An Integrated mHealth Solution for Enhancing Patients' Health Online

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Abstract— **Lack of time or economic difficulties prevent chronic obstructive pulmonary disease patients from communicating with their physicians, thus inducing exacerbation of their chronic condition and possible hospitalization. In this paper we propose a platform that integrates mobile application technologies and cloud computing to provide secure, robust, scalable and distributed backend for hosting health services that improve life quality in a cost effective way.**

Keywords— **Patient monitoring, COPD, ICT application services.**

I. INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is an obstructive lung disease characterized by chronically poor airflow worsening over time. The most noticeable symptoms are shortness of breath, cough, and sputum production. Tobacco smoking and air pollution are the major causes. COPD treatments include: smoking cessation, vaccinations, rehabilitation, bronchodilators, steroids and long-term oxygen therapy. Lack of time or economic difficulties prevent patients from communicating regularly with their physicians, thus inducing exacerbation of their chronic condition and possible hospitalization.

Epidemiological studies conducted in USA, Denmark, Norway, Italy, Spain, Japan and Greece reported an overall COPD prevalence of 4% to 10% in the population [1], , [2], [3], [4], [5], [6], [7]. Other studies have estimated the cost associated with the treatment of COPD patients; £0.8 billion in UK in 2003 [8], $18 billion in USA in 2005 [9] and $2.1 trillion worldwide in 2010 [10]. In [11], the hospitalization costs for the treatment of acute COPD exacerbations represented about 45% of total costs.

Therefore, the prevention of exacerbations of COPD patients in order to improve quality of life for chronic patients and reduce costs is the primary concern of the medical community.

In this paper, we describe an integrated solution that connects COPD patients to their physicians using an innovative combination of cloud and service-oriented computing, online services, data analysis, and mobile phone applications. Part of this work was carried out in project ***Enhancing Chronic patients' Health Online*** (ECHO)[1].The ECHO-platform is expected to monitor patients, verify the diagnosis with online alerts in order to avoid medical emergencies and unnecessary hospitalizations at low cost and at significant savings to the national health system.

The main challenge of our approach is to exploit the vast potential of cloud computing on secure, scalable, distributed, and robust backend for hosting health data and health services and the appeal of mobile application technologies with friendly user interfaces.

II. STATE OF THE ART

Several studies investigate how telehealthcare could improve patients' quality of life and reduce COPD exacerbations. In [12], a literature review was conducted to examine whether telehealthcare (telemetry/telephone calls/home visits by nurse specialists) has improved the management of chronic diseases. Since most studies in the review have been relatively short-term (less than 6 months), no evidence for the value of telehealthcare is verified. In [13], a review showed that telehealthcare increased significantly the quality of life and reduced the number of the patients who visited a hospital. In [14], a systematic literature review demonstrated that hospital at home schemes resulted in substantial cost savings with equal effectiveness and patient safety compared with inpatient care for acute exacerbations of COPD.

Studies have used mobile application technologies to monitor patients and facilitate health in a cost-effective way for both patients and physicians. Though, no study has used the technologies and the architecture similar to our approach. In [15], a mobile assisted home care model uses a mobile application that enables patients report their COPD symptoms. A Web portal is developed for clinicians to manage and analyze patients' data and send feedback when

[1] `http://chroniconline.eu`

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necessary. In [16], a method for computer-aided assistance including event detection, alerting, monitoring and treatment advice at a distance from the hospital is developed. COPD symptoms are collected and interpreted by a probabilistic model to access automatically the risk of worsening of symptoms due to an exacerbation.

A basic difference of the system architecture of our approach and the above studies is that our system implements mobile applications for both the physicians and the patients. Thus, physicians can use a push notification service for immediate alerting of emergent situations. Another capability of our system is that the patients' mobile application gathers data automatically from mobile devices (e.g. GPS location) which can be used in future data analysis. This is the most interesting feature of our approach that is not yet considered in other studies; ECHO-platform supports data processing by means of cloud computing technologies in order to help physicians dynamically adjust treatment plans in a cost-effective way. The combination of cloud computing, data analysis, and mobile application technologies provides health services that improve life quality of patients and reduce costs in the health care sector.

III. HEALTH SERVICES

Echo-platform enables improved monitoring of the patients and management and treatment of COPD exacerbations, by combining human medical expertise with state-of-the-art online service delivery based on cloud computing, data analytics and mobile applications. The goal of monitoring of the patients is to collect and manage data about the health status, medical history, current treatment, and action plan in case of worsening of symptoms. The goal of the management and treatment of COPD exacerbations is to reduce or eliminate symptoms and improve health status.

The methodology applied for COPD is described as follows: The patient provides (on a daily basis) measurements of pre-defined vital signs (e.g. oxygen saturation, heart rate, temperature, peak expiratory flow rate, and walking distance) and answers questions such as: did your shortness of breath increased? Did your cough increased? Did your sputum changed? Did you have chest pain or discomfort? Did you change your medications? These data are transmitted to the system and are made available to the physician who creates and regularly (e.g. at regular follow ups or during unexpected events such as, exacerbations, emergency visits to the doctor or hospital) updates a medical record of the patient. The condition of the patient is evaluated and recommendations/treatments are sent by the physician.

IV. OVERALL ARCHITECTURE

The environment proposed in this paper will consist of a frontend and a backend as shown in Figure 1. In the following we provide details on the frontend (Section IV.A) and backend (Section IV.B). Data management and analysis is described in Section IV.C.

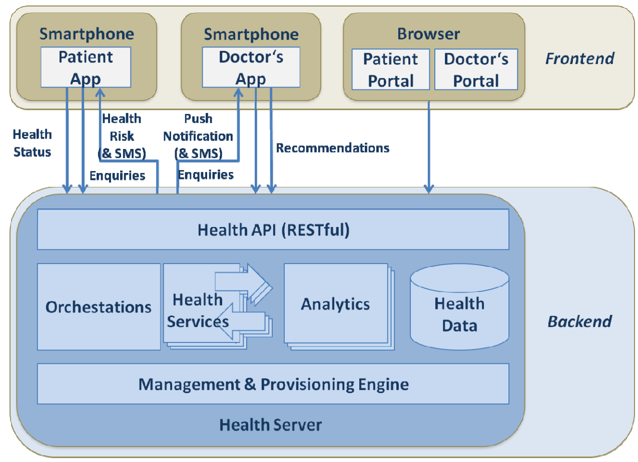

Fig. 1 ECHO overall architecture

A. Frontend

The frontend will either be delivered as apps on iOS and Android smart phones, or as a Web page made available via browser. The notifications of humans will be implemented through "in-app" push notifications to smart phones and through outbound SMS to humans who use the Web portal and should be notified for urgent actions.

There will be two types of applications; The *iChronic Patient App* enables patients to provide information about their health status, and receive recommendations/treatment by the physicians based on their health record, all stored in the cloud infrastructure. If a health risk is detected, the *iChronic Patient App* will receive a corresponding warning. The *iChronic Patient App* provides the following functionality:

- Patient authentication using existing standard secure and authentication protocols of identification management (e.g. SSL, …).
- Linkage of the application to the health record keeping, cloud-based, database.
- A stream of data about the patient's chronic disease condition, their location and any measurements by external medical devices, that could be linked to the smartphone (e.g. through a Bluetooth connection) or could be entered manually by humans.

The *iChronic Doctor App* enables physicians to access/export health data, send recommendations to patients based on their health status and their health records stored on the cloud. The *iChronic Doctor App* receives notifications about health status updates and urgent health situations of a patient that requires immediate reaction.

B. Backend

The Health Server represents the backend of the ECHO platform and will be delivered as collection of cloud services, see Figure 1. In order to ensure interoperability and deployment of the Health Server in various cloud environments the services are managed and provisioned based on the OASIS standard Topology and Orchestration Specification for Cloud Applications (TOSCA) [17], [18] . Therefore, the Management & Provisioning Engine is based on OpenTOSCA[2] which is an open source environment for modeling, provisioning, and managing cloud applications [19]. This way, the environment we propose will be ubiquitously available. As security and compliance to laws and regulations is of utmost importance in the domain of health care, we use the plug-in mechanism of OpenTOSCA to extend the Management & Provisioning Engine to ensure compliance, establish trust, and to enforce security. The efficacy of this mechanism regarding trust and security has already been shown in the CloudCycle project[3] in the domain of governmental applications [20]. Thus, the Health Server of the environment that we propose will be compliant and secure; and it will be hosted in a cloud environment in order to significantly reduce the burden of setting up the environment and ease its management. All health care data are stored in the Health Data component of the Health Server. Health Services and Analytics Services are managing and processing the health care data such as patient data, insurance data, prescriptions, etc. We investigate data management and analysis in detail in Section IV.C.

Both *Health Service* and *Analytics Services* are composed into higher level services with advanced functionality by means of *Orchestrations* offered by the *Health Server.* Supporting this business process based development method makes it straightforward for domain experts to easily create new services. The *Health Server* functionality with all its services is made available via a unified *Health API* following the Representational State Transfer (REST) architectural style [21] ensuring the seamless integration between the backend and the ECHO frontend as well as other external applications, e.g. from health insurance companies.

C. Data Management and Analysis

There are two different sources of health data to be managed. Figure 2 shows the data sources that have to be managed in the ECHO-platform. On the one hand there is the detailed health data entered by a doctor, when a patient has a consultation (shown on the right). This data is very precise and contains a lot of different kind of information ranging from personal data about the patient to measurements that have been taken to diagnosis and prescriptions. On the other hand there is new health data that is acquired by the ECHO-platform on a daily basis. This data is inserted by the patients themselves using their smart phone (shown in Figure 2 on the left side). This data contains answers to predefined questions and measurements that were taken by the patient.

The analysis services are running in the background and analyze all data entered to the system. If new data is entered the analysis functions are triggered and check the new data for critical values. Furthermore, analysis functions are running on a scheduled basis for system improvements.

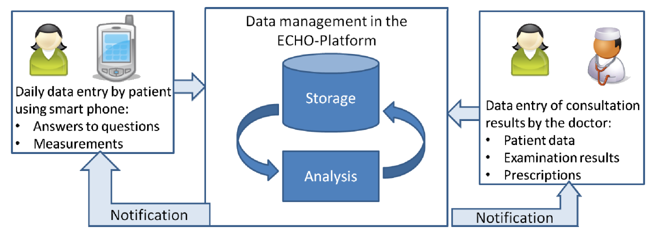

Fig. 2 Health data sources and data management and analytics

The following requirements have to be met by the data management and analytics services of the ECHO-platform in order to ensure the security and quality of the health data and allow a generic and reusable access to the data.

1. Security requirements
   a. Storage in a secure database system that allows encryption of the data.
   b. Database system has to prevent SQL injection attacks.
   c. The interface has to be designed to allow only access via save predefined secure stored-procedures.
2. Data storage requirements
   a. Existing health data repositories or database systems should be used.
   b. Existing health data standards should be used for compatibility reasons.
3. Data analysis requirements
   a. Usage of service-oriented approach for creating analytics services. Hence, different analysis functions can be defined and modeled in a workflow. Layers of analysis services:
      i. Basis services to search, load, and query specific data.
      ii. Service-oriented interface for analysis.
   b. Support of different types of analysis:
      i. Real time, event based analysis.
      ii. Timer based analysis at predefined times or on intervals.

[2] OpenTOSCA: www.opentosca.org
[3] German government funded BMWi project CloudCycle: `http://www.cloudcycle.org/en/`

c. Usage of exiting systems for data mining (Rapid-Miner or KNIME)

These requirements allow the implementation of extended more complex analysis functions to provide the functionality needed in the mobile apps. That results in a library of analysis functions fitting the needs of the application domain. The extended functions are created using basis functions, existing tools, and orchestration. This leads to a high degree of reusability and improves the testing and hardening of the overall system.

Finally, attain high data quality is an important overall requirement. Based on [22] the integrity and timeliness aspect of data quality is most important for the data management and analysis. However, the other data quality aspects are also considered and implemented by the ECHO-Platform.

V. CONCLUSIONS

In this paper, we present the ECHO-Platform that is used to monitor COPD patients and manage COPD exacerbations, by combining human medical expertise with state-of-the-art online service delivery based on cloud computing, data analytics and mobile applications. The purpose of the health services delivered by the Echo-Platform is to improve quality of life and reduce exacerbations of COPD patients. The design of clinical trials in order to investigate the effect of our approach on the improvement of health status is left for future work.

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