Secured Cloud-based Framework for Electronic Medical Records using Hyperledger Blockchain Network

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Abstract: Blockchain technology usage in healthcare has a great perennial to solve many of the challenges healthcare domain has. Due to the growth of data in Health information technology (HIT) and the need to make the data available via a secure manner, blockchain technology can be used to meet these requirements. Starting from data management and the accuracy of the health records, the blockchain technology can play a pivotal role in various areas such as drug prescriptions, pregnancy, supply chain management, electronic health record management, and any risk data management as well as to support better access control, data sharing and managing of an audit trail of medical activities. Blockchain technology can improve medical data availability, data security, data sharing, traceability, and record immutability. The objective of this paper is to propose solution that shows how to leverage blockchain technology to address these challenges in the health care domain and the patient medical records particularly. In this paper we have proposed a blockchain solution for the patient medical records in the cloud. We have implemented a secured cloud-based framework for patient records using blockchain Hyperledger network based on Amazon Web Services (AWS). Our solution using AWS**is** secure, scalable,efficient, and cost effective. The network is built in a Virtual Private Cloud (Amazon VPC) to prevent access it outside of the VPC and having the resources needed only while it used to reduce the cost and make it cost effective.

Keywords: *Blockchain, Healthcare, Cloud Computing, Hyperledger*

1. Introduction

Health information technology (HIT) systems play a substantial role in everybody's life. Medical data, in the form of electronic medical record, is the main asset for those systems [1]. Due to the massive volume of the collected medical data, the high sensitivity of the collected data in addition to the need to enable data sharing of the patients record between the multiple systems used by the healthcare facilities, there are numerous challenges with the current (HIT) systems. Hence, storing this data in a traditional database is challenging.

Given security and accessibility challenges in the current HIT systems, there is a need to foster a new solution to healthcare data management. The new healthcare data management system should be able to fulfill several objectives, including (a) medical records data must be protected against unauthorized use; (b) create trust among healthcare stockholders through data sharing that's patient-centric and transparent; (c) a distributed solution to overcome the limitation of centralized systems; (d) finally, the system should provide a mechanism for data authenticity in order to verify the integrity of medical records data [2].

The blockchain is an innovative, distributed, and immutable ledger technology which becoming a vital element in the revolution of the health information technology systems. Blockchain is a decentralized management solution for data transaction. The Bitcoin cryptocurrency was the first implementation of blockchain technology in 2008[3]. The blockchain technology has its challenges around security, privacy, and scalability. However, it has a great potential to solve various problems in a distributed environment, blockchain technology is applicable not only in the financial transaction systems, but it is transforming our society, as the digital footprint we leave behind through our use of cars, smartphones, healthcare, vote, and even personal identification increases in breadth and depth.

The natural properties of the blockchain technology can be used to realize the objectives mentioned previously: (a) permissioned blockchain networks enable granular access control for medical records can be achieved through, supporting granular-level access mechanisms such as channels; (b) blockchain-supported smart contracts enables patient-centric and transparent data sharing and control; (c) the blockchain distributed consensus mechanism overcomes the limitation of centralization; (d) and, a blockchain is immutable preserving the integrity of data; thus the integrity of the data saved on a blockchain is verifiable and provable.

Blockchain technology could improve information security, data decentralization, search & data dissemination, and data integrity in the healthcare industry. However, the first evolution of blockchain technology was designed mainly for cryptocurrency transactions with no focus to be extended or even applied to other industries such as the health care industry. Currently, there is an emerging effort to use general-purpose blockchain technology to develop healthcare systems. The biggest challenge is being phased is there is no consensus on which blockchain framework is most suitable for developing healthcare applications.

In this paper, we present an electronic patient medical records system that uses Amazon blockchain technology that provides more efficient, secure, and reliable storage and ensure easy accessibility and availability of medical records. We have chosen Hyperledger Fabric framework in this implementation [4].

The reset of our paper is organized as follows: Section 2 provides a brief introduction of blockchain technology, discuss the key characteristics blockchain, different types "permissioned and permissionless" and the different blockchain frameworks "Ethereum" [5] and "Hyperledger Fabric". Section 3 highlights the related work. In section 4, highlights the framework selection and discuss the implementation of the system. In section 5, we have highlighted the system functionality. Finally, we provide the summary of this paper and discuss the future work in section.

2. Background

Blockchain technology is a distributed ledger that shares data between a network of peers [6]. Bitcoin cryptocurrency was the first implementation of blockchain technology in 2008. The main advantage of blockchain technology is lower cost, faster, and more efficient and secured data sharing through the ability to connect distributed network nodes directly without dependency on any trusted third party.

2.1. Types of blockchain

Blockchains can be of three different types: public, consortium and private [7]. Public blockchains can be accessed and viewed by any user who can join and contribute to the consensus protocol [8]. Cryptocurrencies is the major application field for this type of blockchain. Bitcoin and Ethereum are examples of public/ permission-less chains. Consortium blockchains is a partially centralized, where only selected group of users have permissions to view and contribute to the consensus protocol. Private blockchain is distributed in a decentralized manner through the network. One center authority manages the selected nodes that participate in the network [7]. Due to the diversity of the applications and domains that can leverage the blockchain technology, there is no consensus of which distributing qualities and consensus mechanisms are required to label a technology as "blockchain". In table 1 below a comparison of the three different types of block chains is shown.

Table 1 Type of blockchains overview [7]

Property	**Public blockchain**	**Consortium blockchain**	**Private blockchain**
Consensus determination	All miners	Selected set of nodes	One organization
Read permission	Public	Public or restricted	Public or restricted
Immutability	Nearly impossible	Could be tampered	Could be tampered
Efficiency	Low	High	High
Centralized	No	Partial	Yes
Consensus process	Permissionless	Permissioned	Permissioned

There are multiple blockchain frameworks and platforms that can be used or combined together to deliver decentralized systems. The most popular ones are Ethereum [5] and Hyperledger [4] which can be used to develop new systems or create new protocols.

2.2. Current Challenges in Healthcare

There are multiple challenges in the current health information technology systems. Today, the current medical facilities rely on the medical records of the patients. Those records include current and historical data, which are growing massively. The size of the medical records is becoming massive either because the evaluation of the medical devices that can collect data outside of the medical facility such as wearable devices or the quality of the collected medical images. This massive amount of collected medical records requires a secured and sharable central database in order to seamlessly make it accessible between the interested parties.

In 2016 NaimYaraghi [9] published an article on Brookings Institute that has shown the reasons why the medical records are highly vulnerable to security breaches: (a) The medical records contain personal information such as date of birth, social security number, address, e.g., that makes like a treasure for hackers; (b) medical records are shared by many parties such as the patient, medical facilities, doctors and hospitals; (c) data is long lived in order to access the history records. In addition to that Naim's study has shown that data breaches have increased by 1,500% between 2010 and 2016 as show below in figure 1.

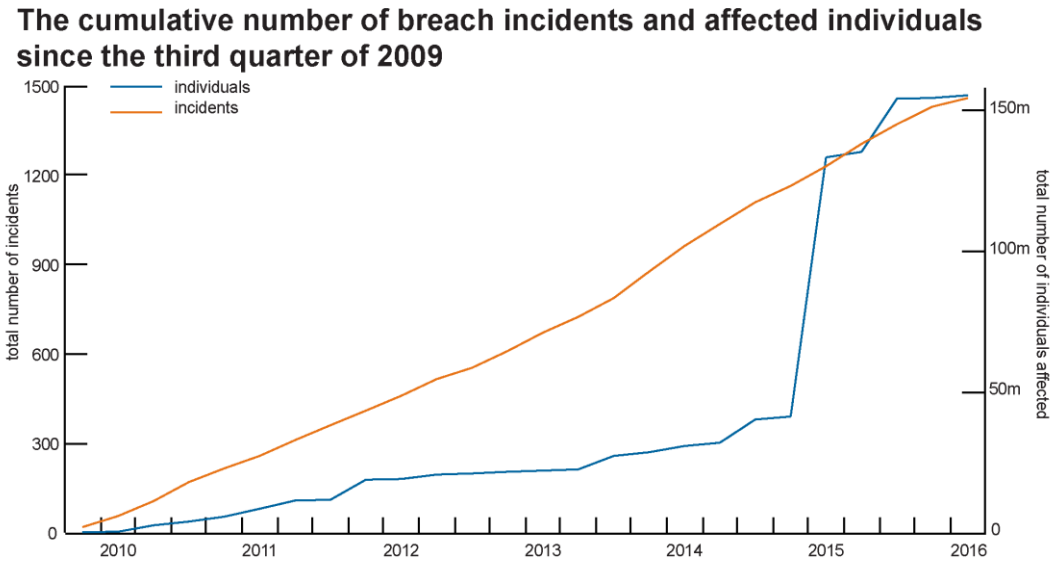

Figure 1: Data Breaches between 2010 and 2016 [9]

Furthermore, patients concern about their medical records gets leaked since there is a potential risk of the medical devices are being hacked while these devices are in use to collect medical data required for a medical analysis [1].

Medical image sharing is another area in the healthcare domain that can take advantage of blockchain technology [10]. Transforming and sharing medical images from physical copies to digital imaging has a significant impact in improving the security and availability of the medical images between providers. The classic way of sharing medical images is for the patients themselves to keep a physical copy on a disk and share it between providers. This solution has the risk of loss of, or damage to the physical copy. Currently, there is a solution called Image Share Network (ISN) that has been developed by Radiological Society of North America (RSNA) [10].

Not only the medical record structed data is increasing, the number and the size of the medical imaging is increasing as well. The medical images plays a critical role in different medical areas such as clinical diagnosis, pathology localization, a study of anatomic structures, and therapeutic strategy[11]. These images require to be

transmitted in a secure manner. There are multiple types of attacks that can impact the images while they are transmitted [12].

Another challenge in legacy healthcare system, is the incompatibility between the different healthcare facility. It's considered a cumbersome to integrate between the internal healthcare systems and external facilities. It's called multi-organizational data exchange problem that requires an easy way to share patients' data between different organizational in an easy and secure way [8].

In order to overcome the challenges listed above, the health care systems have new set of requirements to address the security and data sharing concerns: (a) granular level access; (b) distributed data management; (c) data immutability to guarantee data authenticity and integrity; (d) all transactions should patient centric.

3. Current Application of Blockchain in Healthcare and Related Work

Blockchain technology usage in healthcare has a great perennial to solve many of the challenge's healthcare domain has. Due to the growth of data in HIT and the need to make the data available via a secure manner, blockchain technology can be used to meet these requirements. Starting from data management and the accuracy of the health records, the blockchain technology can play a pivotal role in various areas such as drug prescriptions, pregnancy, supply chain management, health record management, and any risk data management as well as to support better access control, data sharing and managing of an audit trail of medical activities [13]. Blockchain technology can improve medical data availability, data security, data sharing, traceability, and record immutability. Figure 2 shows different applications of blockchain usage in healthcare

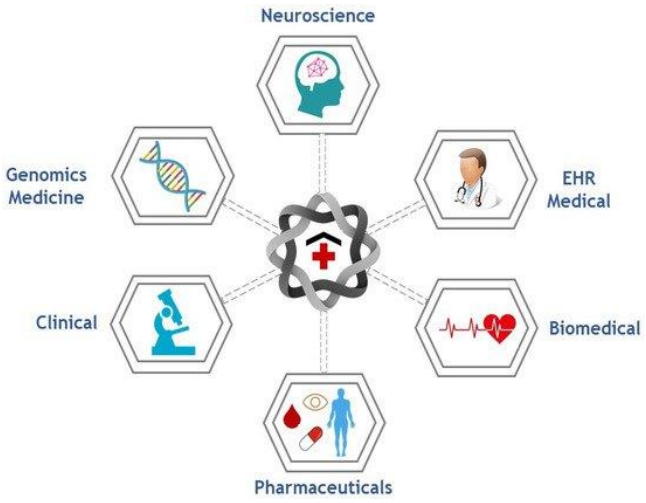

Figure 2: Applications of blockchain in healthcare [14]

Starting from data collection to analysis and research, there are various applications than can benefit from blockchain technology. Electronic Health Record is the vital part and getting it right from the get-go is a key. The next section will cover this in detail and shows a use case of using a permissioned blockchain network to secure the collection and dissemination of that data.

Having the medical records in a secured, decentralize and immutable store, enables further applications such as clinical research where collaboration and data sharing between multiple research entities a becomes available. Data immutability enables another area of application that can take advantage of blockchain network such as medical fraud detection. Blockchain network doesn't allow data modification and provides immutability out of the box where there is no one can alter the transaction which enables transparency and security of each transaction.

In addition to the previous application, there is a huge potential in applying it in several areas in the health care systems such as Neuroscience Research, pharmaceutical industry and Research and Medical Record & Image Sharing. The next two section will cover electronic health records and image sharing application in more details.

In the recent few years, many authors have explored the idea of using blockchain in the context of healthcare [6, 10]. Blockchain technology can help mitigate challenges of current electronic medical records solutions and can create value for treatment process and remote access of patients' medical information and ensuring the protection of healthcare data privacy. We have conducted intensive research on blockchain technology and how this technology can be used in healthcare for electronic medical records management. Most of these researches have theoretical approach only a few have discussed the real implementation of blockchain based medical record systems.

In 2019 Asma Khatoon [15] published an article about using blockchain-based smart contract system for health care management. In that article, Asma conducted a review of the blockchain technology usage in health care between 2016 and 2019 [16-40]. Asma implemented a smart contract-based healthcare management system using blockchain technologies that showed how to apply the decentralization priceable within the medical ecosystem. In additional to applying blockchain principles, other benefits are shown as well such as reduced the transaction costs, reduced the administrative burdens, and removed intermediaries. Daisuke et al. [18] worked on medical records using the Hyperledger fabric blockchain platform where they were sending medical data to the hyper ledger blockchain network. They have collected those medical records using smartphones. The objective of their work is making sure that healthcare data is registered to the Blockchain.Rouhani et al. [18] introduced an approach to address limitations of permission and permissionless blockchain. They have used Hyperledger platform for patient-controlled healthcare data management. Zhang et al. [31] discussed about blockchain, smart contracts and how blockchain based smart contracts has the potential to address different healthcare issues. In their work they adopted blockchain technology for different healthcare use cases. They highlighted the different challenges in the implementation of blockchain technology. They have elaborated that developing blockchain based systems that can address healthcare issues in more efficient ways.

Our proposed implementation is anative cloud-based solution enables us to securely store large scale of patients' medical records. Hyperledger framework is a secured blockchain implementations which provides complete data isolation between a set of participation. Amazon Managed Blockchain eliminates the overhead required to create the network or join a public network, and automatically scales to meet the demands of thousands of applications running millions of transactions. To fully guarantee the security our implementation, our service is running in Amazon Virtual Private Cloud (Amazon VPC). No services outside the VPC can access our resources.

4. Framework Implementation

4.1. Framework Selection and Architecture

Our first step in the implementation was to decide which blockchain framework to use, permissioned or permissionless. Most of the previous related work that we shared earlier have usedpermissionless network and smart contract. Due to the sensitivity of the personal medical record, we have chosen Hyperledger framework to guarantee that only permissioned member can access our blockchain network.

- Permissionless blockchain allows anyone to join the network anonymously without permission, as it allows all members to read the data.Toavoid that behavior, we have decided to use Hyperledger framework over Ethereum because it is a permissioned blockchain platform which identities only permissioned nodes to access the data.
- The patient medical records have sensitive fields such as: date of birth, national id, diagnoses, etc. This data can be accessible to other members in the network if it's permissionless and will require custom implementation to protect it. This data requires additional level of protection to prevent unauthorize access to it. Instead of building a customer solution, Hyperledger permissioned blockchain satisfies this requirement in addition to all other blockchain features. Only authorized network members will have access to the stored data based on their roles.
- In addition to the security and data protection concerns, cost is another factor because Ethereum framework uses proof-of-work (PoW) algorithm. PoWis expensive and requires large number of resources for mining in addition to transaction fees. With expected large amount of transaction, the solution will be very expensive and will limit its usage. In the other hand, Hyperledger framework uses consensus algorithms that are less expensive computationally.

- AWS provides scalability and pay as you go concept. We pay only for the resources we use when it's needed to be used.We have chosen the following services: (a)
  Amazon Managed Blockchain to persist our patient's medical record; (b)Amazon Virtual Private Cloud to run our solution in a private network to protect the network from unauthorized access; (c) Amazon Elastic Compute cloud to deploy the chaincode and client code; (d)AWS Secrets Manager to securely protect the network keys.

4.2. System Architecture and Implementation based on our selection

Our implementation is based on Amazon Managed Blockchain [42] with Hyperledger Fabric framework which provide highly efficient and secure storage for patients' medical records.Figure 3 presents the architecture of our proposed framework. The network is not accessible outside of the VPC which adds additional layer of security. The current scope of this solution is to provide application programming interface (API) to Health Administrator to create, retrieve, update, and delete patient records in Hyperledger Fabric database. This is a vital steptowards building an entire system for different user types such as patients, healthcare providers or healthcare facilities.

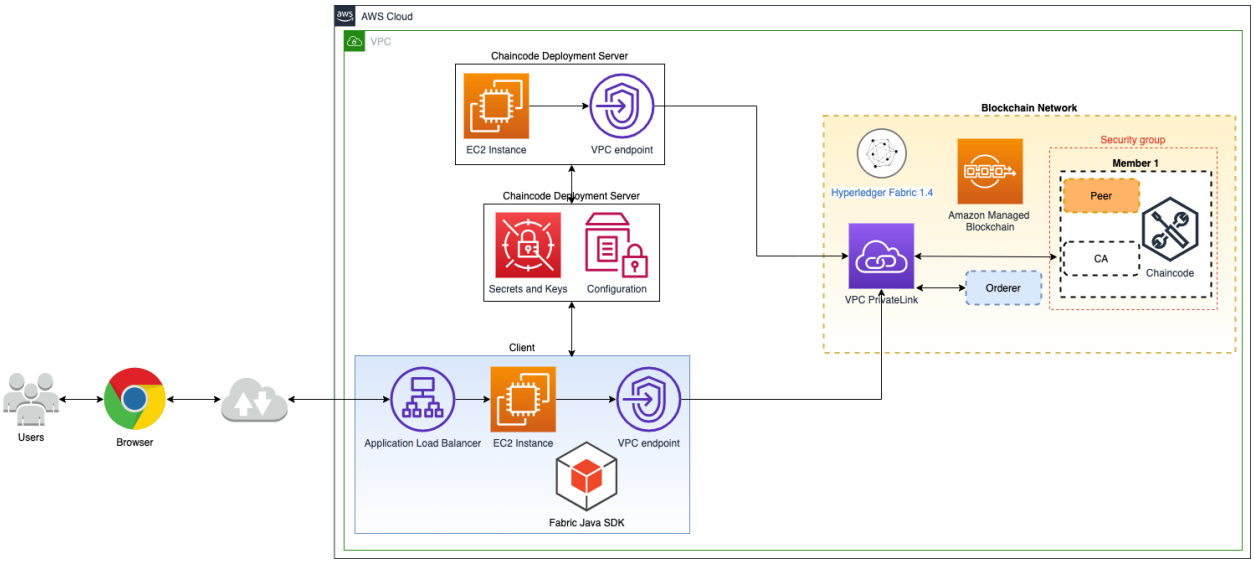

Figure 3: Our proposed Electronic Medical Records Cloud Architecture

Using AWS command line interface, the blockchain network can be created in eight steps as show in figure 4:

1. Create a network and specifying the framework type and in our implementation, we choose Hyperledger Fabric version 1.4;
2. Create a member and small instance type to be more cost efficient during this initial implementation;
3. Create a virtual private cloud endpoint for the network to guarantee that this network can't be accessible outside of this VPC;
4. Create a peer node to interact with other members' peer nods on the blockchain to query and update, and store a local copy of the ledger;
5. Create a client to be able to interact with the network and deploy the chain code;
6. Enrolling an administrative user to the created member CA and the password for this user is stored in Amazon Secrets Manager;
7. From the admin client instance, create a channel to allow the ledger be shared across the entire network if every member is operating on a common channel;
8. In future work, new members can be invited to the network in order to allow different types of users such as administrators or health care providers.

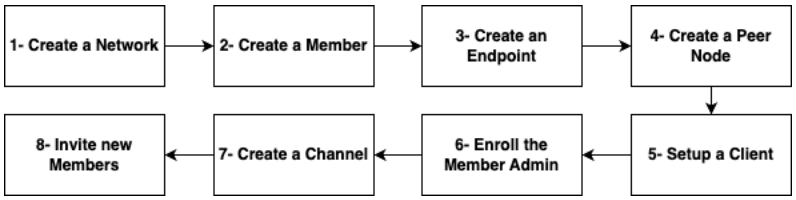

Figure 4: Create Blockchain Network Steps

4.3. System Functionality

We wrote a client application that reads a list of patients' records stored in comma separated file and then makes a create API call to our client application. This client application acts as a healthcare provider who is authorized to perform create or update operations. The user for this client is a preregistered user as we use permissioned blockchain. The system detects duplicate records and returns 409 https status. The patient record contains a list of appointments to allow multiple appointments for patients visits. For every update happens the old records remains unchanged, and a new version of the record will be created as the default behavior of Hyperledger blockchain network. This guarantees the authenticity and immutability of the medical record.

Figure 5 shows who the create patient transaction is executed in a blockchain network. The client application is authorized to perform the create operation and it makes a call to the peer nodes and once the proposal is approved it returns an endorsement back based on the public/private key for the client.

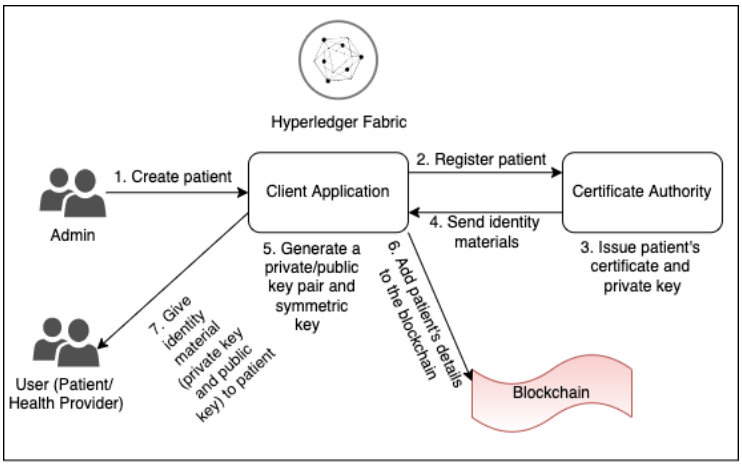

Figure 5: A process flow of a new patient registration

With our role-based access and blockchain network membership configuration patients can only read their latest version of medical records. When a patient tries to access create, update, or delete API, untheorized exception will be thrown as he/she doesn't have access to these operations. If there is an update is required, patient will need to contact the authorized parties to perform the update operations.

5. Conclusion and Future Work

Recently, blockchain technology usages has been increased not only in crypto currency or financial areas, but in different fields such as healthcare systems.

In this paper, we have shared an overview about blockchain and its different frameworks. We have proposed a cloud-based solution using and AWS and have created a Hyperledger Fabric Blockchain Network Using Amazon Managed Blockchain for patients' medical records. Our solution provides efficient storing mechanism and sharable medical records in a secure manner. Our solution uses a private blockchain network to ensure the privacy of patient's medical records. We have presented a secured cloud-based architecture that collects, store patients' records using various AWS services. As part of our future work, we will add more members the network to represent different roles and actors in addition to bringing in real patients' medical records to test the performance of the system.

6. References

[1] Elghoul, M.; Bahgat, S.; Hussein, A.; Hamad, S. "A Review of Leveraging Blockchain based Framework Landscape in Healthcare Systems." *International Journal of Intelligent Computing and Information Sciences* 21.3 (**2021**): 71-83.

[2] Agbo, CC, Mahmoud, QH. "Comparison of blockchain frameworks for healthcare applications." *Internet Technology Letters*. 2019; 2:e122. https://doi.org/10.1002/itl2.122

[3] Nakamoto S., "Bitcoin: a peer-to-peer electronic cash system". 2008. [Online]. https://bitcoin.org/bitcoin.pdf. Accessed March 30, 2019.

[4] Cachin, C.. "Architecture of the Hyperledger Blockchain Fabric,"*Workshop on Distributed Cryptocurrencies and Consensus Ledgers, 2016*.

[5] Paul J. Taylor, TooskaDargahi, Ali Dehghantanha, Reza M. Parizi, Kim-Kwang Raymond Choo, "A systematic literature review of blockchain cyber security, " *Digital Communications and Networks*,Volume 6, Issue 2, 2020: 147-156

[6] Hölbl, Marko &Kompara, Marko &Kamisalic, Aida &NemecZlatolas, Lili. (2018). "A Systematic Review of the Use of Blockchain in Healthcare," *Symmetry*. 10. 470. 10.3390/sym10100470.

[7] Z. Zheng, S. Xie, H. Dai, X. Chen and H. Wang, "An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends," *2017 IEEE International Congress on Big Data (BigData Congress)*, Honolulu, HI, 2017, pp. 557-564, doi: 10.1109/BigDataCongress.2017.85.

[8] Anton Hasselgren, Katina Kralevska, Danilo Gligoroski, Sindre A. Pedersen, ArildFaxvaag, "Blockchain in healthcare and health sciences—A scoping review," *International Journal of Medical Informatics*, Volume 134, 2020:104040

[9] N. Yaraghi, "Hackers, phishers, and disappearing thumb drives: Lessons learned from major health care data breaches ExEcutivE summary Background," 2016.

[10] Patel V. "A framework for secure and decentralized sharing of medical imaging data via blockchain consensus," *Health Informatics Journal*. 2019;25(4):1398-1411. doi:10.1177/1460458218769699

[11] N.M.M. Abdleall; A. E. E. Elalfi; Faten A. El-Mougi, "An Intelligent Educational System for Breast Cancer Management". *International Journal of Intelligent Computing and Information Sciences*, 22, 3, 2022, 39-53. doi: 10.21608/ijicis.2022.136628.1179

[12] Mahmoud Magdy Mohamed; Said Ghoniemy; Neveen Ibrahim Ghali. "A Survey on Image Data Hiding Techniques". *International Journal of Intelligent Computing and Information Sciences*, 22, 3, 2022, 14-38. doi: 10.21608/ijicis.2022.130393.1174

[13] Lemieux, V.L. Trusting records: Is Blockchain technology the answer? *Rec. Manag. J.* **2016**, *26*, 110–139.

[14] Siyal, A.; Junejo, A.; Zawish, M.; Ahmed, K.; Khalil, A.; Soursou, G. Applications of Blockchain Technology in Medicine and Healthcare: Challenges and Future Perspectives. *Cryptography* **2019**, *3*, 3.

[15] Khatoon, A. A Blockchain-Based Smart Contract System for Healthcare Management. *Electronics* **2020**, *9*,

94. https://doi.org/10.3390/electronics9010094

[16] Daisuke, I.; Kashiyama, M.; Ueno, T. Tamper-resistant mobile health using blockchain technology. *JMIR MhealthUhealth* **2017**, *5*, e111.

[17] Vazirani, A.A.; O'Donoghue, O.; Brindley, D.; Meinert, E. Implementing Blockchains for Efficient Health Care: Systematic Review. *J. Med. Internet Res.* **2019**, *21*, e12439.

[18] S. Rouhani, L. Butterworth, A. D. Simmons, D. G. Humphery and R. Deters, "MediChainTM: A Secure Decentralized Medical Data Asset Management System," *2018 IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData)*, Halifax, NS, Canada, 2018, pp. 1533-1538, doi: 10.1109/Cybermatics_2018.2018.00258.

[19] Wu, H.T.; Tsai, C.W. Toward blockchains for health-care systems: Applying the bilinear pairing technology to ensure privacy protection and accuracy in data sharing. *IEEE Consum. Electron. Mag.* **2018**, *7*, 65–71.

[20] Shen, B.; Guo, J.; Yang, Y. MedChain: Efficient Healthcare Data Sharing via Blockchain. *Appl. Sci.* **2019**, *9*, 1207.

[21] Khezr, S.; Moniruzzaman, M.; Yassine, A.; Benlamri, R. Blockchain technology in healthcare: A comprehensive review and directions for future research. *Appl. Sci.* **2019**, *9*, 1736.

[22] Litchfield, A.T.; Khan, A. *A Review of Issues in Healthcare Information Management Systems and Blockchain Solutions*; CONF-IRM, 2019; Available online: https://aisel.aisnet.org/confirm2019/1/ (accessed on 31 December 2019).

[23] Vora, J.; Nayyar, A.; Tanwar, S.; Tyagi, S.; Kumar, N.; Obaidat, M.S.; Rodrigues, J.J. BHEEM: A Blockchain-Based Framework for Securing Electronic Health Records. In Proceedings of the 2018 IEEE Globecom Workshops (GC Wkshps), Abu Dhabi, UAE, 9–13 December 2018.

[24] Zhang, P.; Schmidt, D.C.; White, J.; Lenz, G. Blockchain Technology Use Cases in Healthcare. In *Advances in Computers*; Elsevier: Amsterdam, The Netherlands, 2018; Volume 111, pp. 1–41.

[25] Siyal, A.; Junejo, A.; Zawish, M.; Ahmed, K.; Khalil, A.; Soursou, G. Applications of Blockchain Technology in Medicine and Healthcare: Challenges and Future Perspectives. *Cryptography* **2019**, *3*, 3.

[26] Jamil, F.; Hang, L.; Kim, K.; Kim, D. A Novel Medical Blockchain Model for Drug Supply Chain Integrity Management in a Smart Hospital. *Electronics* **2019**, *8*, 505.

[27] Lee, S.H.; Yang, C.S. Fingernail analysis management system using microscopy sensor and blockchain technology. *Int. J. Distrib. Sens. Netw.* **2018**, *14*.

[28] Agbo, C.C.; Mahmoud, Q.H.; Eklund, J.M. Blockchain technology in healthcare: A systematic review. *Healthcare* **2019**, *7*, 56.

[29] Azaria, A.; Ekblaw, A.; Vieira, T.; Lippman, A. Medrec: Using Blockchain for Medical Data Access and Permission Management. In Proceedings of the 2016 2nd International Conference on Open and Big Data (OBD), Vienna, Austria, 22–24 August 2016.

[30] N. Nchinda, A. Cameron, K. Retzepi and A. Lippman, "MedRec: A Network for Personal Information Distribution," *2019 International Conference on Computing, Networking and Communications (ICNC)*, Honolulu, HI, USA, 2019, pp. 637-641, doi: 10.1109/ICCNC.2019.8685631

[31] Zhang, P.; White, J.; Schmidt, D.C.; Lenz, G. Design of Blockchain-Based Apps Using Familiar Software Patterns to Address Interoperability Challenges in Healthcare. In Proceedings of the PLoP-24th Conference on Pattern Languages of Programs, Vancouver, BC, Canada, 22–25 October 2017.

[32] Kumar, T.; Ramani, V.; Ahmad, I.; Braeken, A.; Harjula, E.; Ylianttila, M. Blockchain Utilization in Healthcare: Key Requirements and Challenges. In Proceedings of the 2018 IEEE 20th International Conference on e-Health Networking, Applications and Services (Healthcom), Ostrava, Czech Republic, 17–20 September 2018.

[33] S. Ali, G. Wang, B. White and R. L. Cottrell, "A Blockchain-Based Decentralized Data Storage and Access Framework for PingER," *2018 17th IEEE International Conference On Trust, Security And Privacy In Computing And Communications/ 12th IEEE International Conference On Big Data Science And Engineering (TrustCom/BigDataSE)*, 2018, pp. 1303-1308, doi:

10.1109/TrustCom/BigDataSE.2018.00179.

[34] PengCheng Wei, Dahu Wang, Yu Zhao, Sumarga Kumar Sah Tyagi, Neeraj Kumar, "Blockchain data-based cloud data integrity protection mechanism," *Future Generation Computer Systems*, Volume 102, 2020: 902-911

[35] Krishnapriya S, GreeshmaSarath, "Securing Land Registration using Blockchain," *Procedia Computer Science*, Volume 171, 2020: 1708-1715

[36] Ahmed Farouk, Amal Alahmadi, Shohini Ghose, Atefeh Mashatan, "Blockchain platform for industrial healthcare: Vision and future opportunities," *Computer Communications*, Volume 154, 2020: 223-235

[37] Qinghua Lu, Xiwei Xu, Yue Liu, Ingo Weber, Liming Zhu, Weishan Zhang, "uBaaS: A unified blockchain as a service platform," *Future Generation Computer Systems*, Volume 101, 2019: 564-575

[38] Dasaklis, Thomas & Casino, Fran & Patsakis, Costas & Douligeris, Christos."A framework for supply chain traceability based on blockchain tokens,", 2019

[39] B. Koteska, Elena Karafiloski, A. Mishev. "Blockchain Implementation Quality Challenges: A Literature Review." *SQAMIA*, 2017

[40] Ingo Weber, XiweiXu , Regis Riveret, Guido Governatori, Alexander Ponomarev, Jan Mendling, "Untrusted Business Process Monitoring and Execution Using Blockchain, " 2016, 10.1007/978-3-319-45348-4_19

[41] Amazon Inc. Amazon Managed Blockchain, https://aws.amazon.com/managed-blockchain/ [Accessed: 01-01-2022]

[42] Amazon Inc. Amazon Web Services, http://aws.amazon.com/ [Accessed: 01-01-2022]