Personalized Healthcare System for Chronic Disease Care in Cloud Environment

Sangjin Jeong, Yong-Woon Kim, and Chan-Hyun Youn

The rapid increase in the number of patients with chronic diseases is an important public healthcare issue in many countries, which accelerates many studies on a healthcare system that can, whenever and wherever, extract and process patient data. A patient with a chronic disease conducts self-management in an out-of-hospital environment, particularly in an at-home environment, so it is important to provide integrated and personalized healthcare services for effective care. To help provide effective care for chronic disease patients, we propose a service flow and a new cloud-based personalized healthcare system architecture supporting both at-home and at-hospital environments. The system considers the different characteristics of at-hospital and at-home environments, and it provides various chronic disease care services. A prototype implementation and a predicted cost model are provided to show the effectiveness of the system. The proposed personalized healthcare system can support cost-effective disease care in an at-hospital environment and personalized self-management of chronic disease in an at-home environment.

Keywords: Cloud, healthcare, chronic disease, metabolic syndrome, decision support system.

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I. Introduction

There exists a large amount of literature related to personalized healthcare systems that aim to deliver effective care to patients with chronic diseases [1]. Recently, the development of an integrated and personalized healthcare system is becoming an important issue in the healthcare industry due to the rapid increase in the prevalence of various chronic diseases. There are several studies that have investigated how to provide integrated healthcare services in home and hospital environments. Since the requirements of home and hospital environments are significantly different, the characteristics of these different requirements need to be considered when building separate healthcare systems and attempting to integrate them seamlessly [2]. Moreover, as the concept of cloud computing has evolved, many studies have reported the potential benefits of cloud computing and have proposed various models or frameworks in an attempt to improve healthcare services [3]–[4]. These studies have focused on developing a model for ubiquitous healthcare services based on cloud computing, which utilizes a large data archive of clinical data records, decision support systems, and the event-based notification and monitoring system of a typical hospital.

Conventional healthcare systems are known to have the following problems [2]:

- Disconnected environments for patient disease management.
- Computational overhead from large volumes of health information data.
- Lack of support for user-centric customizable healthcare systems.

Figure 1 summarizes the major challenges of effective chronic disease care. The key objective is to identify patients having a high risk of chronic disease in advance so that

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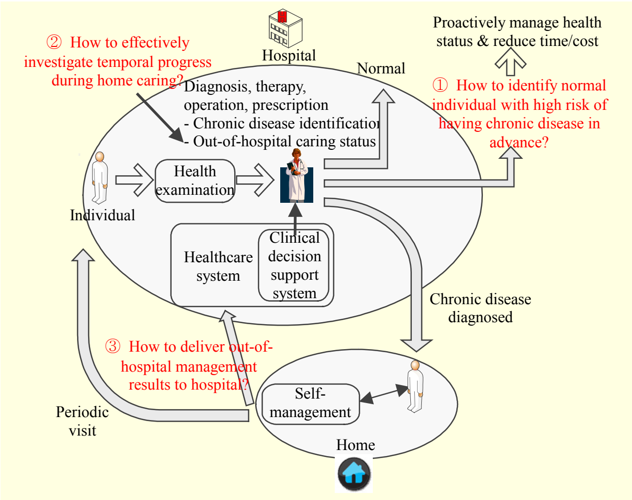

Fig. 1. Major challenges in chronic disease diagnosis and care flow.

physicians are able to proactively manage the health status of such patients; thus, hopefully, reducing both the time and the medical expenditures involved in such cases. It should be noted that, among the many types of chronic diseases, this paper focuses on metabolic syndrome (MS) because of its predictability and relationship with the prevalence of cardiovascular disease (CVD) and diabetes. When an individual visits a hospital for a health examination, a physician typically performs disease diagnosis, operations, therapy, and prescription. Among the many roles of physicians, this research focuses on disease diagnosis, particularly chronic disease diagnosis, because other roles require further knowledge, and, in addition, the performing of medical operations by a non-physician is restricted. During the diagnosis process, the physician identifies an individual's chronic disease based on health examination results and the healthcare system of the hospital. If a chronic disease sufferer visits a hospital after having already received out-of-hospital care, then a physician checks this person's out-of-hospital care status and then tries to determine any changes in health to this person that may have taken place. After the diagnoses procedures, the individual will be diagnosed as being either a normal or a chronic disease patient. However, in the current chronic disease diagnosis method, particularly for MS, it is difficult to determine if a person has only potential risk of having MS. Thus, it is necessary to develop a method for identifying normal persons with high risk of having a chronic disease in advance. When a person is diagnosed as having a chronic disease, the person returns to home and performs self-management in their home environment. After the self-management period, the person visits their hospital, whereby any temporal changes in their disease status can then be checked. It is therefore necessary to develop a method for delivering self-management results to the hospital healthcare system and to help physicians investigate any temporal progress made during home care. To achieve these objectives, we develop a personalized healthcare architecture for home–hospital integrated environments to support MS care.

Many studies have been conducted to help develop healthcare system architectures that integrate home and hospital environments and to reduce the computational overhead of healthcare system architectures by developing broker systems for healthcare service delivery [2]–[7]. However, there have been Jeong and others proposed an integrated healthcare system architecture based on a service-oriented architecture [2]. However, this system does not support a patient-centered configuration, customization, or dynamic functionality update of a home healthcare system, which are necessary for realizing complete personalized healthcare service delivery and satisfying the requirements of a personalized healthcare system [8]. To support customizability and dynamic functionality updates in a personalized healthcare system, we propose a cloud-based personalized healthcare system for chronic disease care. The proposed system is for providing advanced MS care services by combining MS diagnosis services and temporal progress care services. There have been several studies on developing personalized disease diagnosis methods to identify and quantify the health status of patients, particularly in relation to chronic diseases. Jeong and others developed a risk quantification model for MS, which is based on areal similarity degree (ASD) analysis between weighted radar charts comprising MS diagnostic criteria and the examination results of the risk factors [9]–[10]. The MS risk quantification and prediction model is integrated into our proposed personalized healthcare system to predict the risk of developing MS in the future. It also provides a service broker functionality that manages workflows and resources in a cloud environment. The broker also supports the selection of candidate resources for the building and configuration of a personalized home healthcare cloud environment. Using the proposed system, we can provide a patient-centric personalized healthcare service that facilitates cost-effective and personalized chronic disease care.

In the following section, a description of the proposed functional architecture of the personalized healthcare system featuring the service broker–based home-hospital cloud integration is presented. The prototype implementation of an at-home healthcare system and mobile device–based chronic disease status visualization application are described, along with a predicted cost analysis of the proposed system architecture.

II. Functional Architecture for Personalized Chronic Disease Care System in Home–Hospital Cloud

1. Service Scenario for Personalized Chronic Disease Care in Home–Hospital Cloud Environment

The service scenario for personalized chronic disease care in a cloud environment is depicted in Fig. 2. When a patient comes to a hospital, the patient receives several medical examinations to check the patient's disease status and to be provided appropriate treatment. The patient's profile and health information are stored in a personalized virtual machine (VM) in the hospital cloud, and the personalized VM is synchronized with the home healthcare system. When the patient returns to home and monitors their health status using portable sensors, the measured health data is transferred to both a mobile device and to home healthcare system. The patient-specific chronic disease care services are uploaded to the home healthcare system by the healthcare system administrator at the hospital, and the system interacts with the physician and an informant at a remote site. The patient's mobile device shares the measured data with other mobile devices and with the home healthcare system in the home environment. The informant monitors the patient's health data and periodically stores the data in the medical database at the hospital. If an anomaly is detected in the patient's health data, then the informant reports the anomaly to the physician. The physician then examines the patient's health data and makes a diagnosis. If necessary, the patient goes to the hospital for a detailed examination. In the hospital cloud, the service broker system allocates resources in the hospital cloud to the patient's home cloud VM. The broker system divides the workflow of the chronic disease care service into tasks and selects cloud resources to execute the partitioned tasks. During the resource selection process, the service-level agreements (SLAs) of the patients are considered. In addition, the selected cloud resources are used to build VMs for the home healthcare environment.

2. Framework for Personalized Chronic Disease Care System

The functional architecture of the personalized chronic disease care system based on a home–hospital cloud environment is shown in Fig. 3. The system developed in this paper consists of six major components: a VM for personalized home healthcare, the home healthcare system, a home cloud network, the hospital healthcare system, chronic disease care services, and a service broker system. The preliminary version of the personalized healthcare system architecture is described in [8].

A. VM as a Hospital Cloud Environment for Personalized Home Healthcare

This component performs the main operation of the system.

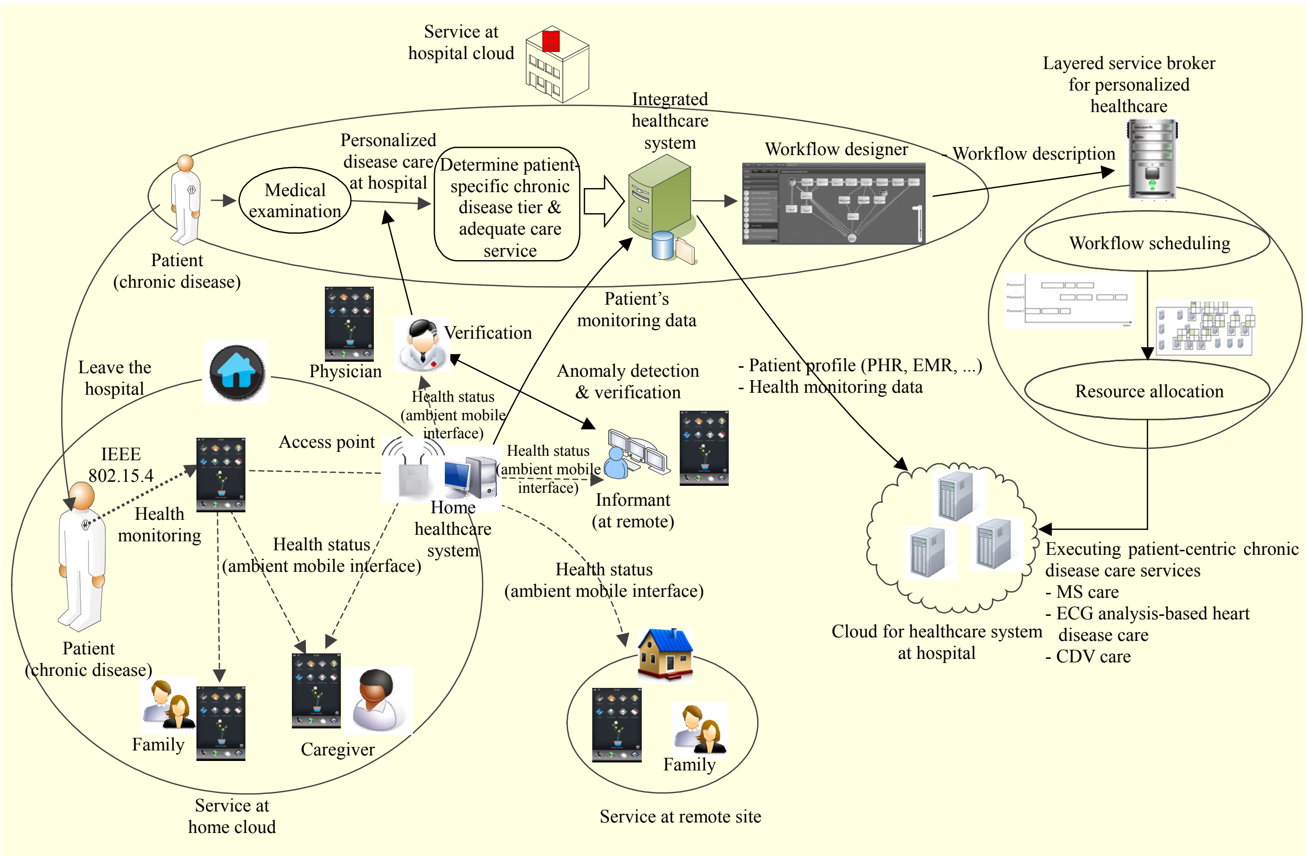

Fig. 2. Service scenario for personalized chronic disease management in home–hospital clouds.

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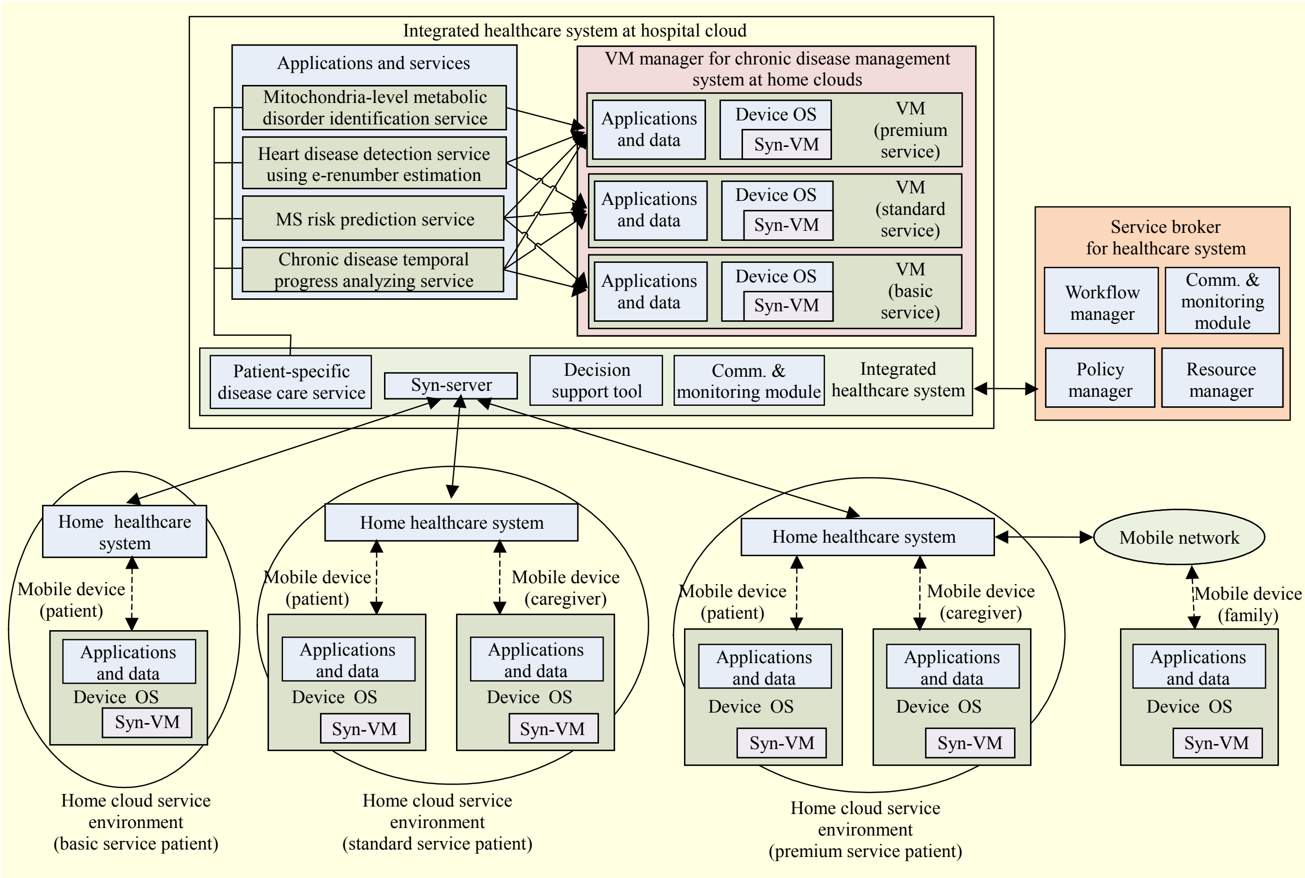

Fig. 3. Architecture of personalized healthcare system for chronic disease in home–hospital cloud environment.

It creates a VM in the hospital cloud environment and customizes the VM according to the patient's profiles; that is according to the type of chronic disease and medical examination results. This component receives information on the patient, including the patient's profile and chronic disease status. This information is embedded in the disease care services and uploaded onto the VM based on the patient's service levels and disease status. The component configures the service parameters according to the patient's health status. The disease care services are installed on the VM by downloading services from an application or service repository. After installing the appropriate chronic disease care services, information on the patient's mobile device for use with the home healthcare service and the synchronization method for the health monitoring data is configured. The creation and configuration of the VM is conducted through the integrated healthcare system at the hospital cloud.

B. Home Healthcare System

The home healthcare system is configured by migrating the VM created in the hospital cloud environment to the patient's home cloud. The home healthcare system communicates with the VM at the hospital through the Sync-Server in the integrated healthcare system at the hospital. When a reconfiguration of the patient's home healthcare system is necessary (for example, a change in the patient's service level or an update of the disease care services), the VM at the hospital will be reconfigured, and the updated VM will be migrated to the patient's home healthcare system. It is therefore possible to provide personalized healthcare services to patients.

When the home healthcare system receives health monitoring data from the patient's mobile device, it analyzes the data using the disease care services installed during the configuration of the home healthcare system by the hospital. The home healthcare system then delivers the analysis results to the patient, the caregiver, and the mobile devices of the patient's family members. For a premium service–level patient, the home healthcare system can deliver the analysis results to the mobile devices at a remote site. At the same time, the home healthcare system transfers the measured data to the VM created in the hospital's cloud environment and can synchronize the patient's disease status and monitoring data. The home healthcare system communicates with the VM at the hospital through the Internet, and the data communication utilizes international standards, such as the Health Level 7 Reference Information Model (HL7 RIM) [11], the Clinical

Document Architecture v2 [12], and the Extensible Markup Language, to improve the interoperability of the system and to ensure integration with existing healthcare information systems.

C. Home Cloud Service Environment

At the patient's home cloud service environment, the patient's mobile device gathers health monitoring data from the portable sensors. Sensor data can be collected through an IEEE 802.15.4 wireless connection [13], which was selected owing to its wide deployment in biomedical devices. The mobile device processes the received data to identify any mispositioning of the sensors and then forwards the data to the home healthcare system through a Wi-Fi connection when the patient is within the home network, or through the Internet when the patient is outside of the home network, to be further analyzed using the chronic disease services. The availability of multiple communication paths ensures the adaptability of the system in a multitude of operating areas and improves its fault tolerance.

D. Decision Support Tool and Visualization Module

The decision support tool which is based on the patient status classification method (PSCM) and the MS risk quantification method can identify and classify the patients' disease statuses [2], [9]. In this paper, we extend the PSCM functionality to provide a temporal progress analysis of the chronic disease, particularly MS. An additional PSCM-Ambient (PSCM-A) module is added to the PSCM to support chronic disease status visualization functionality on mobile devices using a Java-based application interface. Through the application on a mobile device, we can use data in conjunction with the medical diagnosis system as a proactive medical service. The prototype implementation of the disease status visualization interface is presented in Section III.

E. Chronic Disease Care Service: MS Risk Prediction Service

Figure 4 shows the operational procedure of the MS risk prediction service in the proposed system. The risk prediction service is provided as one of the chronic disease care services in our proposed cloud-based personalized healthcare system [8]–[9].

F. Chronic Disease Care Service: Temporal Progress Identification Service

Figure 5 shows the operational procedure of the temporal progress care service for MS, which is based on the chronological distance analysis method proposed in this paper. A subject's medical examination results and profile information are used to calculate the ASD between the examination results

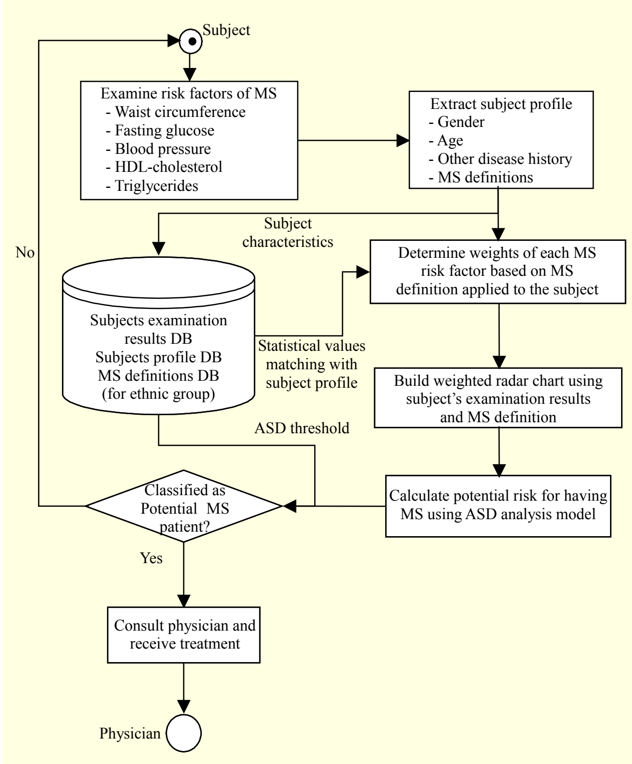

Fig. 4. Operational procedure of MS risk prediction service [8].

and the thresholds of the MS risk factors. The distance function, based on chronological clustering, is then calculated. If the distance result exceeds the designated thresholds for the patient tier classification, then the medical examination results and the subject's profile information are delivered to the physician for further investigation [9]–[10].

To provide patient-centric personalized chronic disease care services, it is necessary to support different service levels in accordance with a patient's disease status. Thus, different types of services are provided to patients based on the patient tier, as shown in Table 1.

G. Service Broker Architecture for Personalized Healthcare System

The service broker is responsible for allocating cloud resources to the patient's home cloud VM. Since our proposed system supports different service levels among patients, the service broker discovers resources and allocates appropriate resources to tasks that are divided into workflows. The service broker architecture is based on an active workflow control scheme, which includes a policy manager, workflow manager, and resource manager so as to guarantee the SLAs of chronic disease patients. Figure 6 shows the functional architecture of the service broker.

A more detailed description for the key components is as follows:

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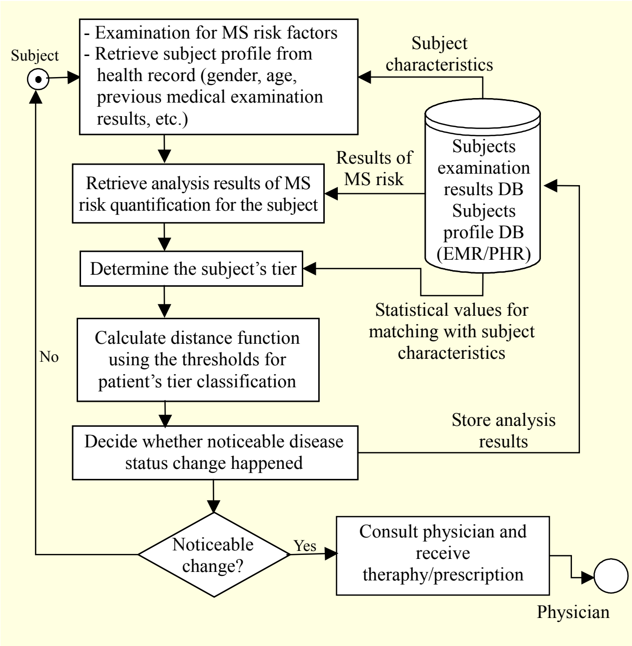

Fig. 5. Operational procedure of temporal progress care service for MS [10].

▪ The workflow manager is responsible for handling workflow applications, which includes the parsing of such workflows into tasks and any resulting dependencies that may occur between tasks. Each task in a workflow is assigned to a specific resource, in accordance with the allocation policy provided by the policy decision tool, by the policy manager.

▪ The *resource manager* monitors the status of resources in the cloud, generates the list of available resources using resource monitoring information, and dispatches the tasks to the selected resources in the cloud environment. The manager is responsible for selecting and managing candidate resources to execute and allocate user tasks to selected resources that can guarantee the users' SLAs. Since the tasks of a workflow may be distributed to various resources in the cloud, a task monitoring function is built within the resource manager to monitor the status of tasks and resources, as well as to handle the workflow execution. Owing to the dynamic and heterogeneous characteristics of the cloud, an error recovery mechanism is also provided in the resource manager. Once a failure occurs, our broker system remaps the failed task to another resource that is selected on the basis of the workflow's SLA.

▪ The *policy manager* determines the workflow and resource allocation. Policy conditions are compared with the users' SLAs, and adequate actions are then enforced by the workflow manager and resource manager in the service broker. The policy decision tool determines the workflow and resource allocation policy of the parsed SLA and the adequate policies

Table 1. Three service levels for chronic disease patients.

Phase	Service level		
	Basic TIER(1) &TIER(2)	Standard TIER(3)	Premium TIER(4)
(Basic) Diagnosis service	-Patient profile (S1) -Disease profile (S2) -MS risk prediction (S3)	-Patient profile (S1) -Disease profile (S2) -MS risk prediction (S3) -MS temporal progress identification (S4) -Physician comments (S5)	-Patient profile (S1) -Disease profile (S2) -MS risk prediction (S3) -MS temporal progress identification (S4) -ECG profile (S6) -Advanced ECG analysis (S7) -Metabolic disorder identification (S8) -Physician comments (S5)
Advanced diagnosis service			-Heart disease analysis (S9) -Collaborator's comments (S10)
Result report	-Web portal (S11) -E-mail (S12)	-Web portal (S11) -E-mail (S12)	-Web portal (S11) -E-mail (S12) -Cell-phone (S13)
Experiences	-Physician with less than 5 years of experience	-Physician with less than 10 years of experience	-Physician with more than 10 years of experience
Duration	6 months	6 months	6 months
Monitoring interval	Monthly	Weekly	Daily
Quality	-Within 1 week -Low reliability -Low security	-Within 1 day -Medium reliability -Medium security	-Within 1 hour -High reliability -High security
Cost	1 unit cost	30 unit cost	200 unit cost

stored in the policy repository. The selected policy is then enforced by the resource manager and workflow manager. The policy decision tool is the actual point at which the selected policy is enforced. The policy enforcement is able to change the resource scheduling schemes according to the policy selected by the policy decision tool.

SLAs for chronic disease care services are delivered to the broker through the integrated healthcare system interfaces. Then, the requests from the chronic disease care services are submitted to the workflow management engine, where they are then parsed into tasks or dependencies. For each application submitted, the workflow manager analyzes the input application and workflow. The manager then divides the

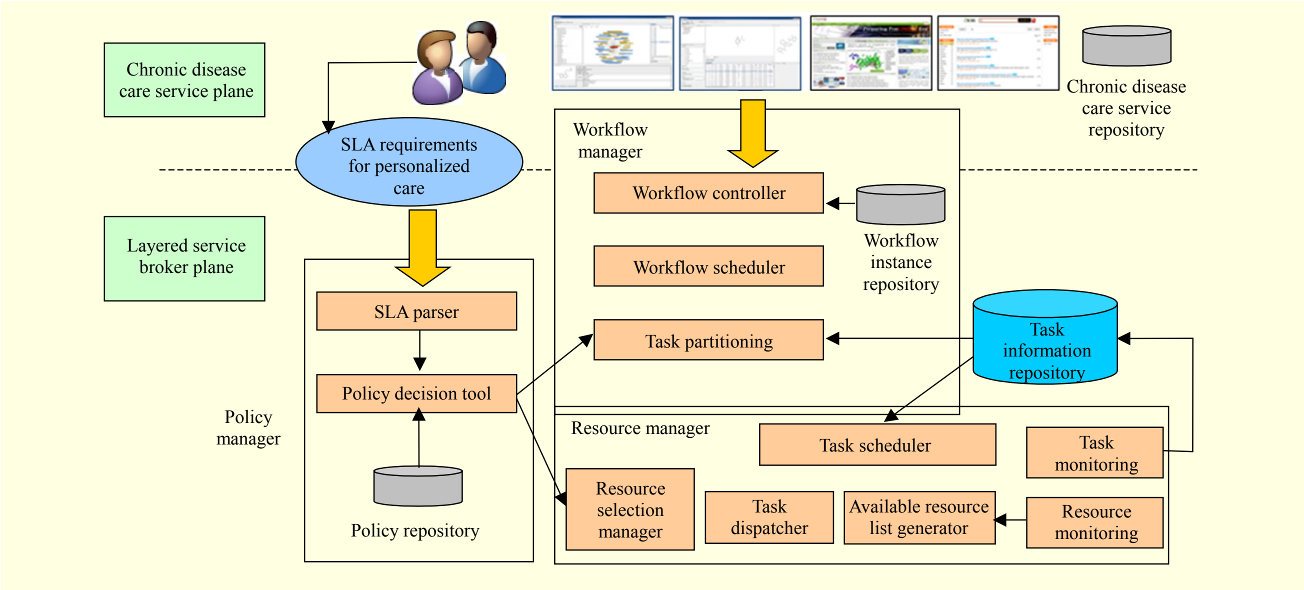

Fig. 6. Architecture of layered service broker system for personalized healthcare system in cloud.

application into tasks corresponding to a workflow. The workflow scheduler maps the tasks into the workflow using policy decisions to achieve an optimized mapping based on the SLA requirements.

After receiving the mapping information from the workflow manager, the resource manager schedules tasks and discovers available resources that can guarantee the quality of service. The resource selection manager chooses resources for executing scheduled tasks and allocates tasks to the selected resources. At the same time, the resource manager creates task and resource managers to manage and monitor the status of the tasks and resources. The resource manager is responsible for monitoring the resource status, generating a list of available resources, and dispatching the tasks into the resources in the hospital cloud environment.

3. Discussion

This section discusses several important issues regarding the proposed personalized healthcare system architecture.

A. Security and Privacy

Since the proposed healthcare system architecture considers a cloud environment, security and privacy issues regarding the patients' health data arise. From a patient's point of view, several health records about the patient may exist in several hospitals. Thus, it is necessary to manage and control the access of the health records in the hospitals through authorization models. In addition, a patient may not want others, such as family members or some healthcare providers, to know of their sensitive health information due to personal reasons. Thus, it is necessary to provide privacy where access to a patient's health records is concerned. It is also necessary to provide authenticity of the health records with respect to both content authentication and source verifiability. Finally, the secure communication between the patient and hospitals needs to be guaranteed by using secure data transport methods, such as Secure Socket Layer, Transport Layer Security, Internet Protocol Security, and so on [14].

B. Comparison with Multi-tenant Architecture

Multi-tenant architecture is an efficient as well as cost effective way to provide cloud services to a large number of customers. The integrated healthcare system architecture presented in [2] is one that can be implemented by using multi-tenant architecture. However, a multi-tenant architecture–based healthcare system has the following weaknesses in comparison to the proposed VMs-based personalized healthcare system in this paper. First, a multi-tenant architecture provides efficiency and large scalability, but the costs of redesigning applications for multi-tenancy can be significant. So, it is difficult to add new chronic disease care services or legacy services, with low cost. Furthermore, dynamic functionality updates of healthcare systems are difficult due to the fact that updates may affect other patients. Also, it is difficult to provide personalized disease care services according to the types and status of chronic diseases with patients. Secondly, a VMs-based architecture provides a more secure environment for patients' health information. Multi-tenant architecture isolates all patients' data and settings information from each other. However, there is the potential for human carelessness or error. For example, a database administrator may mistakenly implement a security policy that affects all patients of a service, but which in fact actually contravenes the policies or rules that some patients need to abide by. Therefore, the proposed VMs-based personalized healthcare system architecture can resolve the above issues.

C. Applicability to Other Chronic Diseases

Currently, our system provides four types of chronic disease care services: the metabolic disorder identification service, the e-Renumber-estimation-based heart disease detection service, the MS risk prediction service, and the temporal progress analysis service. The references of the services are registered in the hospital cloud and provided to patients. Thus, if a new chronic disease care service is developed in the future, then the new service will be placed to the application repository of the hospital cloud and will be installed to the patient's VM in the hospital cloud.

III. Prototype Implementation and Evaluation

This section describes the prototype implementation results of the proposed personalized healthcare system and presents the performance analysis results of the layered service broker system in terms of cloud resource allocation policy.

1. Prototype Implementation of Cloud-Based Personalized Healthcare System with Temporal Progress Care

This section presents the prototype implementation results of the proposed personalized healthcare system for cloud environments. We built a prototype system on an experimental testbed, as shown in Fig. 7. First, a patient downloads an at-home healthcare system application from the service repository onto a mobile device such as a smartphone. The patient can then access a virtual device that is synchronized with the VM within the hospital cloud and allocated to the patient. The service broker is responsible for creating and configuring the VM within the hospital cloud. The VM corresponds to the patient's home healthcare machine, which is a virtual device in an at-home cloud environment. The broker installs the chronic disease care services customized to the VM. The chronic disease care services are customized to the patient's status by means of an SLA between the patient and service broker. Therefore, when an administrator in the hospital needs to update the patient's home healthcare system, the administrator makes an update on the VM within the hospital cloud. Then, the VM within the hospital will be synchronized with the virtual device in the patient's home cloud environment. By doing so, the hospital can effectively manage the status of the out-of-hospital patients.

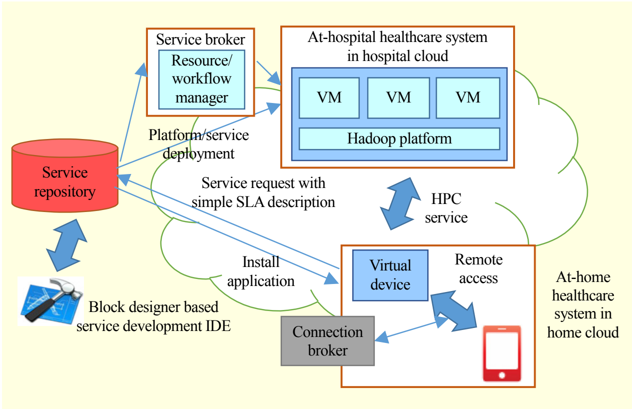

Fig. 7. Mobile application for personalized chronic disease care service.

Our prototype system is implemented on the Android 4.2 platform and supports the two chronic disease care services presented in this paper; that is, the MS risk prediction service and the temporal progress care service [8]–[9]. We will extend our system to support other chronic disease services, such as the electrocardiography (ECG) analysis services presented in [2].

2. Cost Analysis of Personalized Healthcare System

This section presents a predicted cost model for the service scenario of a personalized healthcare system for a home–hospital environment proposed in this paper.

A. Construction of Markov Process Model

Table 2 shows the states of the personalized healthcare system used to develop the Markov process for the service scenario.

The Markov process is being employed as the first component of this model to predict the utilization for this healthcare problem [16]. The transition or change in utilization from state i to state j is influenced by the prior state, and is denoted as

$$P_{ij} = \Pr[X_{n+1} = j \mid X_n = i], \tag{1}$$

where P_{ij} is the probability of going from state i to state j in one step, or one increment, in the time unit.

Because the patient's outpatient flow is managed by a predetermined patient management care plan of the hospital, it is not necessary to consider all previous transitions when determining the next transition. All of the transitions from the resident states require preset exit criteria, and only the previous state influences the opportunity for a transition to an alternate state. This means that being in a resident utilization state two transitions earlier is irrelevant to the state the patient is presently in. The only information needed is the previous transition state,

Table 2. States of personalized healthcare system in home–hospital environment for the Markov process.

State 0 (m_0)	No identified chronic disease
State 1 (m_1)	Self-management at home
State 2 (m_2)	Consult an informant about abrupt change on at-home medical examination results
State 3 (m_3)	Visit hospital (periodic visit or abrupt disease state change)
State 4 (m_4)	Diagnosis by physician
State 5 (m_5)	Laboratory tests
State 6 (m_6)	Discharged from the hospital
State 7 (m_7)	Complete cure

so a memory less or Markovian property is used [17]. The resident states of the transition, based on a utilization of the Markov process, can be defined as follows: the states defined in Table 2 lead to an eight-state Markov chain with an absorbing barrier (state 7), and the resulting one-step transition probability matrix is

$$P_{7\times 7} = (P_{ij}), \text{ where } i=0,\ 1,\ 2,\ \dots,7 \text{ and } j=0,\ 1,\ 2,\ \dots,7. \quad (2)$$

We specify the time interval unit for the probability transition matrix for the utilization to be one unit time T.

Consider the finite number of possible transitions for individuals in the model. Denote by the element

$$P_{00} = \Pr[X_n = 0 \mid X_{n-1} = 0], \text{ for any } n, \quad (3)$$

where P_{00} is the probability that an individual starting in m_0 stayed in m_0 after one time period.

Similarly, the probabilities for staying in the same state after one transition are denoted as follows:

$$P_{00}, P_{11}, P_{22}, P_{33}, P_{44}, P_{55}, P_{66}, P_{77}. \quad (4)$$

Let $f_{ii}^n = \Pr[X_n = i,\ X_v \neq i,\ v = 1, 2, \dots, n-1 \mid X_0 = i]$ be the probability that, starting from state i, the first return to state i occurs at the nth transition [18]. There are 64 possible transitions for an individual in this model. State m_7 (complete cure) is an absorbing barrier or state, defined as a state that once entered, it cannot be exited [18]. This means that the probabilities of transition from m_7 to states m_0 through m_6 are zero and that the probability of starting in state 7 and staying there is 1. Hence, in the probability transition matrix, (2) becomes

$$P_{70} = P_{71} = P_{72} = P_{73} = P_{74} = P_{75} = P_{76} = 0 \ \&\ P_{77} = 1. \quad (5)$$

The matrix can be partitioned into four subsets. The set of transition probabilities $\{P_{77}\}$ has the following two properties:

- It has a period of one.
- Because $f_{77}^n = 1$, it is a positive recurrent.

Combining the previous two properties leads to the conclusion that $\{P_{77}\}$ is an ergodic set. This set will be represented by the submatrix $\mathrm{E}_{1\times 1}$ and can be defined as follows:

$$\mathrm{E}_{1\times 1} = \{P_{77}\}. \quad (6)$$

The next submatrix of the partitioned matrix to be considered is the vector of zeroes.

$$\mathrm{O}_{1\times 7} = \{P_{7i} \mid i = 0, 1, 2, 3, 4, 5, 6\}. \quad (7)$$

Once in the absorbing state, the individual cannot leave this state; hence, all cell entries are zero. The third partitioned submatrix to be defined will be the transient states.

$$\mathrm{M}_{7\times 7} = \{P_{ij} \mid i = 0, 1, 2, 3, 4, 5, 6 \ \&\ j = 0, 1, 2, 3, 4, 5, 6\}. \quad (8)$$

The submatrix M includes all the transient states of the Markov chain. The probability of the first return, f_{ii}^n, for these states (m_0, m_1, m_2, m_3, m_4, m_5, m_6) is less than 1. The final submatrix to consider is the transition from a transient state to an absorbing state. This will be defined as

$$\mathrm{L}_{7\times 1} = \{P_{ij} \mid i = 0, 1, 2, 3, 4, 5, 6\}. \quad (9)$$

An alternative form of the probability transition matrix can now be illustrated with the dimensions of partitioned matrices: $\mathrm{E}_{1\times 1}, \mathrm{O}_{1\times 7}, \mathrm{L}_{7\times 1}, \mathrm{M}_{7\times 7}$. It should be noted that the matrix $\mathrm{E}_{1\times 1}$ is equivalent to the identity matrix $\mathrm{I}_{1\times 1}$. Replacing $\mathrm{E}_{1\times 1}$ with $\mathrm{I}_{1\times 1}$ in the matrix results in the following:

$$\mathrm{P} = \begin{pmatrix} \mathrm{I}_{1\times 1} & \mathrm{O}_{1\times 7} \\ \mathrm{L}_{7\times 1} & \mathrm{M}_{7\times 7} \end{pmatrix}. \quad (10)$$

B. *Predicted Cost Model for Integrated Healthcare Systems Service Scenario*

Determining the mean time or number of cycles an individual occupies in a resident state requires some knowledge of linear algebra as well as of the development of a fundamental matrix for a Markov chain with an absorbing state. Kemeny and Snell [19] developed a methodology for finding the mean time in each resident state before transition into the absorbing state. They proposed the following.

Let $\mathrm{B}_{n\times n}^m$ be a square matrix raised to the power of m. If $B^m \to 0$ as $m \to \infty$, then $(\mathrm{I}-\mathrm{B})$ has an inverse, and

$$(\mathrm{I}-\mathrm{B})^{-1} = \mathrm{I} + \mathrm{B} + \mathrm{B}^2 + \dots = \sum_{i=0}^{\infty} \mathrm{B}^i. \quad (11)$$

For any Markov chain with an ergodic set, let matrix M correspond to the set of transient states, as in (10). Then, $(\mathrm{I}-\mathrm{M})$ has an inverse, and

$$(\mathrm{I}-\mathrm{M})^{-1} = \mathrm{I} + \mathrm{M} + \mathrm{M}^2 + \dots = \sum_{i=0}^{\infty} \mathrm{M}^i. \quad (12)$$

Substituting matrix M, from (10), into (11) proves (12).

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Let $N = (I - M)^{-1}$ be the fundamental matrix for a Markov chain with an ergodic state [16]. The next consideration is the number of times that a transient state is occupied for an individual. Define η_{lj} as the function assigning the total number of times that the process is in state m_j after starting from state m_l (restricting the choices to transient states, $\{m_j \mid j = 0, 1, 2, 3, 4, 5, 6\}$. This quantity can be expressed as the sum of indicator variables.

$$\mu_{lj}^k = \begin{cases} 0 & \text{if the process is in state } m_j \text{ after } k \text{ steps,} \\ 1 & \text{otherwise.} \end{cases} \quad (13)$$

The method for determining the expected number of cycles during which an individual stays in a resident transition state, conditional on having just entered the system, follows [16]. The mean number of days spent in m_j after starting in state m_l is $N_{7\times7} = E[\eta_{lj}]$, as can be seen from the following argument. It should be observed that $\eta_{lj} = \sum_{k=0}^{\infty} \mu_{lj}^k$. Hence, $E[\eta_{lj}] = E\left[\sum_{k=0}^{\infty} \mu_{lj}^k\right]_{7\times7}$. Note that μ_{lj}^k is the l, j element of M^k. Here, η is the matrix whose l, j element is M^k. Then,

$$E[\eta] = \sum_{k=0}^{\infty} E[\mu_{lj}^k] = \sum_{k=0}^{\infty} M^k = N. \quad (14)$$

Denote the expected numbers of days in seven transient states by T', taken from the proper row of N.

The notation for the cost function is (15). Define the fixed cost to be a column vector, where each element of this 8×1 matrix is the averaged costs per utilization state of the system. It should be noted that the elements for the states *no identified chronic disease* (m_0) and *complete cure* (m_7) have no allowable costs associated with them. The cost function can be represented as

$$C'_{8\times1} = \{0,\ c_1,\ c_2,\ c_3,\ c_4,\ c_5,\ c_6,\ 0\}. \quad (15)$$

The model is defined by multiplying T' and (15) with the result

$$F(x_i) = T'_{8\times1}(x_i)C_{1\times8}, \quad (16)$$

where x_i is the conditions of interest (gender, age, and diagnosis).

The value of function F is the predicted cost for an individual. The vector of utilization T' has a dimension of 1×8. The vector of cost C has a dimension of 8×1. Taking their product generates a scalar value, $F_{1\times1}$, which is the predicted cost given the patient's gender, age, and diagnosis.

3. Clinical Applicability for Temporal Disease Status Care

The implemented application on a mobile device helps with managing the temporal changes in MS risk. For example, we can consider the scenario in which a young male individual regularly examines the values of the MS risk factors. The mobile application supports the calculation of the ASD, which quantifies the risk of having MS in the future [8]. If the ASD value of the person exceeds the threshold for young male subjects at a certain time, then the status of each risk factor will be investigated in detail, and risk factors approaching the thresholds will be managed by a physician. In addition, during the following regular examinations, not only the calculation of ASD but also the generation of a visualization chart of the patient's health status will be used to analyze the temporal changes in the patient. Once the ASD value of the subject reaches below the threshold, only the ASD value will be used to regularly manage the patient [8].

Furthermore, since patients with a chronic disease such as MS typically spend most of their time outside of the hospital environment between regular health examinations, it will be helpful for patients to perform self-management with simple applications for personal portable devices such as a smartphone. By regularly analyzing the ASD value and the visualization chart of MS risk factors, it is possible to manage the temporal progress of MS.

IV. Conclusion

As the number of patients having chronic diseases increases, developing a personalized healthcare system is becoming a major issue in many countries. Key requirements for personalized healthcare systems include consideration for separate environments, reduction of computational overhead for health information data processing, and support for customizable healthcare system. However, most existing studies have focused on resolving only the first two requirements, and patient customizability is less considered. To support customizability and dynamic functionality updates in a personalized healthcare system, we proposed a cloud-based personalized healthcare system for chronic disease care. The proposed personalized healthcare system provides effective chronic disease care services, including MS risk quantification and temporal progress care services. The service broker module within the system supports the dynamic provisioning and configuration of the personalized at-home healthcare system in cloud environments. Then, we presented a Markov process–based cost model to predict costs based upon a healthcare service scenario of a home–hospital integrated environment. Finally, we presented the prototype implementation of the personalized healthcare system in home–hospital cloud environments. We expect the proposed personalized healthcare system to be applicable to provide cost effective and personalized chronic disease care.

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