Blockchain-Based Architecture Supporting Hypertension Remote Monitoring in a Cloud Environment

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Abstract

The prevalence of chronic diseases in the world is increasingly high. In Algeria, hypertension is considered the first chronic disease. Furthermore, some problems such as limited resources and professional isolation in the health area complicate taking care of persons with chronic diseases. In this case, remote medical monitoring is a necessity. Indeed, information and communication technologies are valuable tools used to establish and maintain connections among healthcare providers and between healthcare providers and patients. Cloud, blockchain and mobile devices are being promoted as a technology that can play a vital role in health. This paper describes an architecture based on blockchain for remote medical monitoring and hypertension measurement control.

Keywords

Blockchain, hypertension, remote monitoring, electronic medical record, chronic diseases, measurement control.

1. Introduction

The number of undiagnosed persons with high blood pressure, untreated and uncontrolled, is rising. If hypertension is detected early, it is possible to reduce the risk of heart attack and other complications. Self-controlling and monitoring of blood pressure are recommended for managing hypertension, particularly for persons who have limited access to health services due to geographic, physical, or economic reasons [1]. According to [2], any physiological parameter that can be measured can theoretically be telemonitored. It is the case of blood pressure. The use of modern technologies allows the communication and the transfer of information between the health care provider at the clinical site and the patient at his home. According to [3], with more than 1 billion smartphones and 100 million tablets worldwide, these devices can be valuable in health care management. The use of new wireless communications technology, such as mobile telecommunications networks, has greatly boosted telemedicine and e-health.

There are several problems in remote monitoring services for chronic disease in Algeria, such as [4]: (i) current solutions based on manual note-taking are slow (ii) obstacles to real-time data access (iii) medical staff is not up to date on the state of the patient (that curbs the ability of clinical diagnostics and monitoring) (iv) time consuming (v) traditional data storage mode is not conducive to the sharing of resources. Therefore, there cannot be information sharing among all the stakeholders. Indeed, the main difficulties encountered by the projects in Algeria, particularly the remote monitoring and control of chronic patients, are the technical, financial, and human resources difficulties. It is also about lousy information and communication technology policies [5].

Hypertension is considered a public health problem due to its high prevalence and difficulty to control, and it is also described as one of the most important risk factors for cardiovascular diseases. According to [6], patients in ubiquitous remote monitoring systems will be monitored. Therefore, new systems must have special requirements such as always-on connectivity, information storage capacity,

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and patient health care information. This requires introducing new technologies such as cloud computing for data storage and accessibility for decision support.

The usage of blockchain services to improve medical and e-health services has recently become a significant trend. The blockchain, unlike traditional databases, allows users of a dispersed network to transact electronic currency without the need for a centralized, trusted third party. Blockchain is highly suited for reliable information exchange in electronic health records because of its immutability and cryptographic mechanisms for safe communication. This technology can transform the healthcare system in various ways, including the secure exchange of EHRs and data access control among various medical institutions to increase data privacy and security [7]. It suggests a potential future data-sharing strategy that could allow for collaborative clinical decision-making in telemedicine and precision medicine [8].

This paper proposes an architectural approach supporting remote monitoring and hypertension measurement control. This architecture is based on blockchain in a cloud environment. Blockchain proposes exciting concepts for developing our system, such as decentralization and collaboration. This architecture allows the sharing, the fast and supple exchange of information, and opens new perspectives of remote monitoring in Algeria. Besides helping save costs, encouraging the control of patients at their homes may also reduce loneliness and the stress they suffer during a hospital stay. The critical point is to overcome the problem of the unavailability or lack of health personnel.

The remainder of this paper is organized as follows. In section 2, an overview of hypertension in the world and Algeria is detailed. The proposed system's architecture is detailed in section 3. The prototype implementation is described in section 4, and related work is dedicated in section 5. Finally, a conclusion with a view to the future is given in section 6.

2. Background

2.1. Hypertension

Hypertension is defined as systolic blood pressure equal to or above 140 mm Hg and/or diastolic blood pressure equal to or above 90 mm Hg. Normal adult blood pressure is defined as a systolic blood pressure of 120 mm Hg and a diastolic blood pressure of 80 mm Hg. Blood pressure is measured in millimeters of mercury (mm Hg). The World Health Organization [1] estimates that more than one adult in three in the world has high blood pressure, a proportion expected to increase with age: 10% between 20 and 39 years and 50 % between 50 and 59 years. Global statistics of this disease in 2008 show that the number of hypertensive worldwide is expected to reach 1.5 billion by 2025. Across the WHO regions, the prevalence of raised blood pressure was highest in Africa, 46% for both sexes combined. Both men and women have high rising blood pressure rates in Africa, with prevalence rates over 40%. The prevalence of hypertension is higher in some low-income countries, whereas public health interventions have reduced its prevalence in many high-income countries. In contrast, many developing countries such as Algeria see growing numbers of people who suffer from heart attacks and strokes due to undiagnosed and uncontrolled risk factors such as hypertension.

2.2. Hypertension in Algeria

Hypertension is considered the first chronic disease in Algeria. According to [9], it is recognized especially in the elderly. It is not less than 10 million Algerians are affected. Over one-third (1/3) of the Algerian population has high blood pressure. Nearly 35% of Algerians over 35 years have high blood pressure, or 7 million people over 50% of patients are unaware they have hypertension and believe they are healthy due to the absence of symptoms indicative of pathology. Hypertension is the first chronic illness in Algeria. It is the leading cause of death in Algeria. It was observed that only 26% of hypertensive Algerians are followed medically [10]. Moreover, the distance between citizens and health centers and the lack of transportation complicate taking care of persons with chronic diseases.

The health system in Algeria is based much more on treatment than on prevention. Indeed, the Algerian must measure and check his blood pressure, especially if he is obese, diabetic, exposed to stress, or older. We need to promote this tradition to measure his blood pressure.

3. The proposed architecture

Our system's principle is to collect measured data (blood pressure results) from the various physiological measuring instruments using Bluetooth wireless technology to transmit and save these data via the Internet to a remote database stored in the hospital. The proposed architecture supports remote monitoring. Figure 1 illustrates the main components of this architecture. This architecture aims to facilitate interoperability and accessibility to information and supplies actors with the same functionalities as belonging to a single structure (the same place). Indeed, the main objectives of our architecture are summarized in the following points.

1. Support at any time and in any place reduces hospitalization of hypertensive patients, especially for elderly or hypertensive people.
2. Psychological support to patients in such a way that they no longer feel alone with their disease.
3. Avoidance or reduction of risk of degenerative complications of hypertension in the long term.
4. Reduction in-home visits (lack of doctors and nurses, especially in urban areas).
5. Improve the service provided to patients and their satisfaction.
6. Composition of a stable relationship between the patient and the hospital (health personnel).

A Virtual Private Network (VPN) is established between the hospital and the patient home using wireless network links. This is achieved by sourcing the services from an Internet Service Provider (ISP). The measured data are transmitted via wireless connection; the information can be received via smart devices and uploaded in XML format. After, the system receives, processes, and saves the data to the corresponding database location. To this aim, we primarily use the BluetoothTM standard, which is available on almost every mobile phone and on a large and ever-growing number of medical devices such as blood pressure monitors.

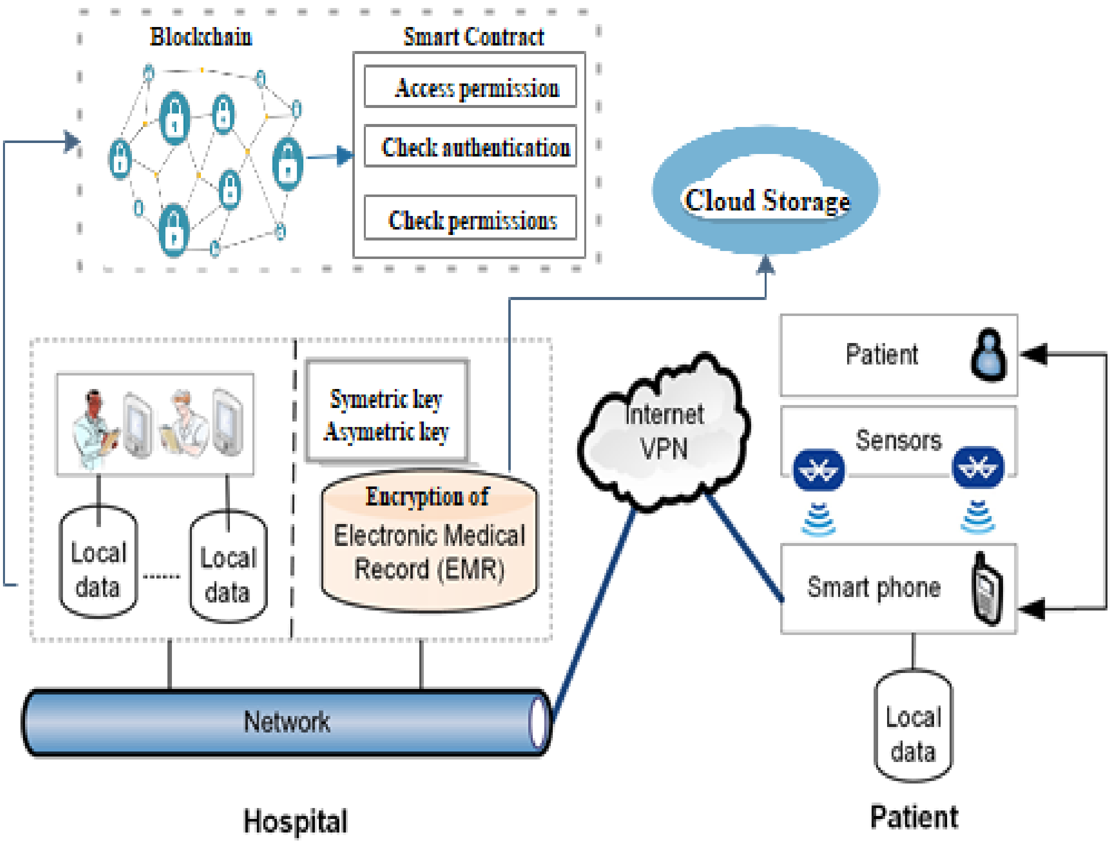

Figure 1: The proposed architecture

Some functionalities of our system are:

- Each hypertensive patient record his levies daily
- Once a member of the medical team detects the unhealthy state of a hypertensive it intervenes
- The system assists in messaging between the patient and the medical team.
- Each user can make personal notes about a patient.
- The system has an action plan, a sequence of rules, advice, and objectives. It is a practical guide for the hypertensive and the medical team.
- The action plan helps the hypertensive to:
    - Better understand their goals and the steps to achieve them.
    - Change his lifestyle as do exercise or eat healthily.
- For the care team members, the action plan allows monitoring the patient's status and knowing if the hypertensive follows the information and medical advice well.
- The system provides the ability to plan and organize medical visits.
- The interest of medical visits is to have a more thorough evaluation of the hypertensive state. While planning these visits allows to :
    - Reduce the number of unplanned and unnecessary hospital visits.
    - Organize home visits or hospitals.
- The system provides the ability to view the levies using graphs

The following sections describe and discuss each component of the architecture and its role in the system.

3.1. Electronic medical record (EMR)

At this level, this is to ensure the entire life cycle of stored medical data of patients. Each record is a trace of information and a tool for communication, information, and coordination between the different structures of the hospital to control and monitor a patient.

The EMR is encrypted using symmetric key encryption before being stored in the cloud. The symmetric key is also encrypted and uses user's public key to ensure patient privacy and data security.

The medical actors will access the databases via the Internet with any mobile device. The patient will access his medical records using credentials from these devices. Each actor has his credential, and the hospital authorities automatically generate and deliver asymmetric keys to access data. Each patient, doctor, or nurse uses their mobile handset to access the medical record. Each of the actors will have a different level of access to the EMR. This is part of the security measures to prevent any leakage of important records. Therefore, the actor needs to be authenticated before viewing the available record.

3.2. Cloud

Most Algerian hospitals do not have sufficient technology to build a private cloud. Indeed, the choice is oriented towards the community cloud. Therefore, it is essential to ensure that the provider has been in the business of providing cloud-related services to healthcare-related organizations. This ensures HIPAA (Health Insurance Portability and Accountability Act) compliance. With the community cloud, stakeholders can collaborate in real-time and share information without investing in expensive infrastructure. In our proposed scheme, the cloud saves the encrypted EMR.

3.3. Blockchain

For his well-known digital currency or cryptocurrency development, namely bitcoin, Nakamoto [9] introduced blockchain technology. Nakamoto employed blockchain technology to fix bitcoin's double-spending problem, but the new technology was quickly adopted for various other uses. Blockchain is a network of interconnected blocks that constantly grow as transactions are stored on the blocks. This platform employs a decentralized strategy that allows information to be disseminated while also ensuring that each piece of disseminated data, also known as data, has shared ownership. Blockchains are distributed ledgers that store batches of hashed transactions and are managed through peer-to-peer networks. A blockchain provides data security, anonymity, and integrity benefits without a third party. Because of these advantages, it is a fair candidate for usage in the healthcare arena, where technological innovation has made protecting patients' medical data a major priority.

The smart contract is a reusable, modular, and executable code produced and installed on the blockchain to impact any task when certain criteria are satisfied. It enables anonymous users to execute transactions and agreements without needing a central institution, external enforcement, or legal system [10]. In the proposed scheme, the smart contract-based blockchain is used to store user's access permissions, verify user's authentication and check user's permissions.

3.4. Local data

Each database is designed to satisfy local needs and not necessarily interact with other local databases. Indeed, doctors, nurses, and patients are very attached to their notes for their use. However, it is essential to share this information with other stakeholders.

3.5. Access control layer

Each actor has his or her credential key automatically generated and delivered by the hospital authorities to access EMR. On the other hand, they supply a username and password to different hospital actors to access databases. The EMR must be associated with access control for designated actors or groups of actors having the right to read the folder's contents and systematically add information or using some conditions. Our solution combines two essential access control models: RBAC (Role-Based Access Control) and ABAC (Attribute-Based Access Control). With RBAC, the users have access permissions according to these roles. It provides easier management of access rights. Indeed, health care systems (especially EMR) contain multiple users playing various roles, e.g., some users have the doctor role, others play the nurse role, and other users play the patient role.

RBAC is insufficient to control access to an open environment like the cloud. The dynamism and flexibility of the ABAC model are significant causes of our choice. The combination of both models allows combining the advantages of each other.

Each user must activate its role and create its session. To open the session, it must identify and authenticate. If the blockchain enables authentication, the session is opened, and the user can decrypt the access objects using his private key and perform operations on these objects according to the access level; else, the session does not open, and access is prohibited. In our model, the authorizations are not associated only with the roles but also with the attributes of the subjects (e.g., the identifier of the doctor), objects (EMR), and environment (e.g., time).

3.6. Blood pressure sensors

These devices replace the necessity of manual data gathering. There are several practical advantages in using these devices, such as:

- It provides always-on, real-time data collecting;
- It eliminates manual collecting work and the possibility of typing errors; and
- It facilitated the deployment process, as wireless networking means no need for cabling or other physical setups.

3.7. Patient privacy

The patient medical records are saved in encrypted form, and blockchain technology is utilized to verify the user's rights. This is an efficient way to ensure the confidentiality of the patient's information and ensure the user's privacy. The patient's data contains vital information such as the patient's medical history, blood group, records, lab results, X-ray reports, laboratory results, and various other associated results and reports. All of this information is crucial for both patients and the institution. Smart contracts are an essential part of this system because they assure transparency, precision, and trust in transactions. Only authorized entities have access to the saved and accessed records in the system. Any untrusted party attempting to gain access to the system is rejected. The framework would ensure that the information was kept confidential and protected from third-party access and the aspect of privacy.

4. Some implementation aspects

To understand the feasibility of our work, a case study is necessary. The goal is to monitor a hypertensive person. Every doctor, nurse, or patient starts the application and authenticates before any activity. The appropriate tools are detected and transmitted via Bluetooth to the mobile phone regarding the person with hypertension. This last sends information to the hospital database. After authentication of the patient, the main interface appears. It is illustrated in Figure 2. It is composed of three compartments:

1. The first indicates the last levy's value, measurement time, and the period since the last levy was taken.
2. The second presents the hypertensive state in the last eight days and the last eight levies.
3. Moreover, the latter gives statistics on the average blood pressure across the 7, 15, and 30 days and the average blood pressure.

However, the measures can be taken and entered manually for some reason (see Figure 3). The patient can consult his measurements and medical records and update personal information. However, each actor can record his or her notes to everyone in his local database. In the case of severe hypotension or severe hypertension, the patient receives a warning. The doctor and nurse receive an alert notification. The patient can consult the evolution of his or her blood pressure throughout the week. For this, he or she clicks on "Follow" to go to the interface "Follow the state," and then on the "Graph" button to enter the graphical interface (see Figure 4). After, he or she selects the type of the weekly graph (see Figure 5). The colors of the blood pressure values are significant (see Figure 6).

Figure 2: Patient measurements manual input screenshot

Figure 3: Patient interface screenshot

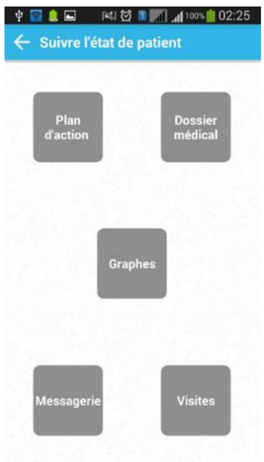

Figure 4: Follow the state screenshot

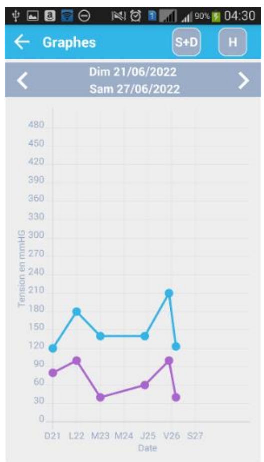

Figure 5: The graph of blood pressure measurements of a week

Hypotension
Hypertension
Severe hypotension
Severe Hypertension
Normal

Figure 6: The blood pressure values

The doctor can see the list of his or her patients sorted by name, age, or blood pressure illustrated in Figure 7, select a patient and consult the patient's daily state via the measurements taken and their medical history. Figure 8 shows that the doctor can prescribe, diagnose, and plan visits (i.e., appointments). The nurse consults the patient records and monitors their status. She can consult the list of her patients, select a patient, and consult the patient's daily state via the measurements taken (see Figure 7).

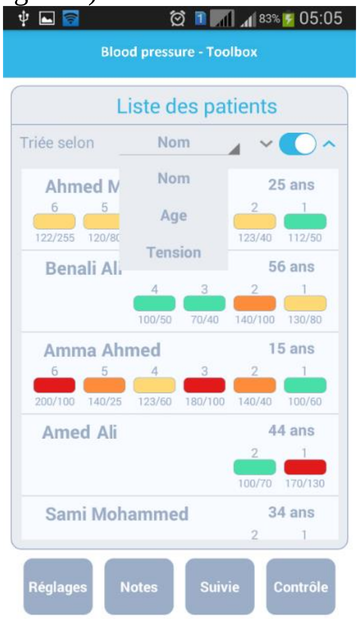

Figure 7: List of patients

Figure 8: The choice of actions

5. Related work

Supported by the WHO, a tele-learning project was finalized by the ANS (Blood National Agency) in collaboration with the ANDS (National Agency for Healthcare Documentation). It is intended for distance education in immuno-hematology and serology to test blood for isolated areas of the country. This first experience was launched in March 2002 [13].

According to [14], data on the management of hypertension in Algeria are limited. This study aimed to evaluate, in current medical practice, the use and benefits of ambulatory blood pressure monitoring (ABPM) for the diagnosis and management of hypertension. ABPM was performed for both therapeutic and diagnostic purposes. The results highlight that ABPM is a very valuable method for detecting inadequately treated patients with antihypertensive drugs.

The work of [15] is a survey of the hypertensive population that provided important data on associated cardiovascular risk factors and BP control rates in Blida, Algeria. These data can be used for future public health studies and as an effective strategy for hypertension control to avoid cardiovascular complications. The work is performed only in general practice consultations.

The author of [4] proposed a global architecture for Telehomecare, adapted to the concrete needs of homecare in Algeria with a case study of diabetic people. This architecture allows fast and flexible information exchange and opens new Telehomecare perspectives in Algeria. In addition to helping reduce costs, encouraging patients to be treated at home can also reduce the loneliness and stress they experience during a hospital stay. The proposed architecture can be widely used for telemedicine. In addition, this architecture can solve problems where there is an interaction of various health care professionals.

According to these works, there are a few projects in Algeria for remotely monitoring patients with chronic diseases. The problem is accentuated by a lack of infrastructure and health personnel.

6. Conclusion and future directions

This paper has presented an architectural approach supporting remote monitoring and hypertension measurement control in Algeria. This architecture is based on blockchain in a cloud environment, allowing interoperability, privacy, integrity and easy data access. It also facilitates flexible interaction across health professionals and between health professionals and patients through the Internet. These actors are geographically dispersed belonging. As future work, we are motivated for the evolution and the experiment of the system to determine the difficulties and possibilities to envisage several improvements or possible extensions.

7. Acknowledgments

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