the computational tasks can be performed with mobile cloud computing.

TABLE III. Implementation of Care pathways Computational Tasks

Computational Task	Processing Hardware	Suitable MCC Framework
Generation of patient Care pathways	Cloud Server	A / B / C
Display of Care pathways as table with time line	Mobile device	–
Resource Scheduling of Care Activity	Cloud Server	A / B / C
Interpretation of information	Cloud Server	D
Display of alert messages	Mobile device	–
Display of authorization forms	Mobile device	–
Analysis of Care pathways data	Cloud Server	A / B / C

A. Workflow

When patients arrive at the emergency department or outpatient clinic of a hospital, a diagnose to patient's complaints of health problem are made by the physician with other medical staff. If the patient has to be admitted to the hospital then a Care pathway is generated and assigned for the patient. The generation of patient's Care pathway takes various input data as listed in Table I. Because of their big size, the input data does not reside in the mobile device but rather in the storage devices of more powerful computers. The patient's Care pathway is presented in the user interface as a table with time line from day one till the day when the patient exits. During the time line, some care activities are scheduled and performed on the patient at specified day and time. The scheduling of care activities using resources optimumly is a computational intensive task and should not be done entirely on the mobile devcie. Before a care activity is performed some information may need to be passed between medical units. For example, before an operation is to be performed, physicians passed pertinent information to the anesthetist. A physician needs to interpret the image of x-rays, results of blood tests, etc and green light from the patient or relative before deciding on scheduling a care activity. These communication, interpretation and authorization activities should be performed effectively with minimum or no errors. Upon completion of each care activity, variance analysis on Care pathway data should be performed for continuous improvement of process quality as well as quality of care. Based on the difference between the standard and actual data, an alert will be or will not be made to the respective medical units or personnel. The analysis of care pathway data and interpretation may be implemented using soft computing and artificial intelligence algorithms. Thus, the execution of the algorithm should not be performed entirely on mobile device.

B. Proposed ways of Implementing Care pathways Computational Tasks

Based on the above description about Care pathways workflow, we extract the main computational tasks that are involved. In Table III, we list them down and propose possible ways of implementing them with MCC.

The letters A, B, C, and D in Table III refers to the MCC Framework specified as subsection titles of previous section. Generation of patient Care pathways, Resource Scheduling of Care Activity, and Analysis of Care pathways data should not be implemented with D and E. It may be possible but further study need to be made to ensure the correctness of the output will be maintained. Interpretation of information should be implemented with D as there are example of such implementation like image recognition in the literature. Computational tasks that can be done entirely on mobile device are recommended to reduce the occurrence of medical errors due to ineffective communication among medical units.

C. MCC Care pathways Design Architecture

In Fig. 1, we propose a software design architecture for MCC Care pathways. Users interact with Care pathways through the top layer modules. The middle layer modules interact with suitable MCC Framework and top layer modules.

D. Evaluations

To show improvements that could gained from MCC Care pathways developed based on the design architecture, we plan to create simulation model representing the associated revised workflow. The simulation experiments will be based on the Care pathways of Myocardial Infarction disease used in the National Heart Institue Malaysia (IJN). Among the metrics that could be studied are costs, communication effectiveness, security, privacy, and types of medical errors that could be eliminated or reduced.

Cost could be associated with savings in electricity and equipment when resources in clouds are used. Communication effectiveness for instance will show how faster certain information is being transfered to destination and how quicker the interpretation of an information (eg. ECG graphs, notes to anesthetist) can be made. New procedures and tightness of security and privacy issues will be analyzed. Common medical errors made in existing system will be identified and the potential they will occur in MCC environment will be assessed.

VII. Conclusion and Future Work

Mobile Cloud Computing has great potential in improving the efficiency of healthcare systems. We have considered the application of MCC in a component of healthcare system called Care pathways. A mapped between Care pathways computational tasks and MCC Frameworks are made and a software design architecture based on MCC is proposed. In the future, we plan to implement each of the computational tasks with suitable MCC frameworks and compare their performance. We also would like to study the performance of MCC Care pathways relative to non-MCC electronic Care pathways.

Acknowledgment

The authors would like to thank the IJN-UTM Cardiovascular Engineering Center which allocate a research grant (Vot no. 01G85) for this project and collaborations from medical specialists and staff in National Heart Institute (IJN) of Malaysia.

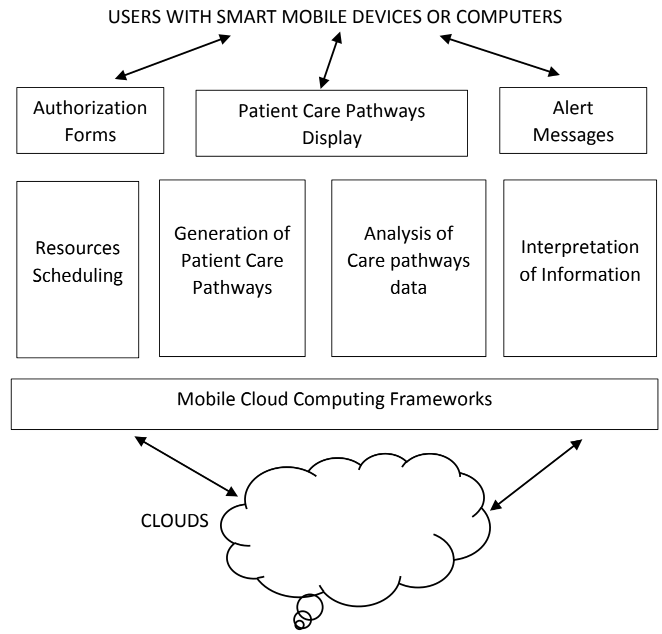

Fig. 1. Software Design Architecture of MCC Care pathways

References

[1] Kitchiner D, Davidson C, Bundred P. Integrated care pathways: effective tools for continuous evaluation of clinical practice. J EvalClinPract, 1996; 2(1):6569

[2] L. L. Leape, Error in medicine, J. Am. Med. Assoc. vol 272, 1994, pp. 1851 1857.

[3] J. T. Reason, Human Error, Cambridge University Press, Cambridge, 1990.

[4] Henian Xia, Irfan Asif, Xiaopeng Zho, Cloud-ECG for real time ECG monitoring and analysis, Computer Methods and Programs in Biomedicine, Vol 110, Issue 3, pp. 253 259, Elsevier, June 2013.

[5] S.Pandey, W. Voorsluys, S. Niu, A. Khandoker, R..Buyya, An autonomic cloud environment for hosting ECG data analysis services, Elsevier Future Generation Computer Systems, vol. 28, pp.147-154, 2012.

[6] A. S. Radwan, A. A. Abdel-Hamid, Y. Hanafy, Cloud-based service for secure Electronic Medical Record exchange, 22nd IEEE International Conference on Computer Theory and Applications (ICCTA), Alexandria, October 2012.

[7] X. Wang et al., AMES-Cloud: A Framework of Adaptive Mobile Video Streaming and Efficient Social Video Sharing in the Clouds, IEEE Trans. Multimedia, February 2013

[8] Jiafu Wan et al., Cloud-Enabled Wireless Body Area Networks for Pervasive Healthcare, IEEE Network, September/October 2013

[9] Al Salamah H, A Gray and D Morrey. Mapping the integrated care pathways into bpm for health case management. S-BPM ONE-Education and Industrial Developments: 4th International Conference. Vienna, 2012.

[10] Yao W. and A. Kumar. Integrating clinical pathways into CDSS using context and rules: a case study in heart disease. Proceedings of the 2nd ACM SIGHIT International Health Informatics Symposium. 2012.

[11] Ye Y et al., An ontology-based hierarchical semantic modeling approach to clinical pathway workflows. Computers in biology and medicine 39, no. 8 (2009): pp. 722 732.

[12] James J., A New, Evidence-based Estimate of Patient Harms Associated with Hospital Care. Journal of Patient Safety, 2013, pp. 122 128.

[13] Health Care Cost Institute. 2012 Health Care Cost and Utilization Report. September 2013. http://www.healthcostinstitute.org/2012report

[14] TIME Magazine. The High Cost of Care. 04 March 2013. http://www.time.com/time/magazine/article

[15] Ofer Shimrat, Cloud Computing and Healthcare, April 2009, San Diego Physician, pp. 26 29.

[16] Muhammad Shiraz et al., A Review on Distributed Application Processing Frameworks in Smart Mobile Devices for Mobile Cloud Computing. IEEE Communications Surveys and Tutorials, Vol 15, No. 3, Third Quarter 2013.

[17] S.Abolfazli, Z.Sanaei, A.Gani, R.Buyya, Cloud-Based Augmentation for Mobile Devices:Motivation, Taxonomies, and Open Challenges , IEEE Communications Surveys and Tutorials, Vol.16, No.1, pp. 337-368, First Quarter 2014

[18] B. Chun and P. Maniatis, "Augmented smartphone applications through clone cloud execution," in Proc. 8th Workshop on Hot Topics in Operating Systems (HotOS), Monte Verita, Switzerland, 2009.

[19] Samimi et al., "Mobile Service Clouds: A Self-Managing Infrastructure for Autonomic Mobile Computing Services," Self-Managed Networks, Systems, and Services , 2006.

[20] Christensen, Using RESTful web-services and cloud computing to create next generation mobile applications, Conference on Object Oriented Programming Systems Languages and Applications, March 2010.

[21] Elespuru et al., MapReduce System over Heterogeneous Mobile Devices, Software Technologies for Embedded and Ubiquitous Systems, 2009