Blockchain Technology For Electronic Health Records

project Design Phase

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1. Introduction

With the evolution of the Internet of Things (IoT) and abundance of health devices and health apps, a vast amount of medical data are recorded and transferred every day. This large database of medical information needs management regarding privacy, security, and availability. Hospitals and doctors need to access to the patient's medical information during the treatment process while ensuring security and privacy of sensitive information of patients as they share them with hospitals and medical institutes. Additionally, according to the Health Insurance Portability and Accountability Act, law enforcement and other specific public agencies may legally access health information. It is estimated that as many as 150 to 400 individuals may access a person's Electronic Health Records (EHR) [1]. Given that the data is shared widely and stored in multiple places, securing it becomes a more significant issue. According to the Ponemon Institute, in 2016, over 112 million medical records were compromised, and such data breach attacks increased by 162% so far in 2017 [2].

Blockchain Technology introduced a financial application that has started a revolution in many fields including healthcare information systems. Blockchain technology can provide a solution that not only helps to secure recording and sharing of medical records but also to assure the privacy of each patient's data by giving their medical data ownership to the patients, themselves. In this study, we conducted a systematic literature review on blockchain technology and healthcare research. In the following section, we reviewed the concepts of blockchain technology. The third section is devoted to research methodology. Section four gives the systematic analysis of the selected papers in research methodology and some research gap identified based on this analysis. The conclusion is given in section five.

2. Blockchain Technology

Blockchain technology is defined as distributed ledger technology, which records transactions in a secure, transparent, decentralized, and efficient manner with low cost. The blockchain is the technology underlies bitcoin, which was introduced by pseudonym Satoshi Nakamoto in 2008. In order to understand how blockchain works, first, it is better to know the bitcoin mechanism. Bitcoin is a peer-to-peer, distributed, and decentralized digital currency. There is no third party as a trusted intermediate in bitcoin transaction system, and anyone with bitcoin can participate in the network, read, write to, and hold a copy of the transactions records [3].

2.1. How Bitcoin Blockchain Works

There are two challenges of the transaction system without central control agency: (1) single point of failure and (2) peer-to-peer double spending of the same digital asset like money. Blockchain technology solves this problem using two mechanisms: hash-chain time-stamping and proof of work algorithm [4]. First, in order to verify each transaction, it should be stored in each computation node in the network. All transactions are timestamped and distributed in the network. Bitcoin blockchain exploits hash-chain as distributed timestamp mechanism to determine the possibility of doing the transaction and maintaining a copy of transaction chain in every node [3]. Second, bitcoin blockchain uses the reward and punishment mechanism for preventing any possible interruption or malicious transaction. Miners are the participants who do the mining process in blockchain, i.e., creating new blocks with enclosed transactions list and chaining them to the previous blocks. Figure.1 shows how blocks are created and chained together. Each block has two important parts: (1) Content: a validated list of transactions. The transacted digital asset can be digital money (e.g., Bitcoin, Ethereum) or any kind of data such as a school diploma, a medical record. (2) Header: which includes metadata, such as (a) Block reference number to the content of the block, known as the hash root, (b) The time the block was created known as timestamp, (c) A link back to the previous block, and (d) A random number (nonce) which is added to the block address according to the proof of work algorithm [3].

In bitcoin blockchain system miners use proof of work protocol in order to find a new address for the new block with specific properties. This property in bitcoin blockchain is a 32-bit crypto number with seventeen zero bit in the beginning. Miners run this algorithm multiple times to get such a number by trying different random numbers (nonce). After finding a new address for the new block, the miner updates the ledger and send it to the entire network. Then the majority of the network should confirm the new block. This process is called proof of work or consensus in bitcoin blockchain system. The mining process is difficult, time taking and costly, this prevents creating invalid and fraud transactions. Therefore, bitcoin mechanism provides rewards for the miner who can add the new block first, as an incentive to compensate the efforts and cost associated with the mining process [3]. Another benefit of using proof of work consensus protocol is that it let blockchain to be immutable audit trails by chaining blocks together using a hash

function. Each block contains the hash value of the previous block's header (Prev.Hash), and therefore if an attacker tries to modify a block, all the upcoming blocks should be modified. Such a modification needs a high computation power, time and cost. Even if the attacker succeeds to create the fraud chain of blocks, replacing it with the honest chain requires the consensus of the majority of the nodes in the network. Thus, the bitcoin blockchain system is highly secure against any modification and failure, and this comes from its specific structure [4].

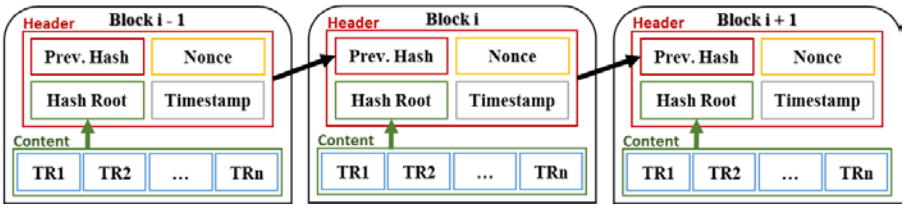

Figure 1: Contents of each block in a sample blockchain

2.2. Blockchain Technology for Other Sectors

Although blockchain was first introduced for finance, there are many other applications, which has been developed and implemented. Blockchain technology, as a horizontal technology, is revolutionizing the future of the transactionbased exchange in different industries such as finance, insurance, telecommunication, and healthcare.

3. Research Methodology

The systematic literature review is selected as the methodology of this study. The aim of the systematic literature review is identifying the previous research on the topic, which is blockchain for healthcare in our case, and then defining the research gaps and future research directions. We firstly identified two research questions:

1. **What are the research topics that have been studied on blockchain in healthcare?** Through scrutinizing all relevant papers in the literature, we built a comprehensive understanding of current research of blockchain in healthcare domain. We also mentioned applications of blockchain technology in healthcare to comprehend its current and potential impact.
2. **What are the research gaps and future research directions in blockchain technology in healthcare research?** A systematic literature review facilitates the identification of challenges and limitations alongside disadvantages of adopting blockchain technology, particularly in healthcare domain. The research gaps and future research directions are based on the identified challenges, limitations, and disadvantages.

In order to find the academic papers, we needed keywords to query on scientific databases. Deciding on the appropriate databases is the next step for running the keyword search. Identification of the relevant papers was made in three steps: (1) Running keyword queries on academic databases, (2) Removing the irrelevant papers by manually reviewing the meta-data, (3) Selecting the appropriate articles by reading the papers.

As the review subject is the application of blockchain technology to healthcare, we identified the keywords as "blockchain," "healthcare," and "health care" for the search queries as shown in Table 1. Identification of relevant scientific databases is also a challenge since the reviewed area is composed of two topics that are not directly related. Blockchain is a concept that has foundations in computer science and applied mathematics while spreading over various domains from finance to healthcare. Healthcare is already an established and broad area of research. To find the all relevant papers, we searched the following major databases of information technology and healthcare: ACM Digital Library, EBSCO, IEEE Xplore, ProQuest, ScienceDirect, Medline First Search, and Medline ProQuest.

Table 1. Results of queries in scientific databases

Query	**"Blockchain" + "Healthcare"**		**"Blockchain" + "Health care"**		**Total Number of Reviewed Keywords and**
Database	Search Result	Reviewed	Search Result	Reviewed	**Papers**
IEEE Xplore	6	6	0	0	6
ACM Digital Library	1	1	0	0	1
ScienceDirect	0	0	0	0	0
EBSCO	0	0	1	0 (irrelevant)	0
PLOS One	0	0	0	0	0
ProQuest	3	1 (duplicate)	1	0 (duplicate)	1
Medline ProQuest	1	0 (duplicate)	0	0	0
Medline First Search	2	1 (duplicate)	5	5	6
Total	13	**9**	7	**5**	**14**

The column, “search result,” gives the number of publications identified by the queries of only keywords field of the databases. After we read the abstract of each paper to understand if it is relevant for further analysis. The column, "reviewed," gives the number of papers obtained after this filtering study. Search queries yielded 20 papers, and the manual reviews of papers decreased it to 19. The removal of duplications resulted in a set of 14. After scrutinizing all these papers and eliminating those that do not fit the outlined criteria, we ended up with 14 studies for detailed analysis.

An initial analysis of the selected papers showed that three papers published in 2016 and others in 2017. The three papers published in 2016 have been cited 55 times according to Google Scholar records. These show that the topic is new and trending. Five of the selected papers are conference papers, and others are journal articles.

4. Systematic Analysis

In this section, we analyzed the selected 15 studies, identified and listed the advantages, disadvantages, and challenges of employing blockchain technology in healthcare. For simplicity and clarity, we categorized them from the perspective of people, process, and technology.

4.1. People

Advantages: Blockchain technology can enable interoperable, unified and secured view and exchange of electronic health records [7, 8]. Patients can own their medical records instead of storing this sensitive information separately on the networks of various healthcare providers. Since the data is unified, any updates to the data are done globally. Upto-

date data is available when it is needed [7]. Patients can also choose whom to share the data. Thus, control can be oriented more towards the consumer while having balance with other important players in the system [7, 8]. Blockchain technology provides the authorities the ability to access health records when needed [9].

Disadvantages: Once the provider has a patient's data, they could possess it permanently by any other means, although the patient may not want it [10].

Challenges: Patients are not much aware of this new technology. Apparently, there would be confusion on where the data would be stored and who can have access to this data [7].

4.2. Processes

Advantages: Security is a critical issue for healthcare processes. The blockchain technology can provide high tamper resistance, hence vulnerable health data can be promised to be kept with high-level security [8]. Moreover, since the health data from various sources can be stored on the distributed blockchain that does not rely on one central storage facility, government and other organizations would be liberated from the liability of handling enormous amounts of data [11, 12]. Blockchain has the potential for the automated validation of claims, verify eligibility verification, and preauthorization that may increase the transparency, authenticity, efficiency, security of the process [13]. Because of the transparency in the shared infrastructure a new confidence level would be attained among patients and medical stakeholders [14] in addition to the increased security.

Research is another critical aspect of healthcare sector that blockchain technology can help. Its decentralized approach to manage permissions, authorization, immutable audit trail, and to provide rapid and secure access to longitudinal research data [4, 13]. For example, an organization, MedRec, proposes a mining model that allows medical researchers and healthcare stakeholders to mine for aggregated medical data in the network [11, 12]. Blockchain technology may enhance the development of drugs and medical devices and could reduce the production of counterfeit medicine and clinical trials by decreasing the amount currently spent on confirmation by the third party [8, 11, 14]. Blockchain technology can also help developing new hardware and software to improve healthcare processes. It can tackle the problem of proper use and integration of new devices into the existing network that has sensitive health records[15].

Blockchain also offers to make healthcare processes easier and more robust. In blockchain, data is stored in a single format and interconnected among various organizations, no matter at which place the health record was processed. This reduces the complexities of maintaining and sharing EHRs [7]. Moreover, the possibility of human error and processing times would be reduced because the system could minimize human involvement with data [8]. The features such as robustness and availability provide the preservation of records by storing a whole copy of historical data record on each node and making them available to access to the users at all times [4]. The origin of the assets is traceable, thus the reusability and robustness of verified data increases. This is also referred as data provenance and is essential for some healthcare processes such as insurance transactions [4]. It is also estimated that in the future, healthcare application users may receive financial benefits for their data provided for medical research [14, 16].

Disadvantages: Blockchain technology also has some cons. There is still a great deal of hype and uncertainty about this technology [5]. This causes issues about the legality of this technology (e.g., for access management) [7]. In order to implement the changes to the current infrastructure required for this technology, it must be legally approved first.

Challenges: Several potential barriers exist concerning ethics and operational guidance, compliance with regulatory requirements, and the technical barriers related to data storage and distribution [13, 15]. Determining the data sharing conventions is one of these challenges. For example, it is a question to be answered how a patient can choose which data to share and to whom. Patient, as the owner of the data, must authorize a healthcare provider to access the data. If for any reason, the patient is not able to do that, it is unclear who has the authorization to do so on behalf of a patient. It is also not clear that what amount of health data need to be stored online and if the data can be shared with one another indefinitely or for a fixed amount of time [7].

While data within the blockchain can be de-identified and encrypted, the data security still may be vulnerable due to poorly maintained or outdated codes in an incident involving a decentralized autonomous organization [8, 13]. Even though a user is anonymized by a hash value, the user can still be identified through inspection and analysis of the publicly available transaction information, and therefore provides only pseudonymity instead of anonymity [4]. While blockchain can prevent data block fraud, it remains a challenge to guarantee the identity and authenticity of the informant and stakeholders [4]. The transparency aspects make it difficult to protect data against malicious traffic analysis while maintaining accountability and transaction privacy [17].

Transition to the blockchain technology in healthcare processes have some other problems. A sufficient amount of training is required for healthcare providers and patients. Users have to be trained on how to design and manage the distributed controllers and network functions to ensure vertical and horizontal scalability, and how to autonomously orchestrate network functions and services across the softwarized middleware [17]. Additionally, the transition may take a long time, and during the transition, there may be some issues in the processes. For example, currently, for patients capability of self-reporting the symptoms of their sickness is app-specific. That means patients can only access this feature if their provider's medical system implements it [10]. Therefore, this kind of issues should be resolved to make the transition smooth. Additionally, there is still need for metrics to measure the efficiency of this technology in healthcare. Some researchers propose to include metrics such as policy compliance, high-level computation ability, authentication, interoperability, scalability, cost-effectiveness, and domain-specific healthcare requirements [10, 16].

4.3. Technology

Advantages: The blockchain technology infrastructure is flexible, adaptable, agile, and secure with high performance and low latency [17]. It offers much for healthcare sector as it does for other sectors. With the help of decentralized technology, time consuming and resource-intensive authentication and information processes can be avoided which makes healthcare procedures quicker [13, 14]. Blockchain technology has been in use. Software designed to ensure the transparency of medicine manufacturing process to track medical distribution, and ensure the authenticity of prescriptions for compliance with the Drug Supply Chain Security Act [13].

Disadvantages: Cost and complexity can cause negative consequences for healthcare stakeholders. Because of the high-cost of data centers, many EHR services may migrate to third-party providers, which in turn healthcare providers may have to pay to access the data [7]. The technical complexity of the cryptography and networking involved can be difficult to understand for all stakeholders. Many patients might be reluctant to manage their medical records owing to the complexity of blockchain setup [5]. Another technical disadvantage of blockchain is that it is not ideal for data with high temporal resolution and also issues with handling multi-dimensional data, such as complex text, images, and graphs [8]. Moreover, since it is an open network that anyone can join, it needs massive computing power for effective tamper resistance [8, 17].

Challenges: The cost-effectiveness and efficiency of handling large volumes of data have yet to be tested in production environments. Once the traffic increases, the transaction time can get long depending on the protocol; thus impacting the scalability [4] and required computation power. The practicality of expenditures and set up for hardware, software, implementation, and support need to be assessed while transitioning current electronic health system to blockchain-based technology [13]. Moreover, a global standard is also needed to store, access and share encrypted data in the cloud [12]. The last challenge is that until now there is no proof to indefinitely say the data blocks cannot be spoofed, decrypted, or rearranged, thus questioning the security aspect. Hypothetically, if the whole network is taken over by the malicious attackers, there is a 51% chance of security threat [4, 7].

5. Research Gaps:

From the systematic analysis of literature review for blockchain in healthcare, evidently, this technology offers many advantages for healthcare. Being an open-source technology, and its promise in providing high-level security and transparency during data sharing and financial transactions, the interest in adapting blockchain into electronic healthcare has been increasing exponentially. However, despite the hype and gaining popularity, we have identified some principle research gaps that need to be addressed in this field. Firstly, although blockchain technology promises secure sharing through a distributed network, there is always a possibility that hackers may find a way to break the security system. A research study says having 51% malicious nodes would make blockchain vulnerable to security threats. In this context, profound research has to be done on how to combat if such situation was to occur in the real environment. Secondly, if the blockchain technology were to implement globally across all the health providers, would the intense data traffic could be handled, while still maintaining the speed and scalability? Thirdly, maintaining high-cost data centers that require vast amount of electricity is another cost related challenge. Patients might not be ready to share the financial burden, considering the fact that already the medical costs are very high. Fourth, access management, legal issues, regulatory issues should be made taking all nations' medical policies into consideration. Alternatively, the notion of having a unified data storing and sharing system would be far from reality. Training the stakeholders on the usage of this new complex system would be another grave challenge. There are many more challenges to address. However, the above mentioned are to be tested indefinitely before investing in this technology.

6. Conclusion

In this paper, we introduced blockchain technology, which is well known for its application in cryptocurrencies but in fact, has a broader application from finance to healthcare. Research on blockchain has emerged since 2012 intensively. However, integration of blockchain in healthcare is new and trending area..