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Procedia Computer Science 160 (2019) 281–288

Procedia Computer Science

www.elsevier.com/locate/procedia

The 9th International Conference on Current and Future Trends of Information and Communication Technologies in Healthcare (ICTH 2019)
November 4-7, 2019, Coimbra, Portugal

Data exchanges based on blockchain in m-Health applications

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Abstract

The most important aspect of handling data in the healthcare industry is its seamless and secure transition across intercepting nodes. Effective elimination of third-party entities and ensuring direct links between patient and healthcare provider can result in the transmission of error-free, unduplicated data. The use of blockchains can open up opportunities to counter the current requirements due to their ability to safely share information across nodes and networks from the access point and secure the safety of transactions. Currently, sharing medical data is observed to be slow, incomplete, insecure, and provider-centric. These shortcomings prevent data interoperability and are a consequence of lack of foundational, structural, and semantic inoperability. By applying the blockchain technologies with appropriate markers, the safety of patient data can be ensured during data transmission. This paper evaluates the potential use of blockchain technology in association with mobile-based healthcare applications.

Keywords: mobile healthcare; blockchain technology; data exchange; machine-learning algorithms.

1. Introduction

The field of information and technology is the foundation for smart cities applications. It bridges between manual and automated systems, thereby improving the quality of life, effective case management, economic development, the sustainability of information, ease of use, etc. This paper further investigates the efficient incorporation of

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10.1016/j.procs.2019.11.088

machine learning in mobile health applications with the use of blockchain technology to advance the field of personalized medicine with the aim of improving users' quality of life.

Lately, mobile health systems have been developed to capture relevant input data and analyze it by processing and deducing inferences. A set of interventions is coordinated based on these inferences and then communicate the same to other systems. "Sensors" are employed to collect raw data. These sensors may either be on-body type or embedded within phones. There are three main types of sensors – biomolecular, imaging, and bioelectric sensing [1]. Despite the construction of multiple algorithms and incorporation of machine learning into core healthcare protocols, a gap prevents its complete clinical usage.

1.1. A brief state of the art in the context of the study hypothesis

For machine learning to provide optimal results, the following parameters must be addressed: excellent performance, appropriate management of missing and noisy data, transparency and rationality regarding diagnosis or treatment plan, and algorithm's ability to apply itself effectively in order to reduce the number of tests needed to extract significant and relevant information from the available datasets [2][3]. For this purpose, rather than testing algorithms, the application development needs to test the learning purposes. However, the use of machine learning in the healthcare industry is hindered by incomplete or noisy data, data security, system inoperability, analysis of patient-generated data, and other access inconsistencies [4].

The use of blockchains can open up opportunities to counter the current requirements due to their ability to safely share information across nodes and networks from the access point, and secure the safety of the transactions. The current paper attempts to validate the hypothesis that personalized medicine via mobile health applications based on server-blockchain technology incurs benefits in areas of diagnosis, treatment planning, and patient monitoring.

The most important aspect of handling data in the healthcare industry is its seamless and secure transition across intercepting nodes. Effective elimination of third-party entities and ensuring direct patient and healthcare provider networking can result in the transmission of error-free, unduplicated data. Based on this hypothesis, the paper attempts to fulfil the objectives of analyzing the pros and cons of this technology, understand the practical implications for diagnosis, formulate treatment plans, and monitor patients with chronic conditions such as Cardiovascular Diseases (CVD), Hypertension (HTN), etc.

The "Digital Universe" has been estimated [5] to measure about 40,000 Exabyte by the year 2020. This increase in the quantity of digital data and the increasing fluidity of information exchange procedures has resulted in the need for complex analytical tools which can interpret both real-time and stored data. Such data can be analyzed by physicians through open application programming interfaces (APIs) and help improve patient management systems. Additionally, this paper also attempts to analyze the type of database that is most suitable for the applications mentioned above in the healthcare field.

2. Blockchain technology in mobile health applications

Communication of health-related data from and then back to a smartphone via blockchains is a certain alternative in the current scenario. The blockchain technology, which originated from the Bitcoin, acts as a peer-to-peer (P2P) ledger technology for transactions. In the field of healthcare, these transactions mostly involve large amounts of data, which need to be evaluated based on three essential elements. These are: are scalability, access security, and data privacy [6].

Health data is regarded as highly sensitive information, and storage in clouds may risk exposure. Additionally, newer electronic health record maintenance systems should provide their users with control over their data. With the increasing usage of wearable sensors and mobile-based applications, a smartphone-server-smartphone communication system with the help of blockchains is the need of the hour. A recent study was performed to evaluate the efficacy of a mobile-based healthcare application for sharing and collaborating data with the help of a blockchain [7]. In the study, a user-centric system of data sharing was designed to connect six devices, namely, the user, the wearable device (in this case the sensor in the smartphone), the healthcare provider, the insurer, the cloud database, and lastly, the blockchain network.

Interactions between these entities are properly represented in the flowchart depicted in the next figure (Fig. 1). In this design, the blockchain serves the three main purposes of collecting data from the sensors embedded within the body or the wearable devices, to ensure access to data by both providers of healthcare as well as insurers upon request, and lastly, for recording every attempt or request to access the stored data.

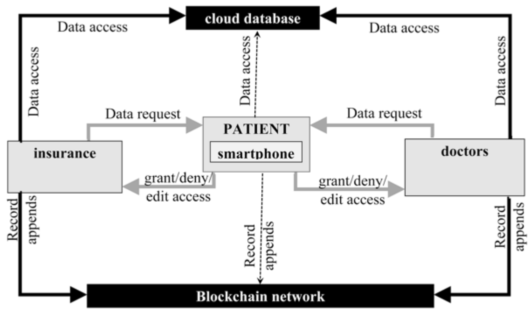

Figure 1

Fig. 1. Blockchain in m-Health.

The system implementation protocols include three main components of personal health: data collection, personal health data integrity, and data sharing and collaboration. While the first component is associated with the collection and storage of information from sensors, the second component deals with data flow from the sensors to the ledger where they are finally anchored. In this case, given the ability with regards to data integrity and validity, a tree-based data structure is enhanced. Each root of the Merkle tree is bound to a specifically identified blockchain transaction. The third component of data sharing involves the documentation of the event corresponding to the request of access to specific data by different parties, i.e., the user, the physician, and the insurer [7]. Depending on the direction of the data transaction, a specific operation is carried out as observed in the chart depicted below:

Table 1. Data Transaction Operations in Blockchain Technology [7].

Health Data	Operator	Operation
Personal Health Data	User	Update, Query
	Healthcare provider	Query
	Insurance company	Query
Medical History	Healthcare provider	Update, Query
	User	Query
	Insurance company	Query
Insurance Information	Insurance company	Update, Query
	User	Query
	Healthcare provider	Query

Access control practices can be implemented via a customized system built on the Hyperledger Fabric, a permission-based blockchain which validates every request to access data. The Hyperledger Fabric generates a certificate bearing the information of the access type and the chain code. Each chain code is tethered to a specific channel of data transaction, and access is granted by the party seeking it based on users' permission. The main functions of the chain code include deployment, invoking, and query assessment. In total, this systematic protocol enables both privacy protection and access control, thereby enhancing the control users have on data related to them. Additionally, system evaluation procedures are user-centric, allowing users to control the extent of information sharing. In this study, an assessment of the long-term integrity and validity of large data sets revealed that the proposed system could handle the processing of large data sets collected at high frequencies, as observed from the graph presented below:

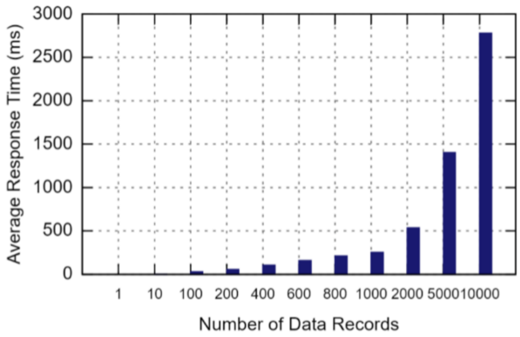

Fig. 2. Time for Integrity Proof Generation [7].

2.1. The utility of mobile-based healthcare applications for personalized medicine

The use of smartphone-based applications at a national-level can facilitate the work of public health groups in alerting clinicians by constantly moderating the epidemiological data about infectious diseases, genetic mutations, and other data sets about pharmaceutical trials [8]. The ecosystems of mobile healthcare apps are generally based on open application programming interfaces (APIs). API-enabled electronic health record systems indicate an easy and customizable mobile-based experience in users' accessing health records electronically. The figure given below provides an apt demonstration of the use of the electronic health record system in the public programming interface (Figure 4). Instead of the standard view of EHR data, an ecosystem determines the inclusion of a third-party application into an open uniform programming interface. Having a set of common APIs, not only allows for the generation of newer mobile user apps but also encourages healthy app-based competition, improving the efficiency of electronic healthcare systems [9].

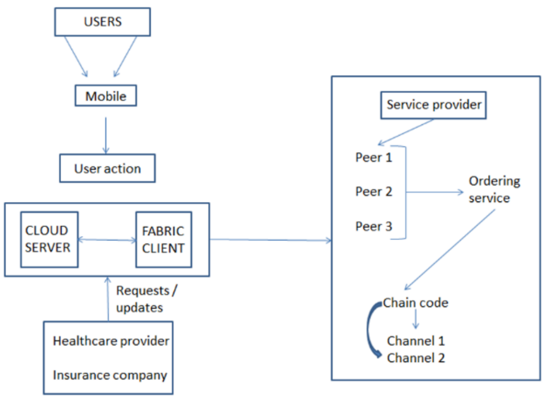

Fig. 3. Electronic Health Record (EHR) systems with public interfaces [7].

Despite its obvious benefits, there are some barriers which can hinder the adoption of mobile health applications. These barriers include cultural differences between the technological and medical professions, fragmentation of mobile application systems due to difficulties in deployment, unreliable network coverage, financial limitations, loss of data during device change, loss of efficiency in areas of low literacy rates, regulation of access to data by third parties, and importantly, other security concerns [10]. Currently, open API-based mobile healthcare applications run on smaller scales, resulting in benefits such as structured data storage, third-party funding for large-scale research, and effective illness prevention protocols.

Mobile computing devices such as personal digital assistants, smartphones, and tablets combine the technological powers of computation and communication with a variety of features aiding the transmission of data. These include high-quality cameras, voice recording systems, global positioning systems, etc. From a healthcare professional perspective, mobile computing devices can aid in the categories of information management, time management, record maintenance, communication and consultation. The future scope of this model also involves its use for research purposes [11].

3. Personalized medicine via m-Health applications

The main advantages associated with the use of mobile phones in healthcare are: improving the parameters of communication between healthcare professionals and patients, improving the maintenance of health information systems, formation of a repository of healthcare information enabling evidence-based practices, and lastly, software applications for clinical purposes. An application, commonly known as an “app” is a software developed specifically for a computer or a mobile phone. Healthcare apps are generally associated with the prescription, diagnosis, practice management, coding and billing, etc. [9]. Although these apps cannot replace their desktop versions, they are meant to complement classical applications. Mobile technology cannot only assist healthcare professionals in acquiring information via sensors but also in computing, analysing and communicating related data. Traditional designs of mobile healthcare apps include a predictive computational model that can help in characterising human behaviours. Human behaviour is non-linear and generally uncertain, mandating the use of theoretical models in conjunction with simulation tools to achieve valid results [12]. Some of the commonly used mobile-based healthcare applications are shown in the table below.

Table 2. Commonly Used mobile healthcare Apps [10]

Evernote	Note-taking and Organization
Google Drive	Organisation and Storage
Doximity	Social Networking for the physicians
Medscape	Medical References
MedPage Today	Medical News
Diagnosaurus	Analysing possible Differential Diagnoses
Quantia MD	Continuing Medical Education

Mobile-based apps are also used to identify the supply chain for specific medications and to ensure their authenticity. Applications such as the *Epothecary* use phone cameras with GPS systems to identify the barcodes on drugs and authenticate the sale of a drug, tracing it to the buyer. Apart from these areas, applications have also been designed to improve patients’ general wellbeing. These include apps which track physical activity, help in de-addiction, make important health-related decisions, etc. Another application, known as the “*12580 system*”, provides a mobile-based appointment booking service in the Guangdong Province of China. This calling system is said to serve about 4.25 million patients who seek primary care as well as specialist services. This application is especially successful in the healthcare system of China, wherein both primary and specialized healthcare centres are the same. A total of 36 call centre seats have been used to help users of this mobile-based service. The future scope of these applications includes the prompt identification of at-risk individuals during infectious outbreaks, performing remote diagnosis, thereby saving time [13].

In recent years, mobile technology is especially focused on reducing the impact of cardiovascular diseases on at-risk populations. The increasing extent of smartphone ownership of approximately 60% in Europe and 72% in the United States in 2015 has resulted in a concurrent increase in the usage of health-related apps. Multi-component technology-based interventions have been designed against cardiovascular diseases. Systematic reviews have evaluated the performance and efficacy of apps which use interactive platforms, tele/video-monitoring, messaging/phone-based, or sensor-based applications. These technologies aim towards improving the maintenance of healthy lifestyle practices, improve adherence to the treatment protocols and can be used singly or in association with traditional treatment protocols for this purpose.

A recent meta-synthesis of both quantitative and qualitative data in a systematic review analysed the effectiveness, acceptance, and usefulness of patient-centric apps on a smartphone or a tablet device. The review stressed the importance of the use of standalone apps every day with minimum interference from the physician and the clinical environment while garnering patients' perspectives regarding the use of these applications. A total of 1354 records were evaluated and studied before obtaining the final ten studies which were included in this meta-synthesis. The 607 subjects who were treated or observed in these ten studies spanning over five countries, either underwent targeted interventions or rehabilitation related to adverse cardiovascular events. The evaluation observed parameters such as rates of re-hospitalisation, knowledge related to the disease, overall well-being, physical parameters such as body mass index, weight, cholesterol levels etc., quality of life, and adherence to intervening protocols, etc. It was concluded that the modifiable risk factors associated with cardiovascular diseases were able to result in the improvement of the evaluated parameters; however, for only a short period of time [14]. The exact rate of efficiency of these apps can only be quantified with the help of long-term randomised controlled trials.

4. Open application programming interfaces in healthcare

An API allows a software program to communicate with other programs, allowing for the flow of data and improving function. APIs serve as points of communication which can serve as the inlet for a constant stream of data. An open source can enable the connection of apps to data warehouses, thereby reducing the time dedicated to its development, enhancing cross-platform standardisation.

A study was performed to evaluate the effect of open source technologies on the creation of a web-based application which can store, monitor and analyse healthcare-related data. The Epidemiologic Visual User Environment, i.e., the *EpiVue*, is built on open source software, to visualise the data related to public health. The components of this software are the storage database, the Java application server, the statistical, computational toolkit, and the geographic information system. This software is functional on a variety of computing and operating systems such as Linux etc. The study revealed that *EpiVue* successfully visually analysed the epidemiological data while allowing its users to upload their datasets in the form of spreadsheets, which are geospatially organised and visualised [15].

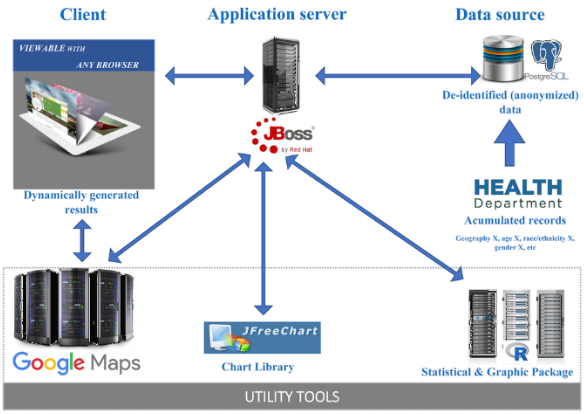

Fig. 4. General Application Architecture [15].

The open APIs has helped the vendors of the health information technology (IT) industry to provide the tools required for the functioning of the application. Resource builders, such as the SMART API, form an open source into which HTML5-based apps, are embedded. Such open sources promote interoperability due to the use of cloud-based services [12]. However, it is imperative to consider the privacy and security issues associated with open APIS while identifying the potential barriers to its use. Establishment of task forces to monitor the systems connecting to open APIs can monitor the direction of data flow, securing the EHRs.

5. Database types in healthcare technology

The advent of healthcare technology has served as a boon, especially in the field of management of healthcare data. The high amount of data generated has resulted in the utilization of technology to contain the data explosion. A variety of data storage systems have been introduced and used to store and organize healthcare data. Analytical technologies, such as the Big Data Analytics, attempt to obtain the knowledge required to formulate evidence-based protocols in real-time [16]. In such large volumes, data aggregation becomes problematic with SQL, which cannot support multi-table queries and limit data scalability. The SQL uses relational algebra to extract relevant datasets from large databases with the help of its advanced syntax levels. The large volumes of healthcare data make it impossible to use relational databases such as the SQL [17]. In such cases, the NoSQL provides the required storage space and power to analyze large volumes of data by being flexible enough to characterize unstructured data. There are four different types of NoSQL databases which can be applied in the healthcare field: the key-value stores, the column-oriented databases, document-based stores, and graph databases [18]. These systems are non-relational and are widely distributed, making them useful to scale large volumes of uncharacterized data, as opposed to SQL which requires prior knowledge about the structure of data. The SQL databases can improve their performance by improving their horsepower, thereby enunciating the importance of hardware in these systems, making them economically ineffective. Archiving and making it available to users at their request are some of the most important aspects of healthcare data. The NoSQL is better suited for this purpose as it provides a flexible scheme.

Extraction of required data also depends on the nature of the query placed by the user. While more complex queries are easily synthesized by the SQL databases, due to their relational structure, simpler datasets can be extracted from uncharacterized datasets with the help of NoSQL.

6. Implications on personalized mobile healthcare

The use of blockchain technology in mobile healthcare fields can help in the improvement of peer-to-peer communication of data. This technology can have solid implications in healthcare. The presence of fragmented and unstructured data is the biggest hindrance in the healthcare sector. Additionally, the lack of links which connect the systems sharing these data pose a threat to the security of data, resulting in the requirement of an interoperable ledger such as the blockchain technology [16], [19].

Sharing of medical data in the present day is observed to be slow, incomplete, insecure, and provider-centric. These barriers prevent the interoperability of data and are a consequence of the lack of foundational, structural, and semantic inoperability. Lack of trust among healthcare providers, concerns regarding the privacy protection of the shared data, and concerns regarding the scalability of large datasets have restricted the use of mobile technology in the field of medical data exchange. Review of available literature revealed about seven blockchain technology use cases in medical health management systems, which include: prescription tracking of opioid drugs, data sharing through telemedicine, sharing information related to cancer after patient authorization, creation of cancer registries, a digital identity management system for patients, accessing personal health records, and automation of evaluation of health insurance claims [20].

Irrespective of its usefulness, the adoption of blockchain technology comes with its fair share of barriers. While storage capacity on blockchain ledgers is limited, these gas limits (i.e., the maximum amount of computation allowed) are challenged by using specialized flyweight patterns. Concerns of data privacy on the blockchain can be addressed with the help of proxy patterns, which can improve the interoperability while maintaining patient privacy. Scalability of healthcare data can be maintained with the help of system patterns such as the publisher-subscriber pattern, which can detect changes in the relevant data sets. By applying blockchain technologies with appropriate markers, the safety of the patient data can be ensured during the transmission of data.

7. Conclusions

In conclusion, blockchain technology in personalized mobile healthcare systems can help to provide patient-centric care and offers patients complete authority over the sharing and privacy of their data. The blockchain technology also enables the communication between healthcare providers, insurance providers and users. Blockchain offers a decentralized storage system spanning across geographical locations, aiding in the real-time sharing of the digitized data, reducing the cost and time taken to process data queries otherwise.

Mobile-based applications have a widespread use due to the vast number of people with access to them. In circumstances where epidemiological data can be collected using mobile phones with or without biological sensors, such as infectious outbreaks, it becomes easier to identify at-risk individuals across geographic positioning, resulting in the provision of risk-prediction and immediate intervention. A useful application with its widespread use, an open API, and improved interoperability can transform the basic structure of the delivery of healthcare.

Further research can target the development of blockchain systems in conjunction with mobile technology, making the healthcare system a modular plug with increased cost-effectiveness.

8. Future implications of using blockchain technology in healthcare

The use of blockchains in the future can fundamentally eliminate the use of a third-party, thereby safeguarding patients' data. The future of blockchains in healthcare can secure digital transactions, distributes data equally with no scope for altering or tampering it, protect data with a cryptographic hash, provide the user access via a mobile interface dashboard. The use of reliable commodity hardware in addition to an open API reduces the cost required to store, share and analyze the bulk of patient-related data. The flexible data structures can help accommodate any edition of the existing data without compromising its safety. The real-time data collection through mobile sensors can result in the development of early action plans as and when deemed required by the team of healthcare providers. The scope of blockchain technology with mobile applications in healthcare is vast, and further long-term randomized controlled trials are needed to develop an efficient program.

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