Implementation of a Cloud-Based Personal Health System for Cross-Border Collaboration

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Abstract. This paper presents a brief overview of the concepts of collaboration, communication, data exchange and challenges for a patients' centric health information system, simultaneously used in two different countries for cross-border citizens. The system intends to create a Personal Health Record (PHR) for participants (patients, doctors, pharmacists) that includes the patient's current and past health status, prescriptions and referrals. Using these data, we can contribute to creating a better and higher-quality health service system in cross-border regions. The electronic prescription (E-Prescription) and the electronic referral (E-Referral) are the important points in the process of digitization of the cross-border PHR system. Their transformation from written to electronic form creates digitized records that can enable the treatment of the patients in another participating country. The main goal of the software system presented in this paper is to enable cross-border collaboration in the healthcare domain between two neighboring countries: North Macedonia and Greece. Both countries have their own health record systems. In this paper, we address the challenges in communication and synchronization between the created webPHR systems for the Cross4all project.

Keywords: PHR, Digital Health, System Integration, E-Prescription, E-Referral, Cross-Border Collaboration.

1 Introduction

The healthcare domain is a complex environment that benefits significantly from the introduction of information systems and electronic patient health records. This process produces a huge set of sensitive data and creates a large number of different

challenges and opportunities in the process of automation and utilization of such data. As a result, systems integration in the healthcare domain becomes a composite process that involves creating cohesive platforms from components that are not specifically designed to work together. Such components usually are stand-alone systems that operate in different computing environments and produce a large amount of incompatible data. This paper describes in detail the integration of Cross4all WebPHR applications (PHR system in North Macedonia and PHR system in Greece), their interconnections with a mobile application for citizens, a mobile application for professionals, an e-Prescription and an e-Referral system as well as their interoperability [8] [12].

To ensure collaboration between these applications, it is necessary to comply with suitable healthcare protocols for that purpose, protocols that enable secure communication and data exchange, as well as flow control [13]. On the other hand, it is essential to specify appropriate design patterns to facilitate communication between systems and to harmonize endpoint data formats. The paper also gives a comprehensive overview of the medical data transformation processes, data itself, and the different changes on the data because of the impact from the various applications that manipulate them [8] [14] [15] [17]. Different problems regarding the sharing, encryption and synchronization of medical data and their possible solutions are also presented. The operations presented within this paper include E-prescription and E-referral sharing in a secure manner [13]. According to that, aiming to establish a secure connection between these applications, each application uses the capabilities provided by the HTTPS secure protocol such as end-to-end data encryption. In addition, all of these applications export functionalities of the OAuth 2.0 security protocol for client authentication and authorization. Regarding the OAuth 2.0 security protocol, each system authenticates clients using the unique bearer token. Furthermore, as a primary communication protocol, the RDF Turtle data format is adopted exchanging throughput over the aforementioned HTTPS secure communication channel.

The main task of the system presented in this paper is to enable the availability of medical records for patients, anytime from anywhere [12]. There are many benefits to different users of this system. The doctor's role as a user of this system gains access to detailed medical information about their patients regardless of whether they have been treated in their own country or abroad (specifically in this case of North Macedonia). Furthermore, patients as users of this system have open opportunities and are free to do their regular medical examinations whether they are in their country or cross-border regions.

The rest of the paper is structured as follows. The background work is described in Section 2. The next section depicts the architecture of the system, while the subsequent session highlights the KeyCloak Security Service. Section 5 describes the WebPHR system that operates for Cross4all participants in cross-border regions, composed of WebPHR, e-Prescription and e-Referral system and 2 mobile applications for monitoring of vital life signs that store data in WebPHR database servers, depending on the country of living of the patient. The last section provides concluding remarks.

2 Background Work

Digitalization confronts medicine with huge challenges and opportunities. Different systems have been developed in the past in various areas of medicine, starting from the simplest systems for managing medical data and data for the patients up to the complex systems that enable real-time monitoring of the health status of the population, and all that in order to establish better and higher quality services to society. In a dynamic society where technology is evolving enormously and the amount of information is increasing day by day, the availability of information is a key process. Accordingly, authors in [4] have presented cloud-based solutions that enable the availability of medical data for the population from anywhere and at any time. Furthermore, the authors in [9] have designed a patient-centric system that enables the population not only to upload their medical data but also to visualize and analyze them.

The environment packed with many different smart IoT (Internet-of-Things) devices and sensors pose a different perspective in medicine. Inspired by it all, the authors in [10] process the various technologies currently in use regarding reminding the schedules for taking medicines, remote monitoring and tracking patients. Furthermore, the authors in [6] have presented a Medication Management System (MMS) whose aims are to automate the whole process of medication management and drug supply using IoT-based devices. While on one hand, we have IoT-based applications that establish a completely new sensory infrastructure, on the other hand, we have applications that are based on the existing sensory infrastructure that is in the devices that people use every day, the mobile devices. Accordingly, the authors in [8] present some aspects of the developed novel cloud architecture intended for the Cross4all project related to the usage of mobile devices. Moreover, the authors in [2] present a platform that helps doctors and patients to be in more close communication through appropriate drug management mechanisms that patients should receive daily.

Data mining techniques have gained momentum in the last decade. All this is especially evident in the healthcare domain [7] because advanced medicine provides large amounts of useful data on daily basis. Accordingly, the authors in [1] process various data mining techniques that can be applied in the healthcare domain. Furthermore, the authors in [3] have presented various data mining techniques applied to real medical patient data including time series. More specifically, the data-set used in [3] contains real medical data for a patient from two medical fields: stabilometry and electroencephalography.

The Cross4all model takes advantage of all mentioned technologies and concepts, using the concept of patient's centric system used in cross-border regions [12] [17]. The starting point of this system was the scenario of the creation of electronic personal health records (PHR) for patients in cross-border regions in a secure way and according to the participant countries' law [15]. The central point of the cross-border architecture was the webPHR system [12] [14] that collects data in two database servers on the two sides of the border, depends on the patient's country of living [8]. The security preferences are set to AAA with KeyCloak servers [13]. Two different mobile applications are connected with WebPHR – mobile application for professionals and mobile application for citizens [15] [17]. Mobile applications use the Bluetooth connection to store data in mobile devices and they are sent to the WebPHR of the

patient [20]. All these data are at the disposal of the patient, who is the PHR owner and central person in the webPHR system [12]. The patient can grant permission temporary to the selected medical person – role doctor who can access to their PHR and see the patients' current and past conditions [14], diseases and take action creating some new examination with their own medical devices, creating prescription or referral for the patient, using e-Prescription or e-Referral system [12]. We have to mention that all digital assets from the Cross4all eco-system are made following the Web Content Accessibility Guide (WCAG) compliance standards and are accessible for the disabled population, elderly citizens and children, which increases nowadays [18] [19]. The usage of this patient-centric model demands efforts for increasing digital health literacy and e-health literacy as well as the awareness for self-healthcare management of the population [18].

All mentioned parts of the Cross4all eco-system are tested in the real environment in the two cross-border countries [14]. This webPHR system can be used together with medical devices connected as IoMT connected with mobile applications. The patient who owns PHR can benefit from this system and connected medical devices because of the increased number of evidence-based medicine data, needed in the process of decision making when the medical persons (doctors) have to take some action for improving the patient's medical status and give some prescription or give him some referral to specialists [15]. In addition, the patient who is in the distance from hospitals and has medical devices for monitoring vital signs of living can benefit also from this system. The patient from distance can have online help from their selected medical person because the patient can have their e-prescription or e-referral according to the stored data from these medical devices as evidence-based medicine data [14] [15]. All mentioned scenarios and Cross4all tools will be briefly explained in the rest of the paper.

3 Cross4all System Architecture

The architecture of the Cross4all eco-system discussed in this paper is composed of applications developed in different technologies using different principles. The main component of the architecture in the Cross4all security system is KeyCloak that is used to protect all modules of the platform and both webPHR systems. Two instances of such KeyCloak system work in different environments to establish secure access to the webPHR systems [5]. Moreover, platform architecture consists of two systems that operate in two participant countries in the Cross4all project. The webPHR systems communicate with each other using RDF-Turtle as a data format over the secure HTTPS protocol. Figure 1 presents all constituent components of the Cross4all platform.

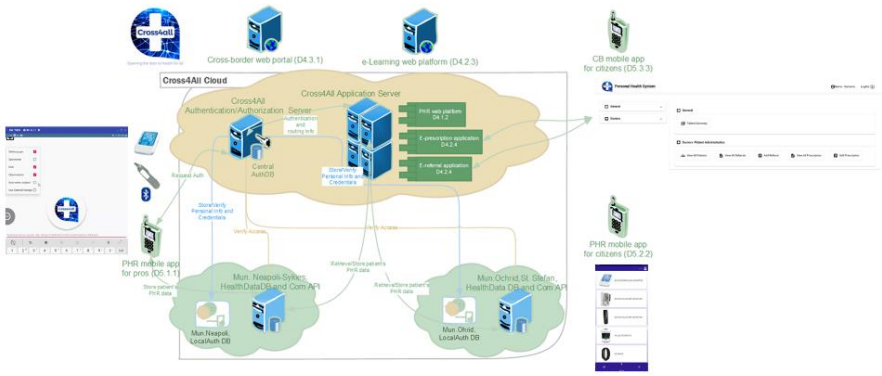

Fig. 1. Cross4all eco-system main Architecture.

4 KeyCloak Security Service

The KeyCloak system is an open-source Identity and Access management solution developed in the Java programming language that offers a wide range of features that aims to protect present-day applications and administrations. Some of the key features that offer the KeyCloak system are presented below:

- Single-Sign-On
- Identity Brokering and Social Login
- User Federation
- Client Adapters
- Admin Console
- Account Management Console
- Standard Protocols
- Authorization Services

Within the Cross4all platform, the whole process of authentication and authorization users takes place through the KeyCloak service, ie more precisely through one of the two available instances. Each KeyCloak instance aims to serve specific requests. Requests intended for the E-PHR in Greece are served by the KeyCloak instance in Greece, while the requests intended for the E-PHR in North Macedonia are served by the KeyCloak instance in North Macedonia, respectively.

The quintessential workflow starts when a client access one of the E-PHR applications. The E-PHR applications are available at different web addresses that facilitate the process of forwarding requests to the right KeyCloak service. Accordingly, there are two possible use-cases described below:

- If the client accesses the web address that corresponds to the E-PHR in Greece, the request will be automatically forwarded to the KeyCloak instance in charge of the security of the E-PHR system that operates in Greece.

• If the client accesses the web address that corresponds to the E-PHR in North Macedonia, the request will be automatically forwarded to the KeyCloak instance in charge of the security of the E-PHR system that operates in North Macedonia.

These KeyCloak instances are synchronized with each other all the time and contain all data related to the clients from both countries that participate in the project.

5 WebPHR System in North Macedonia

WebPHR System that operates in North Macedonia is composed of four main applications (WebPHR, cloud-based PHR application, mobile application for citizens, mobile application for professionals, and in addition e-Prescription and e-Referral system) and each of them has its own role/purpose. The WebPHR applications contain the patient healthcare record with different types of personal data connected with patient's health, data collected from mobile applications for citizens and professionals as well as scanned documents that patients receive during physical examinations in the hospital. The mobile applications for citizens and professionals offer a variety of services to both medical staff and patients and store data into patient PHR. The e-prescription and the e-referral system are mostly connected with the decision of a medical person – doctor in order to create a prescription for the patient who can be in both cross-border sides and can use prescription and referral according to their need for medical healthcare.

5.1 WebPHR Application

The WebPHR system is a cloud-based application developed according to FHIR standards and given ontology frame taking into consideration the personal healthcare data privacy issues in two country participants. Figure 2 presents the structure and the used technologies in the development process of the web-based E-PHR application.

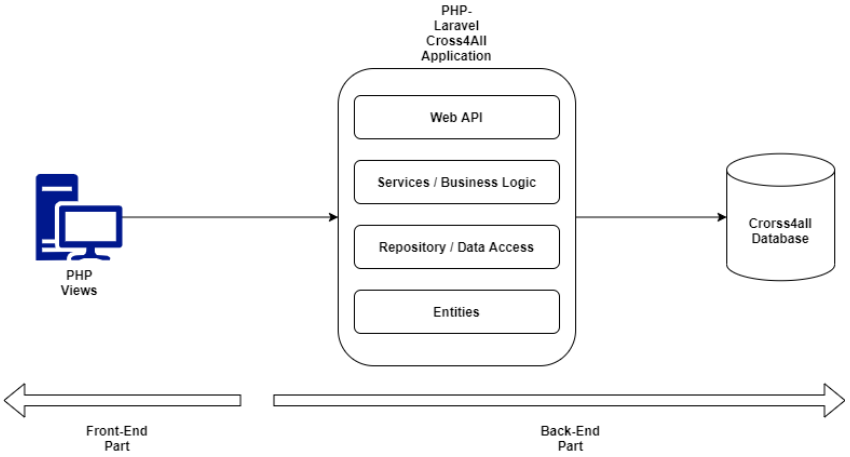

Fig. 2. Structure of the WebPHR application.

The main purpose of the web-based PHR applications is to digitalize PHR data as well as to collect medical data and documents from hospital information systems. The digitalization of such obsolete medical documents opens up a wide range of possibilities [12] [14]. One of the most important possibilities is that PHR enables the freedom of the patient to be treated in two countries participants and to have in the PHR history of examinations, referrals and prescriptions to be available to doctors in both countries. For this purpose, the WebPHR application contains two roles: patient and doctor. The patient role on this application has access to his/her own medical records/documents. The patient can give the grant permission to the Doctor role who can access the patient PHR. The doctor role on this application can have a detailed view of all patients that have given the grant permission to this Doctor and who is registered on the system. In addition, the doctor role can enter e-referrals or e-prescriptions for patients who gave him the grant permission. Figure 3 presents a personalized view based on the role played by the accessing user.

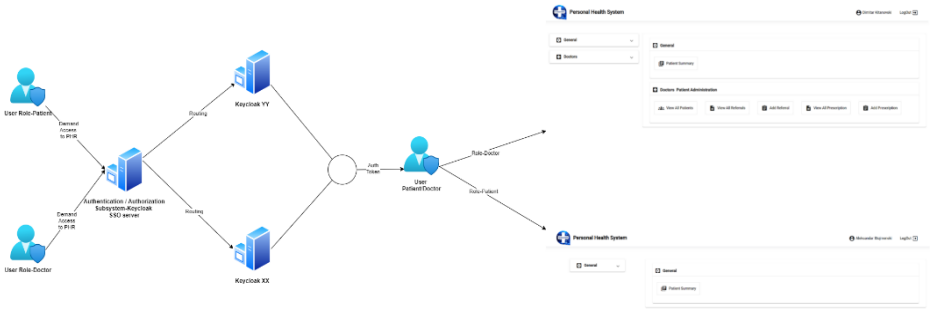

Fig. 3. Cross4all WebPHR role-based personalized view.

5.2 Mobile applications – for citizens and professionals

The Cross4all eco-system contains two types of mobile applications for monitoring the vital signs of living of the patients. Mobile application for citizens is mostly connected with the behavior of role Patient who can have this mobile application connected with medical devices according to the concept of IoT. The patient can start this application and save data into their PHR through mobile apps for citizens connected with some medical devices for measuring the vital sign and send to WebPHR. The doctor role can have access to the WebPHR and see the patient's data who gave him the grant permission and can advise this patient to take some actions or give some prescription through e-prescription system or send him/her to a specialist through the e-referral system [15] [19].

The role Doctor in the WebPHR also can have an appointment with the patient and make some measurement using the mobile application for professionals [17] connected with medical devices as Littman stethoscope, ECG, weight scale, body temperature, spirometer, blood sugar, SpO2 meter or blood pressure monitor. The doctor can start the mobile applications for professionals, collect data into mobile devices

with Bluetooth, and then sent them into the patient's WebPHR database. According to these data, the doctor will have evidence-based data for better decision-making and give recommendations to the patient or give them some e-prescription [15].

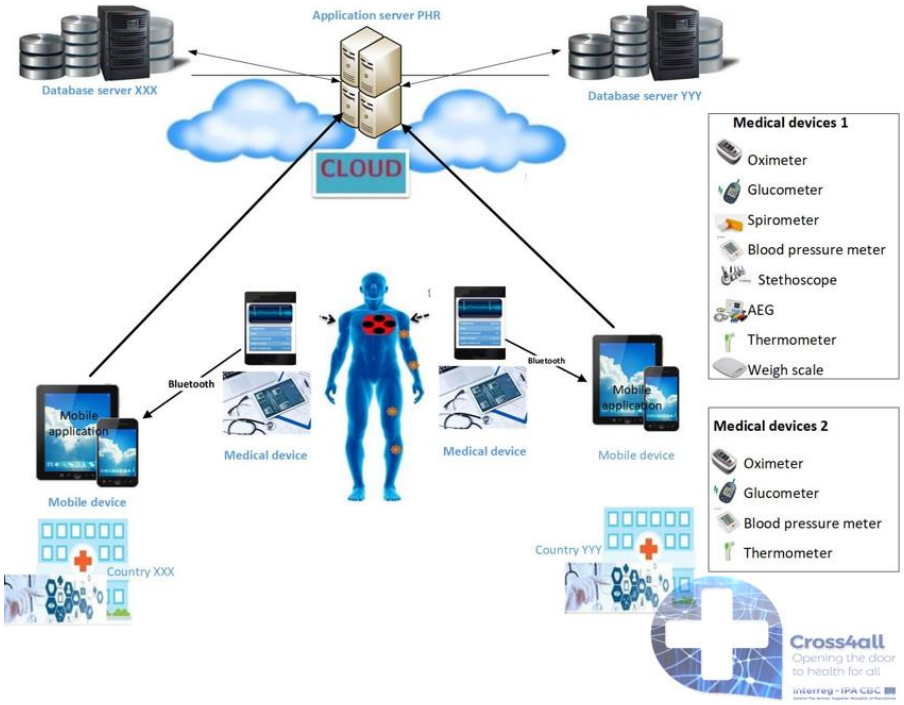

Fig. 4. Cross4all Mobile apps: for citizens and professionals connected with WebPHR.

5.3 E-Prescription Module

The purpose of this module is to enable the doctor's role to create medical prescriptions related to their patients in digitized form, rather than creating them on paper, especially when the patient crosses the border. This module enables the creation of medical prescriptions and their storage in a centralized place in patient's PHR. Using this form of prescription, the doctor enables the availability of the medical prescription of the patient, regardless of the place where the patient resides at the moment. This concept gives the freedom to the patients to buy their medication anywhere (in their own country or abroad). Figure 5 presents the activities that have to be performed to create a medical prescription for a specific patient.

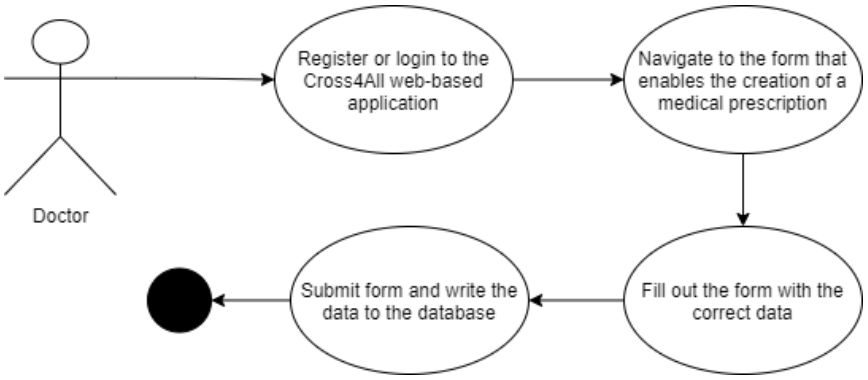

Fig. 5. Activity diagram for creating a medical prescription

On the other hand, this module enables the patient role to preview all medical prescriptions related to them. Additionally, this module enables to share particular medical prescriptions with the role Pharmacist or the Doctor role within this system.

5.4 E-Referral Module

The main goal of this module is to enable patients to undergo a medical examination in a foreign country, providing a digital referral form created by a doctor located in their own country. The module enables creating of e-referrals and storing them into the cross-border PHR system. Afterwards, the patient can choose to which doctor he would like to share his medical details (including the e-referral). Using this form of referrals, the doctor in the foreign country can receive all medical-related conditions for the patient without having to read paper documents written in a different language. The disease history of the patient is identified with ICD 10 [21] codes unified by the World Health Organization, enabling foreign doctors to read the patient's history without confusion. Figure 6 shows the interaction with patient's referrals through different doctor's institutions.

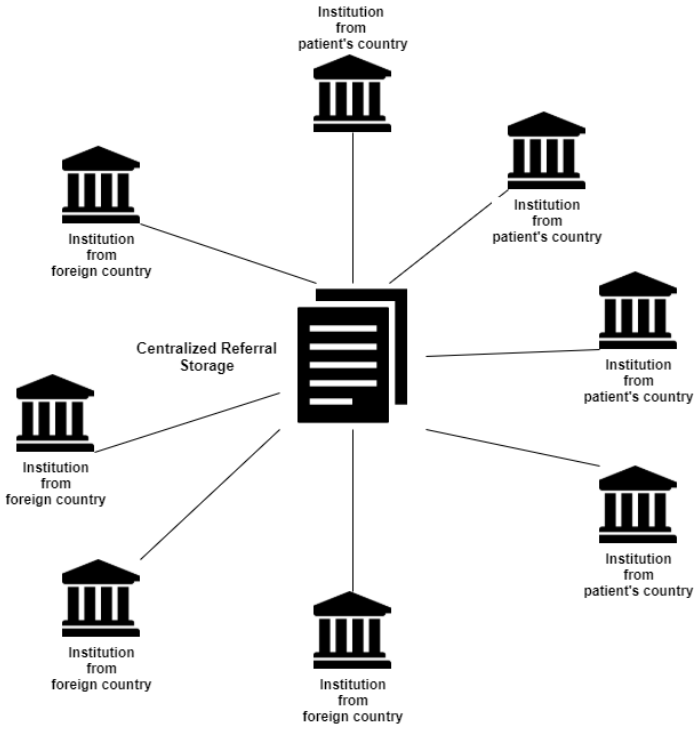

Fig. 6. Activity diagram for creating a medical prescription

6 Conclusion

Today's emerging healthcare situation demands quick access to patient's healthcare and medical data. Many problems arise from a lack of information for patient's chronic diseases and their treatments data stored in private HIS without the possibility of their integration. With a concept used in the Cross4all project and the proposed model of a WebPHR, PHR-centric healthcare system according to HL7 standards we tried to solve some problems about the lack of information about the patient health-related data when the patient cross border. Many security and privacy problems across the border were solved especially in the part of PHR, e-prescription and the e-referral system. This model of the cross-border cloud-based PHR integrates also mobile applications for citizens and professionals connected with sensors for monitoring vital signs of living as well as medical devices connected with mobile devices with Bluetooth. As the Cross4all eco-system supports the roles of patient, doctors and pharmacist and the main role is the patient role, the patient can temporary give the grant permission to the doctor role to see their PHR, to create new data entry into their PHR with the mobile application for professionals or create e-prescription or e-referral. In this case, the doctor role can give temporary grant permission to the role of the pharmacist.

The patient also can have his/her own sensors for the vital signs of living monitoring and in this way to provide data for their medical situation and behavior. These

data also can be sent to the WebPHR and doctor can see these data from distance. This system provides evidence-based medicine and can help for improving the process of decision-making of the doctors from which benefits the patient as well as the doctor.

It is worth mentioning that the exposome and omics data can be used in the future by the patient and doctor role, providing a healthcare risk assessment of the patient, taking into consideration its PHR status, disease, medical data, exposome and omics data [11] [16].

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