Integration of IoMT Sensors' Data from Mobile Applications into Cloud Based Personal Health Record

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Abstract. Mobile applications for vital signs measurement are popular in ambient assisted living environments. They typically include various wearables and devices with their applications connected with the production company with some security preferences. When a manufacturer develops and markets a specific sensor, a smartphone application is developed. Many of the sensors and devices are secured and can work only with its host application developed by the manufacturer. However, for these sensors and devices related to a patient's cloud-based Personal Health Record (PHR), different mobile applications must be created to connect all additional wearables or IoT-based medical sensors or devices to the appropriate cloud-based PHR. All data from these mobile applications needs be collected into the PHR database securely and in time to store medical information for the patient's health in the PHR. This paper presents the integration of two types of mobile applications – for medical professionals and citizens with the PHR, intended for the Cross4all project. The paper explains how the mobile application is integrated with different sensors and devices and the cloud PHR. We also describe the challenges that have arisen from the pilot project implementation and solutions. The presented concept improves cross-border evidence-based healthcare and integrates the e-prescription and e-referral system intended to solve some cross-border healthcare problems for foreign citizens.

Keywords: e-Health · Health information systems · Mobile applications · IoMT · PHR

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1 Introduction

The current large amount of IoMT-based devices, including wearables and sensors for remote patient monitoring, are designed in order to increase efficiencies, decrease care costs, and improve outcomes in healthcare. They also tend to improve e-health services by improving the possibilities for medical care in the distance, especially in a pandemic situation. Healthcare organizations are increasingly leveraging the potential of IoT and IoMT (Internet of Medical things) with their ability to collect, store, analyze, transmit and use health data. Thus, the IoMT has a vital role in personal-EHRs.

When we are talking about the PHRs, we can say that the health-related data can be collected from various sources. The sources can be EHRs, patient's records from health providers as prescription data, labs' data, bio-monitoring data, referral data, or directly from a sensor for vital signs measurements or some general-purpose data as exercise habits, diet statistics, and food or some screening or exposome data, etc. [1]. The cloud-based personal health record (PHR) concept supports collecting data as scanned medical documents for the patients, information beyond the patient's medical history, such as data related to conducting healthy life, style of living, and living conditions. These data can form a more holistic representation of the person's health lifecycle, and covering all kinds of physical, psychological, and social aspects. In this cloud-based PHR-based approach, the records are fully owned by the patient [2], controlled and secured simultaneously [3].

The Cross4all project concept combines the power of cloud computing as well as service-oriented architectures. It provides patient-centric care, including telecare possibilities, self-care elements, and increasing evidence-based healthcare management in a cross-border environment. The project includes several mobile applications for medical professionals and patients, focusing on serving the needs of the older people, people with disabilities [2] and geographically or socially isolated persons. This integrated Cross4all ecosystem with applications and many features aims to provide a wide range of capabilities. When the patient decides to create their PHR on the project, the patient becomes a PHR owner. The patient then can use the web platform through his/her device and store, view and use their health profile and history, medication plan, visits to health service providers, and all according to FHIR standards [2, 3]. A patient can also upload additional medical-related documents, such as data obtained from a mobile application for vital sign measurements and connected sensors or medical devices. The patient can also find, select, and share data from his/her PHR with selected cross-border healthcare professionals. The selected medical professionals can monitor patients' health, give advice, prescribe some drugs through an e-prescription system, or create e-referral for specialists of other medical institutions. The patient can grant temporary permission to selected medical persons or pharmacists to gain medical care.

The paper explains the real pilot of project Cross4all. The pilot implements cross-border cloud-based PHR and uses mobile applications for medical professionals and citizens in the real environment in Greece and R. of North Macedonia. Many challenges and possible solutions were taken into consideration during the process of implementation of the Cross4all pilot. The second section provides an overview of recent related works, while the third section highlights some points of the deployment of medical devices and sensors through the usage of mobile applications for patients and professionals and their connection with the cloud PHR. The fourth section emphasizes some aspects of data acquisition from devices and storing them into cloud PHR. The actual data acquisition is discussed in the fifth section. In the conclusion section, directions for improving the quality of implementation and proposals for future work are given.

2 Related Work

Many researchers consider IoT and IoMT challenges in the last decade, focusing their research on different issues. Some of them consider end-user privacy and security challenges for IoT healthcare applications [17]. They consider IoT its layered architecture, describe privacy and security services, providing to view confidentiality as privacy and security intersection. Some authors [4] analyze the ideas as well as the impacts of IoT on the new e-health solutions designing and identifying the main challenges that determine successful IoMT-based e-health system adoption.

A general overview of IoT in healthcare medical systems is presented in [5]. It discusses applications connected with IoMT as well as medical data analysis. In addition, the advantages of IoMT in the healthcare sector is discussed. IoT-related threats, some issues of factors determining the future trends of IoT in medical and healthcare systems are also taken into consideration. The role of IoT as well as the role of other interdisciplinary fields are considered in the paper in order to boost smart and pervasive healthcare. An automated telehealth monitoring system for monitoring and measuring different physiological parameters of the body using Arduino is presented in [6]. IoT devices are proposed to collect and store the needed parameters as well as evaluate the data gained from the IoT devices. Data are sent and stored to the cloud system, in database in PHC. In case of emergency, the tele-ambulance is called and it is integrated with all medical facilities in disposal, to save lives in emergencies. At the same time, there is no time to take the patient to the main hospital. The paper [7] surveys various usages of IoT medical and healthcare technologies, reviewing the state of the art services, applications, recent trends in IoT-based medical and healthcare solutions. Also, the paper considers various challenges posed, including security and privacy issues, service providers, and end-users experiences. In addition, the paper takes into consideration some innovative IoT-enabled technologies as big data, cloud computing, block chains, fog computing and others in order to leverage modern medical and healthcare facilities as well as to mitigate healthcare resources' burden.

The authors of the paper [8] have identified key components of the end-to-end IoT healthcare system and propose a wider healthcare model that could be applied to a wide range of IoT-based healthcare systems. The focus is on monitoring sensors for various healthcare parameters, cloud technologies as well as long and short-range communications standards. The original contribution is made by focusing on Low-Power Wide-Area Networks (LPWANs), highlighting their unique suitability for use in IoT systems. Paper [9] considers how promising technologies such as ambient assisted living, cloud computing, wearables and big data that are being applied in medicine and healthcare industry. In addition, in the paper various regulations for IoT and e-health regulations are taken into consideration as well as some policies worldwide in order to determine how they can assist in the IoT and cloud computing's sustainable development in the healthcare industry.

The analysis and a systematic review of the future technologies instrumental for a large-scale of the Human H-IoT systems development are presented in [10]. This paper identifies also how these new technologies are used in the future course with aim to improve the Quality of Service (QoS). The paper [16] survey IoT security and privacy issued and pointed out of some state-of-the-art solutions that can be taken as a practical guide for how to develop a modern IoT or IoMT application. Some aspects of a circular economy in the healthcare domain are also considered in the paper. Some points of how to create the mechanisms for protection of data that have to be acquired from the devices to the cloud ends and how to process, transmit and store them, in order to be reused, are also given in the paper.

A taxonomy for mobile health applications is described in [12]. The taxonomy attempts to classify applications that have to be controlled by a healthcare facility but it has to be used by the medical practitioners for healthcare-specific data exchange as well as to provide healthcare and medical communications. The important issue is to present to interested data custodians, as consultants and auditors who are responsible for overseeing health information security. This is just a brief holistic review of statements of used technologies for the project.

3 Mobile Applications Connected with Devices or Sensors for Vital Signs Measurement

The project Cross4all uses the potential of the IoT concept together with the PHR concept to increase the number of people that access high-quality health and social services in the cross-border area, thus promoting safe aging, early prevention, and independent living for all [2, 11].

Two categories of health-related mobile applications were developed in the Cross4all project: one for citizens and one for professionals (medical practitioners). According to the findings presented in [12], they support personalized healthcare and remote monitoring and provide support to clinical information management. The first category of this kind of application communicates with multiple personal healthcare devices that are user-friendly [13]. The application supports remote monitoring and measuring of patients' vital signs. This application saves data into PHR with user involvement [14]. The collected data is being used and evaluated by the users or by medical professionals. A mobile device/tablet and internet connection are involved in exchanging collected data between patients and medical providers. The second category of mobile applications is those used by medical professionals. Both applications are based on the Android operating system. The Android operating system is chosen for several major differences (and in our case, advantages) rather than iOS. Firstly, Android enables more low-level access to the Bluetooth communications stack than iOS. Secondly, the distribution and installation of the Android apps are far more straightforward than the distribution of iOS apps.

4 Installation and Integration of Mobile Applications with the Cloud-Based PHR

The two versions of mobile applications have been developed. Mobile application for patients uses day-to-day monitoring devices such as blood pressure monitor, blood glucose monitor, weight scale, pulse oximeter etc. Mobile application for the medical professionals and the previous devices uses more complex medical devices and sensors, such as digital stethoscope, Bluetooth ECG. Both applications need permissions to access the Bluetooth and Location services of the Android OS. They used their native application integrated with the backend - webPHR cloud application and provide saving data into patient's PHR.

The integration of the mobile applications with the underlying backend consists of communication with two distinct services: (1) Authentication sub-system, which is OpenID Connect, based Keycloak server, and (2) Backend API service that is storing the medical health data for the PHR. Since the location of the services is not hardcoded in the applications themselves, to support changes between staging and production environments, the only thing left to configure is the URL locations of the Keycloak services and the URL of the backend API that is done during the first start of the apps.

The registration of new users in the PHR Cloud is supported through the Keycloak Web Registration form opened directly in the smartphone application, so no other device is needed to enroll new users (patients) in the Cloud PHR.

The medical professionals have to use a separate application for each device (Fig. 1a). The mobile applications are connected with the Cross4all mobile application. The patients used one application with many modules (Fig. 1b).

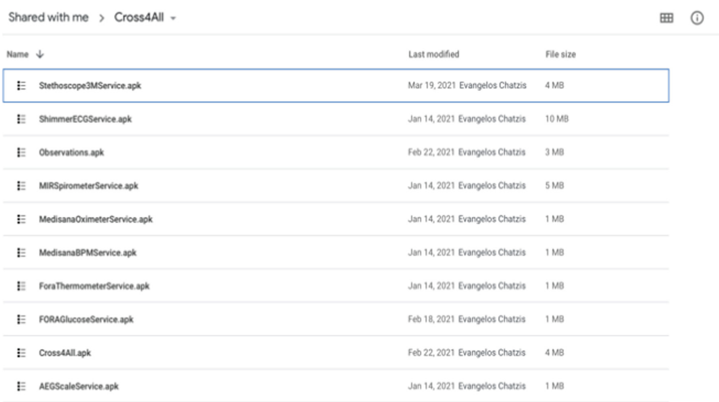

Fig. 1a. Main HCI for Mobile applications for medical professionals.

Fig. 1b. Mobile application for the patients.

5 Data Acquisition into the Cloud-Based PHR

The proposed IoT methodology includes cross-border use, with a focus on the needs of older and disabled people [15] as well as geographically and social isolated individuals. This approach provides the data collection, creating a patient database and data analysis for effectual patients' treatment. The proposed workflow processes of the IoMT concept make the connections between healthcare appliances, PHR, Internet, a mobile application for patients and medical professionals, and services using eight steps.

Step 1: Downloading and installing. From available applications (Pulse Oximeter PM150, Blood Pressure Monitor BU550, Glucose Meter Fora Diamond MINI, Ear Thermometer Fora IR20b, Vitalograph COPD-6, Weight Scale AEG PW5653 BT) the medical professionals and patient download and install the mobile application/s on own mobile device.

Step 2: Bluetooth connection. The sensor-based medical device and the mobile device (tablet) communicate through Bluetooth, and connection has to be established. For the ECG and the stethoscope, the user has to pair the device with the tablet. In the tablet's Bluetooth, the setting is input 4-digit pair code.

Step 3: Vital signs measurement. The sensor-based medical device measures the patients' vital signs.

Step 4: Measured data collection. After measuring with the corresponding device and once the measurement is completed with the button "Start a measurement and click here when it is completed" or "press here to link" (for the pulse oximeter) the name of the device will appear on the screen. Communication between devices is established, and the mobile application collects the patients' data from the device.

Step 5: Start communication service. When the device's name appears on the screen (Fig. 2a) with the button "Start Service", the connection can be started with Cross4All Platform. The message "connect with Cross4All Platform" will appear, and the device is ready to be used.

Step 6: Settings. Data acquisition into patients' cloud-based PHR (Fig. 2b).

Step 7: Sharing. The patients grant permission to their PHR to selected doctor/s.

Step 8: Patient data utilization. The doctor logs in with their credentials (username/password) created via the web PHR or with PIN created during the first login. Once logged in, if the patients have given permissions to their file, the doctor can see a list of records of measurements. After selecting a patient, the doctor can "START RECORDING SESSION", and offers suitable treatment (Fig. 3a).

Fig. 2a. Communication between devices

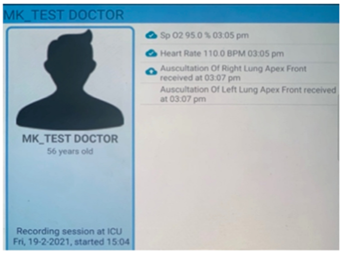

Fig. 2b. Data acquisition into PHR

The workflow process in patients' mobile application contains the first seven steps (Fig. 3b). Before the first step, the patient must create their PHR on the project webPHR cloud system. The patient can access to webPHR through their mobile devices or info-kiosk in the public healthcare institution.

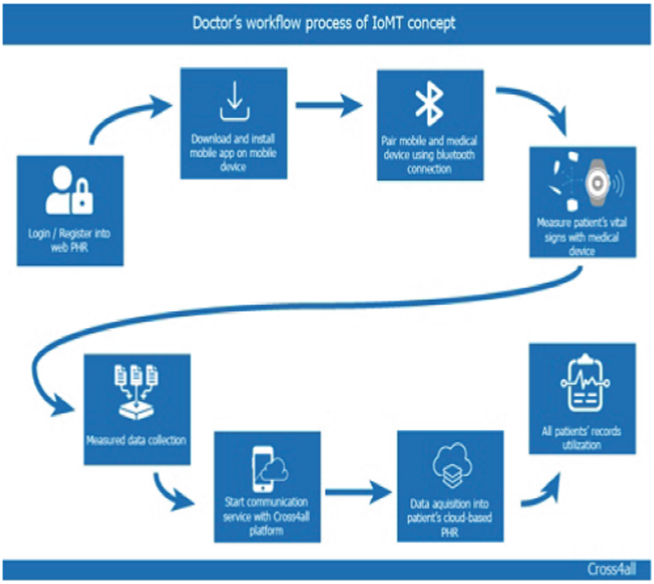

Fig. 3a. Doctor's apps workflow processes of used IoMT concept.

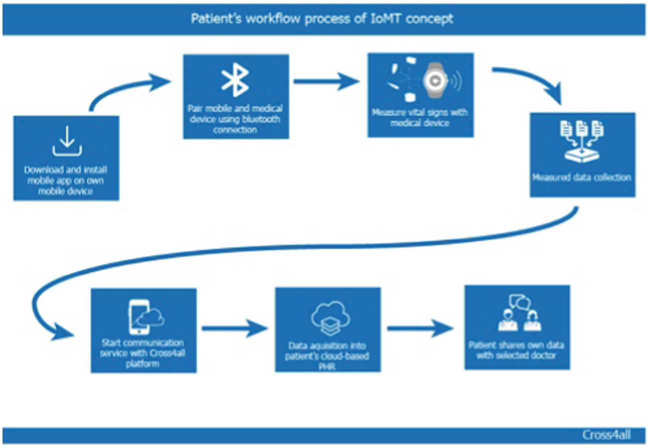

Fig. 3b. Patient's apps workflow process of used IoMT concept.

Fig. 4a. Mobile application for medical staff – Observations

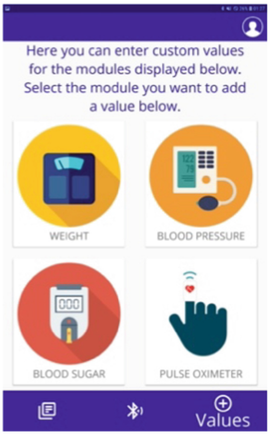

Fig. 4b. Modules for manually entering

The medical practitioners have an opportunity to enter values manually with mobile application Observations (Fig. 4a). For entering a value manually, the mobile application user first has to select option Observations and specific icon (Fig. 4b) and after that enter the measured value. In addition, the patients can also enter values manually with modules for manual data entering.

Medical professionals' medical devices, sensors, and applications are more complex, but they are still easy to use. An example would be Littman stethoscope - after pairing with the tablet, the mobile application has to be connected with the stethoscope. The medical professional selects a body area from the screen (Fig. 5) and starts the recording from the application or the stethoscope directly. For all recorded measurements to be synchronized, the mobile app needs some time (Fig. 6).

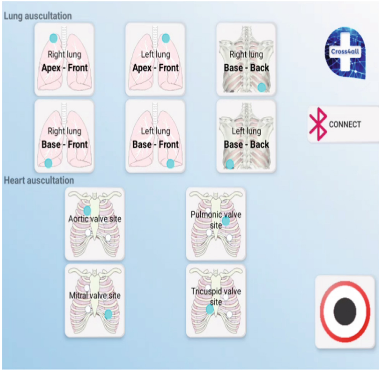

Fig. 5. Littman stethoscope application

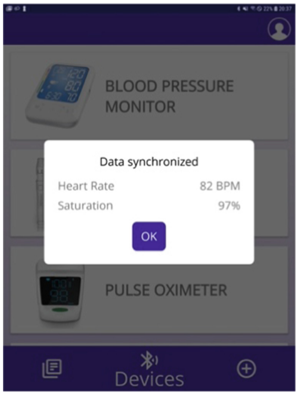

Fig. 6. Data transfer to the app

All acquired data has been uploaded and can be viewed from WebPHR and shared with health care professionals (Fig. 7). It is a central point application for patient's PHR cross border that integrate all patient's healthcare data [2], including e-prescription and e-referral system (Fig. 8).

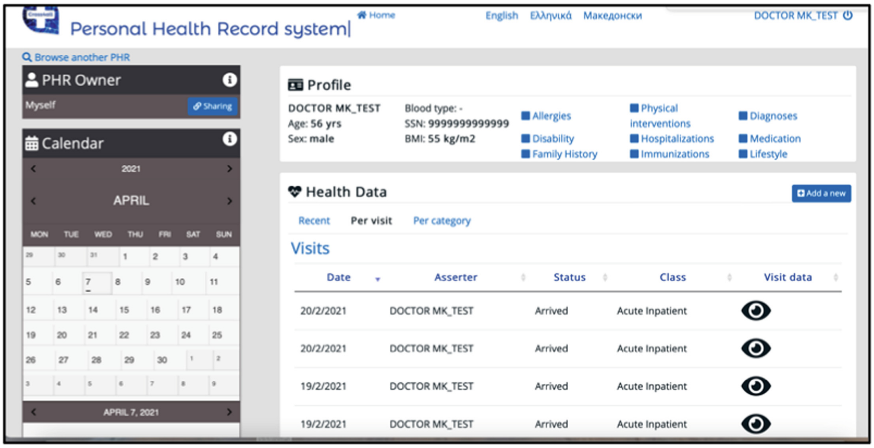

Fig. 7. Web PHR-shared data with a medical professional.

In the PHR, the patient's data are organized in Allergies, Disabilities, Family History, Surgeries, Immunizations, Diagnoses, Medication, and Lifestyle data of the patient. In addition, in the PHR, laboratory results and DICOM images can be displayed.

This Cross4all ecosystem integrated as applications and features, in full, provides a wide range of possibilities and capabilities [2]. Cross4all interconnected services contain the systemized cloud webPHR monitoring system for patients, cloud-based computing, data analysis and smart medical care, and all sensor-based medical devices, Bluetooth, Internet, mobile applications, cloud-based platform, etc. [13] as well as secure management of the data of each PHR [7, 16, 17].

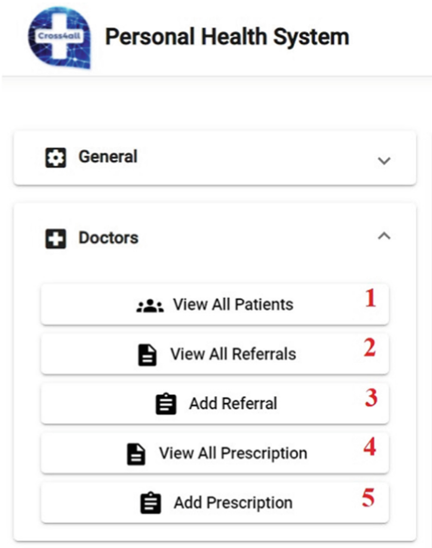

Fig. 8. Cross4all e-Prescription and e-Referral system for Medical professionals.

6 Actual Data Acquisition – Case Study

Although the installation of the applications is straightforward, and the integration of the applications with the backend does not need users' activity, the users need professional support at the very beginning of the pilot project. The users needed help with the installation of mobile applications on their mobile devices. In addition, they needed help during the initial workflow process.

The users were completely supported by a team from the Faculty of Information and Communication Technologies-Bitola, one of the project partners. Considering the user needs, they installed and prepared mobile devices with mobile applications, prepared web PHR manual, and mobile apps manual for both medical practitioners and patients. There were many trainings for users, mobile team, and doctors, some of them online. The eLearning platform with a digital health and healthcare literacy courses related to e-health, health information and services from electronic sources, and information how the patients and medical practitioners can effectively use the Cross4all tools (webPHRs, devices, mobile apps) was created.

The Pilot project implementation of Cross4all project was smoothly done because of the collaboration with all partners. Firstly, the level of digital healthcare literacy had to be increased for the patients and general practitioners who run the pilot. They created PHR for all project participants and studied the possibilities provided by webPHR and mobile applications with sensors. After that, the citizens were included: they were educated firstly, and then they created their PHR. The general practitioners provide sensors for citizens connected with webPHR with the Mobile application for patients for vital signs measurement for some distance citizens. Disabled people were also included in this project, and for this reason, the digital assets were accessible, providing WCAG compliance standards.

7 Conclusion

The more convenient methods of measuring and collecting medical data through wireless sensors and IoT devices have led to the possibility of having much more data for patient health tracking and medical analysis and self-care, especially needed in the pandemic. The Cross4all project intends to combine the power of cloud computing and service-oriented architectures and provide patient-centered care, including telecare possibilities, self-care elements and increasing evidence-based healthcare management in a cross-border environment where patients are mobile and not always physically available to their general practitioner. The health data collection and health data itself are the responsibility of the patient. However, since the collection is done by convenient medical devices, stored, and presented by a smartphone app, the patients are more likely to collect more data since they can always access it and see trends and some other insights regarding their health. One of the advantages of evidence-based medicine is that the end-users, i.e., patients, have to be aware of their current health situation and are willing to collect and measure more health data about themselves.

This approach has shown a need for greater attention from the authorities to increase the digital health educating of the health practitioners for this type of concept to be applied to a broader audience that is necessary for the future. In the next period, the number of available medical practitioners will not increase as the number of patients needing care and monitoring, especially for the patients with comorbidities that require constant monitoring of their vital signs.

This integrated Cross4all ecosystem of applications and characteristics provides a wide range of capabilities. Although the users initially feel slightly confused, the doctors and mobile teams become familiar with the workflow, mobile application, and PHR for a short time. The patients, especially the older people, have more significant user problems and had to increase their digital and e-health literacy.

This concept is necessary when the number of available medical staff decreases and the number of patients with chronic illness and comorbidities that require post-monitoring of their vital signs increases. Implementation of this concept needs much awareness of the benefits of increasing m-health and e-health digital health education and training, and additional staff support to get used to the number of patients.

As future work, we will try to capitalize the gained knowledge from the Cross4all project to integrate more countries in the system and to create the platform for multi-country healthcare collaboration. In addition, many other devices as IoMT sensors can be included in the application for measuring vital signs of life for citizens and professionals as well as their integration with backend PHR application.

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