A Blockchain Solution for Universal Electronic Health Record: Mexican Healthcare System Case

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***Abstract*—The Mexican health system cover around 69 million people by public healthcare programs and private institutions. A universal electronic health record (EHR) is a fundamental software to enhance the quality of medical services and administrative procedures, and only until 2013 the law focused in this topic was decreed. Due to this, the EHRs in Mexico are very fragmented and have little coverage throughout the country, also they do not comply the international requirements and the totality of the public standards. In this work the technical, functional and legal requirements for EHR systems are presented and described where blockchain technology arise as a fundamental framework to meet them, also a review of conventional server-client EHRs in Mexico and the most important blockchain based EHR implementations are exposed. Finally, the architecture, the components description and the software design patterns necessary in a universal EHR are exposed and explained, in which the technical and functional requirements are accomplished, and in the case of the Mexican healthcare system the legal requirements are met too.**

***Index Terms*—Electronic Health Record, EHR, Blockchain, Mexican Health System, Decentralized Storage.**

I. Introduction

As most of the countries in the world, Mexican health system has two main components: public and private. The public sector is composed of social security institutions that provide service to formalized workers through the public institutions such as Instituto Mexicano del Seguro Social (IMSS), Instituto de Seguridad y Servicios Sociales de los Trabajadores del Estado (ISSSTE), among others. These institutions have been used to implementing public social health programs like IMSS-Bienestar, Seguro Popular de Salud (SPS). These public programs are focused on people without formal health security. On the other hand, private entities can be accessed by everyone that can afford the service and it is provided by institutions that not belong to the government.

According to the last population census, Mexico has 126 million of people inhabitant [1]. A Mexican patient can be assisted in one of the 4903 hospitals in the country [2]. The private hospital are the majority, with almost two thirds of total, but also most of them are small establishments (only around of 6% of them have more than fifty beds [2]). In contrast, the IMSS is the biggest public institution, there almost 69 million affiliated people are assisted, and IMSS-Bienestar more than 11 million of not affiliated persons [3], between them assist the sixty-three percent of the Mexican population.

Public and private institutions lack fundamental problems that can not be allowed in a critical industries such as the healthcare system like a low number of medical personnel (a hundred thousand deficit [4]), a restricted per capita budget (second-last in the OECD countries [5]), a not reliable and non-standardized electronic health record (EHR), medicine shortage [2], etc. In this work we present a decentralized application architecture that focus on the most demanding features in the medical industry for the EHRs, from law accomplishment to the specific requirements in the healthcare institutions to manage patients, doctors and the administrative workers.

Medical records in Mexican hospitals, electronic and not electronic, are stored locally, in a centralized server (electronic) or physical proceedings. These records are not shared neither among other hospitals, patients or doctors, and even sharing data between different hospital sections may be difficult. Useful and valuable patients health information is lost or mutate due to the fact that records are only stored locally, since they are not transferable, patient can not access to his own record (unless a court order demands it), even the details of the record are lost if a transfer to other hospital is needed, as the record given to the patient is only a summary. It is also common the misinterpretation of handwritten records and the loss of a paper or prescription, this cause a bad diagnosis, bad treatment and even death, being medical errors the third leading cause of death in the USA [6].

The EHRs were not considered in the Mexican General Health Law until 2013, when NOM-024-SSA-2012 was decreed, which imposed on the health industry that an EHR system would be mandatory. In the NOM-024-SSA-2012 the criteria and requirements are established for the gen-

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eration, storage, interpretation and exchange of information among Electronic Health Record Information Systems [7]. There the requirements imposed for the EHRs are technical and functional, since the connectivity requirements demands an architecture that meets the open connections with some government web applications/APIs. In general, the technical and functional requirements in NOM-024-SSA-2012 and the observed by patients and doctors, for a universal EHR are as follows:

- Interoperability. The ability to exchange information between hospitals, institutions and medical doctors is required, where the patient owns his data and also has the power to share their records to multiple or different health providers, pharmaceutical companies, research institutions, etc. The capability to add complementary information to his record like vital signs history, administered vaccines, diet, recreational drugs, hours of rest and exercise, etc. is mandatory.
- Low latency. A rapid response is fundamental in critical operations as medical ones. This is a tough task mainly because of the amount of data that needs to be processed, stored and queried.
- Big data storage. Management and storage of a large amount of data must be supported, since a hospital generates approximately fifty Petabytes per year [8]. A distributed storage scheme must be used to guarantee this characteristic, mostly for imaging files.
- Data robustness. Information always be available, private, secured and protected to data leakage, immune to changes and losses. Blockchain technologies, through its natural cryptography properties, can guarantee immutability of the records, authentication of patients and doctors, and also security and privacy of the data [9].
- Treatment optimization and utilization of the data. Correlation of historical data of a specific patient to improve of their treatments and diagnosis assistance through Artificial Intelligence (AI) is one of the most priorities, because 97% of the health data is not used or even accessed after their collection [10].
- Medical inventory. Besides the medical record, a list of available medicine, medical equipment, items, vehicles, furniture are fundamental, as well as traceability of all these medical objects is desired.
- Compatibility with generation of assisted reports. Automatic reports generation for institutions that interact with the law as insurance companies, pharmaceutical institutions, etc. The advantages of these reports are the streamlining of legal issues, the protection of patient rights and transparency due to the immutability of registers.

In addition to the technical and functional requirements, a universal EHR demands international standards to allow the interoperability, information privacy and software requirements, the most important them as described below:

- International Statistical Classification of Diseases and Related Health Problems, ICD. It is an international standard, published by the World Health Organization (WHO), and as its name indicates, it classifies and encodes diseases, symptoms, causes of diseases, injuries and death, etc. The most recent version, ICD-11, was approved in 2019, and it is mandatory to be adopted in any electronic health record system [12].
- Health Level Seven/Fast Healthcare Interoperability Resources, HL7/FHIR. FHIR is a standard for data format, encoding and exchange of information between different health systems, an evolution from previous versions of HL7, that supports standard web communications like HTTP/HTTPS, JSON, XML and REST API support [13]. Interoperability can be achieved with both ICD and HL7/FHIR because the data is well formatted and obeys both standards, the remaining task would be the transmission of information through a secure channel.
- Digital Imaging and Communications in Medicine, DICOM. Imaging standard that establishes the way in which medical images are stored, printed, acquired, compressed (without loss) and shared through a network [11]. This is an especial standard for every EHR application, mainly because imaging is the most demanding area of the project, in terms of storage, processing and data acquisition processes.
- Cryptography. The privacy of data is a main topic to be solved and an aspect to take into account, since the information shared between systems are confidential and private. HTTPS protocol for internet related communications is widely used in web applications like [21]. Blockchain raises as a key technology that employs cryptography natively, and which recently has been adopted by many of business projects. Blockchain in EHRs has been employed for the construction of decentralized records in which each node of the network has a copy of the medical registers, where the records are immutable since any addition or modification operations to the database are registered, using cryptography and making this chain of linked entries immutable, even if that registered information belongs to the authentication, diagnosis, prescriptions, treatments and laboratory tests. Finally, the decentralized finance (DeFi) enables the peer to peer exchange of cryptocurrencies between patients or members of the network allowing the establishment of new types of medical services, and making introduction to the industry easier. [14]- [16].

This work presents a solution for the universal EHR that meets the requirements before stated, composed by a web client in which medical institutions will build the records by registering every medical activity. A blokchain, also known as ledger, containing medical information of the institution, text data and imaging files of the patients. Distributed databases implemented through blockchain technologies, and a REST API as interface between the web client and databases to guarantee instantaneous access, data integrity and immutability. The implementation of standards like HL7/FHIR to enable the storage of medical records meets the interoperability requirement between institutions, which is a mainly feature within the objective of the proposed system.

The structure of this paper is as follows. In the section two we present a summary of EHRs in Mexico and also blockchain based EHRs. The section three describes the proposed universal EHR system. Section four, presents the discussion giving the advantages and disadvantages of the proposed system, and finally, the conclusions section is exposed.

II. Electronic Health Records

This section explores Mexican EHRs, we introduce two EHRs raised as public initiatives and officially used in the states of Colima and Ciudad de México (CDMX), that have achieved great results, also a private project that is in accordance with NOM-024 is described. The main characteristic of these EHRs is that institutions and medical doctors have the power over data, patients have not control on their own records. Secondly, countries like Australia, Estonia and Finland have EHRs similar to the ones reported in Mexico [17], then we focused to blockchain based EHRs, three of the most important are briefly described, where patient empowerment over his data is the main objective.

A. EHRs in Mexico

Mexican EHRs were born twenty three years ago with NOM-168-SSA1-1998 and since then, sixty five public health EHRs were created [19]. State governments are the main promoters, being Colima and CDMX the ones that have achieved significant results. "Sistema Administativo del Expediente Clinico de Colima" (SAECCOL) is present in every public hospital that assist non-social workers, a total of 134 facilities [18]. Its main objective is to register medical information in a digital, continuous, efficient and allowing the storage and exchange of EHRs between the hospitals network of the state. The main components of this EHR are a desktop application and a real time updated website. This system has also been implemented in some institutions in Guanajuato, Chiapas and 202 hospital facilities in Tlaxcala that corresponds to a 100% coverage in that state.

"Sistema de Administracion Medica e informacion Hospitalaria" (SAMIH) is an EHR that connects thirty one hospitals around Mexico City. It has been recognized as a platform that fulfills HL7 requirements [19], and as a consequence interoperability within the hospitals is guaranteed. SAMIH has reduced waiting times for the patient, improved security and identification of patients with a unique and only record in the system, a better tracking of vaccines, allergies, drug dependencies, etc. Since its implementation, more than four million of patients have been registered and contributed to the generation of health statistics employed in the development of more efficient public health programs.

On the private side of EHRs, there are systems that are mostly adapted to the specific requirements of the institutions. Medisel is an EHR offered mainly to individuals and medical doctors [21]. It is a platform aligned with NOM-024-SSA3-2012, used by more than two thousand medical doctors, with the record of five million of patients and being active since 2007. This platform includes telemedicine services, prescription administration, laboratory tests, statistical reports, appointment administration, among other functionalities.

B. Blockchain based EHRs

Currently, there are several EHRs that take advantage of innate characteristics of blockchain technologies, being a distributed database acting like a historical ledger, and giving immutability to the recorded entries in the ledger, enabling desired behaviors to the cryptocurrencies, DeFi, etc. A summary of EHRs based on blockchain technology is introduced.

Medicalchain is a decentralized platform that allows the exchange, usage, and fast access of medical data [14]. They use blockchain technology to create a single EHR of the user that has total control of who can view his records, how much and for how long. Medicalchain is also a platform for digital health applications fed by the data of the user. Currently, two applications are being developed in this platform, a telemedicine app that enable a user to consult a doctor at the distance and an marketplace that allows a commercial negotiation between the user and third parties for the usage of his health data.

Medical Veda is very similar to Medicalchain, they have a distributed EHR, decentralized data management, where the user is the owner of his data and has the power of sharing and negotiate with third parties for the use of their records [15]. An attractive aspect of this project is the introduction of capabilities of DeFi, in which peer to peer lending enables users to carry out procedures and also gives this opportunity to doctors so that they can get capital for medical projects. This is made through an ERC-20 token deployed in the Ethereum network. AI-based chat bots that use big data and machine learning are also available for mild diseases or an initial diagnostic.

Solve.Care [16] have as main objective to diminish the excessive healthcare administration costs, where up to 30% of medical bills goes towards administrative fees, this money should be directed to improving healthcare services. By utilizing blockchain technologies individuals control health related operations as making appointments, sharing records, comparing prices, managing prescriptions, make payments, etc. Their first client was a big health organization, Arizona Care Network that has 250 thousand patients, five thousand doctors and two thousand locations. In Table 1 the main blockchain related characteristics of the projects mentioned are shown.

III. Proposed System

The proposed EHR system is based on development technologies such as Blockchain, Model View Controller (MVC), Distributed Databases, REST API and the Ethereum platform to implementing an ERC 20 standard token. The architecture

Table I
BLOCKCHAIN BASED EHRS

Characteristic	Medicalchain	Medical Veda	Solve.Care
Blockchain technology	Ethereum/ Hyperledger Fabric	Ethereum/ Hyperledger Fabric	Ethereum
Consensus protocol	Proof of work/ PBFT	Proof of work/ PBFT	Proof of work
ICO/IEO (USD)	$0.25 ICO	$0.16 IEO	$0.1 ICO
Capitalization (USD)	$1,284,914	-	$23,390,436
Marketplace	Yes	Yes	Yes
Status	In Operation	In Development	In Operation

PBFT: Practical Byzantine Fault Tolerance
ICO: Initial Coin Offering
IEO: Initial Exchange Offering

of the whole EHR system meets the SOLID principles [22] and the architecture requirements for blockchain applications [23] to optimize the development and support processes starting from the software design step. The general architecture of the proposed system is shown in Fig. 1 where each layer only can invoke methods in the layer below and the result must be given to the layer above accomplishing the Inversion Dependency Principle. The transversal layer must contain only utilities, helpers and entities definitions. Each component of the system, its technology and main objective are described below.

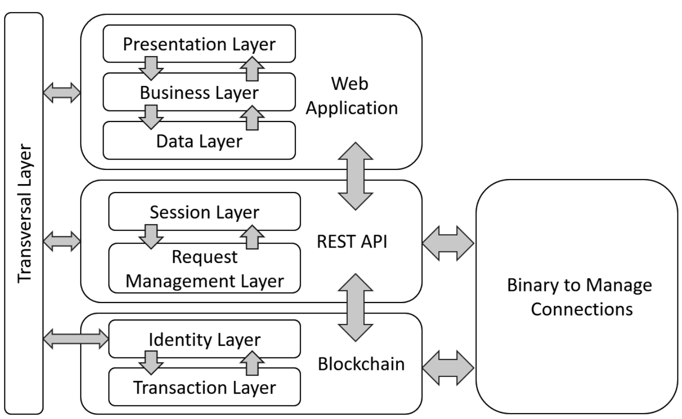

Figure 1. Components, their layers and interactions in a universal EHR system.

A. WEB Client

The user interface of the EHR system must be implemented as a WEB Application, and the design pattern that must be used is MVC, because its implementation allow to add new features, updates and bugs corrections easily, since the structure of the project diversifies its specific functionalities at the level of single files, so by this way the Single Responsibility Principle and Open/Close Principle are implementing in the system.

B. Distributed Database

The data storage technology is a critical issue considering that the loss and mutability of the data is a common problem in today's EHR systems. Due to this, a fast and immutable distributed database is needed to store information, so the Blockchain technology is mandatory to meet that requirements. All data within the database must be encrypted using a symmetrical cryptography, since the patients must have the keys to have greater control over their own information.

C. REST API for Blockchain Access

An API REST server is needed to access the storage information in the EHR system by a structured read processes, and the changes made it to records must be done through transactions, so the immutability and traceability for information of EHR is ensured. The REST API must be implemented through the HTTPS or TLS protocols to prevent phishing and others identity supplanting techniques.

D. Binary to Connectivity Management

To allow a third party nodes to contribute with the decentralized EHR database to empower the patients and doctors, a desktop multi-platform application to management the connection to the blockchain network is fundamental, since through this software the community have a way to verify the integrity and transaction history of the EHR data, even without an access to the information decrypted. This binary allow to any user to join and have a copy of all information, but the keys remains only belongs to the patient preserving the privacy of data.

Taking into account each component definition of the technological solution, we now explain the way that they are integrated to meet the technical, functional and legal requirements for a universal EHR implemented within Mexico.

IV. RUNTIME AND DISSCUSSION

The medical institutions are the only type of nodes that can access to the WEB Client and REST API. The client must be implementing in a traditional server-client schema using the MVC pattern, since each computer within the VPN of hospital must have to access to the client to read/modify the information, this must be conducted through an Object Relational Mapping (ORM) component to bring the capabilities needed for the data model. In the same way, the REST API must be allocated within the same server to manage the requests generated by any user in the web client and interact with the blockchain network as read/writer peer. To allow the decrypt and writting information in the blockchain the subscribers must be verified, this is done through the use of the binary to manage connections, this send request to a central server to obtain a proper credentials, and the verification must be done manually. Also, this connection generate a token to specific permissions requested.

All the requirements are reviewed in the following points, to expose how to achieve it and how it should work.

A. Standards

All information in the distributed database must be encrypted and the key is only given to the medical institutions by previous approve from the patients. The structure of the database must contain a constant values for the ICD standard, by this way the relation between the records of each patient must refer to that registers. Also, all information stored must formatted following the resource-type pattern exposed in the HL7/FHIR standard to ensure the native compatibility with the standard. Finally, the DICOM standard must be implemented through the use of a compression/decompression algorithm recommended, a compatible VPN network structure for institutional users, and with an interface that make the read/write processes seem a conventional server-client schema.

B. Interoperability

Being one of the main requirements, it is fundamental to provide a native interoperability capability within the universal EHR, this can be reached through the standard implementation mentioned above and including import/export services within WEB Client. That services must taking into account the extension resources types (FHIR) and private specific structures mappings.

C. Low Latency and Big Data Management

The low latency is reached through the use of the decentralized database, since exists two types of servers. The first is the private and third party members that join to the blockchain, and the second is the local server of the medical institutions which is an anchor peer of the blockchain network, also, this decentralized structure gives the big data management capability to the universal EHR system. For the case of distributed database with blockchain technology the consensus protocol must be chosen taking into account a quick response of the network (Proof of Elapsed Time protocol is recommended).

D. Data Robustness and Immutability

The blockchain technology provides a native immutability and data robustness to the information stored, but also the consensus protocol must be chosen prioritizing the stability of the network, because protocols like PBFT have the chance to corrupt the network if the "bad" nodes exceeds the 33% + 1 of the total of nodes.

E. Medical Inventory and Assisted Reports

The assisted reports are of two types, AI assisted diagnostics for the patients and medical reports for the insurance or pharmaceutical companies etc. Since the EHR system have the whole clinical history of the patients, AI assisted reports for treatments and diagnostics can be generated with more accuracy, having a direct impact in the patient healthcare. The autogenerated medical reports for several types of companies are useful, since the data provided and the traceability of the information are the most demanding and desired characteristic, and due to the technology used in database this capabilities are covered. The medical inventory and traceability is included within the EHR system with the blockchain technology capabilities.

By the criteria exposed above, the recommended technologies to implementing the components in the universal EHR should have frameworks with Long Time Support (LTS) versions, due to this the suggested frameworks are shown below. For the WEB client is mandatory an MVC framework like CakePHP (PHP), React (Javascript) or even DJango (Python). In the case of REST API server this can be implemented in any web server framework like NodeJS (Javascript) or ASP.NET (C#), and the blockchain distributed database must be developed with a framework that allows to manage the join/leave processes from an independent binary, the read/write permissions and compatible with TLS protocol.

V. Conclusions

The technical and functional requirements for a universal EHR were introduced, also the legal needs for this type of application in Mexico were shown too. A brief review of conventional server-client schema and blockchain based EHR implementations were presented, where the blockchain emerge as a critical technology that must be in charge of managing the stored information. Starting from whole requirements we presented the architecture of a universal EHR system, also the technologies, target objectives and their descriptions of the components of the system were presented and explained. Following the structure and design patterns specified in this work, the EHR system developed meets the technical and functional requirements specified in the Mexican General Health Law NOM-024-SSA-2012, at the same time, the international standards like HL7/FHIR implemented gives to the system a native interoperability with the existing EHR systems allowing a smooth market transition.

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