International Journal of Information Systems and Supply Chain Management
Volume 15 • Issue 3

HealthCare EHR:
A Blockchain-Based Decentralized Application

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ABSTRACT

Blockchain technology is currently playing a significant role in providing a secure and effective means to share information in a variety of domains, including the financial sector, supply chain management (SCM) in various domains, IoT, and the field of health care systems (HCS). The HCS application's interoperability and security allow patients and vendors to communicate information seamlessly. The absence of such traits reveals the patient's difficulties in gaining access to his or her own health status. As a result, incorporating blockchain technology will eliminate this disadvantage, allowing the HCS to become more effective and efficient. These potential benefits provide a foundation for blockchain technology to be used in various aspects of HCS, such as maintain the patient electronic health record (EHR) and electronic medical records (EMR) for various medical devices, billing, and telemedicine systems, and so on. In recent years the decentralized applications or Dapps have been rapidly emerged as the hot research topic and being adopted by various fields such as banking, medical and business, etc. The Dapps are nothing but digital applications which run on a peer-to-peer network outside the purview and control of a single controlling body. This research work focuses on developing a decentralized application Healthcare EHR for storing and sharing medical data among the patient and the doctor.

KEYWORDS

Blockchain, SCM, HCS, EHR, EMR, Dapps

1. INTRODUCTION

In a peer-to-peer network, blockchain provides a safe and advanced network for executing and exchanging information between multiple nodes. According to Gartner, blockchain is one of the top ten most important innovation trends for 2018 (Shukla, R. G., Agarwal, A., & Shukla, S, 2020). It is stated in (Abdellatif, A. A.,et al, 2020) that using a public blockchain can reduce the need for trustworthy nodes for exchanging information. The ongoing transaction will be validated by that node alone if a trustworthy node is deployed. When data is exchanged in a blockchain network, three primary components are present: Blocks, Nodes, and Miners. Miners create new blocks in the network, which is referred to as mining (Khan, F. A., et al., 2020). The preceding block's hash value must be remembered and referenced when generating the new block. Along with creating new blocks, miners also contribute to the solution of the NONCE in order to become the authority for certifying a transaction (Tanwar, S., Parekh, K., & Evans, R. 2020). When a block is successfully

DOI: 10.4018/IJISSCM.290017

mined, all nodes in the network agree on a value, and the miner is rewarded financially. In blockchain technology, the node is the most critical element which has to main the DLT installed in the network for sharing the information (Zhang, P., et al, 2017). The nodes have a copy of the blockchain, and any mining that takes place within the network must be approved by the network as a whole. Blockchain transparency allows the patients to view and examine the corresponding EHRs stored in the network (Zhang, P.,et al, 2018).

With the advent of blockchain technology in terms of bitcoin by Satoshi Nakamoto, it is being developed rapidly and brings attention from various researchers in academia and industry (Blum, F.,et al, 2020;W. Cai, Z. Wang et al, 2018). Blockchain technology is a decentralized system that is deployed in a peer-to-peer network to store transactional information, also known as blocks, in a public database called a distributed ledger that is accessible to any active network participant (McGhin, T.,et al, 2019). Due to the features such as decentralization, immutability, security, and transparency the blockchain technology is becoming the most promising and prominent technology advent for internet-based communication (Ratta, P.,et al, 2021).

Secure and scalable data sharing is essential for the healthcare decision-making system. Traditional clinical data initiatives, on the other hand, are typically fragmented, impeding effective information flow thus preventing the patient from making sensible treatment decisions (Siyal, A. A., et al, 2019). Blockchain technology plays a vital role in providing a secure platform for storing and sharing medical records among the patient and the doctor. Implementing DApp has its own benefits and challenges with respect to blockchain technology (Al Omar, A.,et al, 2019). The benefits and challenges of the healthcare system based on DApp are addressed in Table 1 and 2 respectively.

Table 1. Advantages of blockchain technology in the healthcare system

Functionality	Benefit in healthcare
Network Structure	The peer network structure provides a secure infrastructure
Cryptography Mechanism	Enables the system to prevent the unauthorized access
Distributed Ledger	Secure access control
Decentralization	Avoids the limitation of single point failure
NONCE	Acts as the authorization process in choosing the validator of a transaction
Smart Contracts	Helps in increasing transparency and transaction execution by automating the process.
WoT	Dependable election mechanism for choosing a validator for one transaction.
Permissioned Transaction	Since any sort of data alteration requires authorization from all parties, the degree of interference with stored data is decreased.

Table 2. Limitation of blockchain in the healthcare system

Functionality	Effect in implementing blockchain technology (BCT)
Storage Limitation	A considerable amount of storage is required to store a large amount of hospital and patient-centric data, which is an extremely challenging task (Satamraju, K. P. 2020).
Dynamic Records	Healthcare data is constantly changing. Data changes every second and must be saved in blockchain blocks on a regular basis. The alteration procedure takes a long time because authorization from each participant is required, which adds to the time complexity.
Network scalability	The blockchain's decentralized framework makes it difficult to add more healthcare systems to the existing blockchain.
Vendor Interest	There are various systems that have no interest in sharing EHR as they prefer to follow the legacy system for maintaining those.
Shifting the traditional system to DApp	Doctors are following the conventional way while writing prescriptions for their patients and show little interest in EMRs. The transition from the legacy system to the BCT is extremely difficult (Zarour, M., et al, 2020).

The contribution of this research work is to share the medical data between the patients and doctors to provide an improvised decision system for the health care system. The objective of this research work is summarized below.

- To develop a DApp using the blockchain system for the health care system.
- To provide a cost estimation method for calculating the overall cost for implementing the developed system in a real-time scenario.

The structure of this research article is as follows. Section 2 shows the overview of blockchain technology with the open-source Ethereum platform. The requirement of the blockchain based healthcare application is discussed in section 3. The section 4 holds the literature review done during the research work. The proposed work is addressed in chapter 5. Section 6 represents the cost estimation method for evaluating the implementation cost of the proposed work for deploying the model in the real-time scenario. Finally, section 7 holds the overall conclusion for the research work.

2. OVERVIEW

In the current section, the basic concepts of blockchain and blockchain-based PKI along with the blockchain environment taken during the research are discussed.

2.1 Blockchain

Blockchain is a peer-to-peer network in which there will be no more centralized concept present like the conventional system and resulting in an advanced framework for handling the transactional records in a peer-to-peer network. Blockchain technology is based on communication between different nodes without deploying any central authority for validation purposes (Udokwu, C., Anyanka, H., & Norta, A. 2020). This technology came to the front in the year 2009 in terms of the first cryptocurrency known as Bitcoin which had enjoyed a lot of capital in various fields. Bitcoin has played a vital role in converting the blockchain concept into a distributed database known as the ledger which has been made available for all participating peers in the network (Pop, C., et al, 2020). Basically, the blockchain is the combination of the blocks containing the data and key. Immutable, decentralization, security,

distributed ledger technology (DLT) are the trending features of blockchain technology which are addressed below (Wang, S., et al, 2018).

- **Immutable:** This feature enables the network to maintain integrity inside the peer-to-peer network while making some transactions. It allows all participating nodes to keep the entire copy of the transaction and without the permission of the nodes, the data can not be altered. In addition, it ensures that once the transaction record has been updated then it is not possible for any node to roll back for any kind of modification (Sun, Y., et al, 2018).
- **Decentralization:** It means there will be np centralized controller for any kind of the single point of control. This ensures that there will no central authority who will be validating the transaction every time so that the network can become more consistent.
- **Security:** Along with the immutability and decentralization the blockchain enforces the security parameters such as private key, the public key, and hash function to make the blockchain-based communication more dependable (Latif, R. M. A., et al, 2020).
- **Distributed Ledger Technology (DLT):** The DLT is nothing but a distributed database stores the transaction information and the participant information which be made available for all participating node more retaining the data integrity (Singh, A. P., et al, 2020).

Blockchain is becoming very powerful and useful due to its pervasive features such as immutable, decentralization, smart contract, and consensus protocol. The centralized database known as DLT removes the limitation of the centralized system. Due to these characteristics, the blockchain is providing a robust and secure network for a transaction without any fraud (Bryatov, S. R., & Borodinov, A. 2019).

2.2 Ethereum

Ethereum is a decentralised, open-source blockchain that enables the developer to design and implement smart contracts. The native cryptocurrency of this platform is Ether, which is the second largest cryptocurrency after bitcoin. The Ethereum Virtual Machine (EVM) is a 256-bit register stack that allows for network consensus by providing the same post-transaction state for a given pre-transaction state and transaction (Khatoon, A. 2020). Gas is a medium of trade within the EVM that is used to calculate a transaction fee, which is the amount of ETH a transaction's sender should pay to the miner who is involved in the blockchain transaction (Zhang, P., et al, 2018). Each sort of activity that the EVM can conduct has a hardcoded gas cost that is roughly proportionate to the number of resources (that a node needs to spend to perform that operation. The sender must set a gas limit and price when starting a transaction (Figueroa, S., Añorga, J., & Arrizabalaga, S., 2019).

2.3 Smart Contract

It is a collection of code and data which will be executed in a network during a transaction. Different nodes can execute the smart contract but the execution should result in the same output and be stored in a DLT. It can do computations and also can store information. The smart contracts must be deterministic to give consistent output upon procuring the same input condition. The smart contract implementation in a blockchain makes the network automatic which can trigger itself upon arriving at some predefined condition (Zhuang, Y., et al, 2020).

3. REQUIREMENT OF THE BLOCKCHAIN-BASED HEALTHCARE SYSTEM

For developing a healthcare-based application various factors need to be considered. In contrast to other techniques, blockchain technology is widely used in developing a HIT application due to its decentralized characteristics. For developing HIT-based applications the requirements need to be

acknowledged. Various application systems use different kinds of use cases with different technical requirements (Griggs, K. N., et al, 2018). In this current section, those issues are addressed along with various techniques to deal with those concerns. When developing a HIT-based application the privacy is a primary attribute that needs to be focused (Justinia, T., 2019). According to the typical blockchain concept, not all transactions in health care should be made e. There are regulatory and legal requirements that must be observed when handling healthcare data. As a result, any blockchain architecture that is utilized to build healthcare apps should have a thorough set of privacy safeguards (Kavathekar, S. S., & Patil, R., 2019).

Security is closely tied to privacy. To prevent all types of data theft, HIT systems must be established and developed. In HIT every actor should be easily recognizable, as should their behaviors. Security criteria for healthcare apps, like privacy, are enforced by rules and must be followed (Azaria, A., et al, 2016). Blockchain technology should provide a powerful authentication and access control technique for regulating the participating node and the data. The transaction throughput is another factor to consider when selecting a technology stack for designing healthcare applications. In some circumstances, such as remote patient monitoring (RPM) systems, healthcare applications must be able to grow in terms of speed and transaction throughput. The number of nodes that can participate in the consensus mechanism determines the transaction throughput or scalability of blockchain frameworks (Zhou, L., Wang, L., & Sun, Y., 2018). Consensus is concerned with how the blockchain network's transactions are processed and are discussed in more detail in the next section. They must first be validated before they can be regarded as valid transactions. This number could be as high as all of the network's nodes or as low as a single network node. As a result, the various blockchain frameworks have different techniques for achieving consensus, which are important concerns (Latif, R. M. A., et al, 2020).

4. RELATED WORK

In (Azaria, A., et al, 2016) Azaria al. represents the problems faced during medical record sharing and also describes the solution based on blockchain technology to handle this. The developed work was based on the key agreement protocol to solve the issues of sharing the medical records. The DApp is was develop on a public blockchain with EMR as the key factor. In (Zhou, L., Wang, L., & Sun, Y., 2018) Zhou et al. proposed a blockchain-based DApp for securing the information exchange between the different users. The application was developed on Ethereum environment with cryptography, nonce as the key functionality. Latif et al. (Latif, R. M. A., et al, 2020) had developed supply chain management (scm) for dealing with the transaction history of the patient. Every transaction on the developed scm must be digitally signed by the user.

In (Angelis, J., & da Silva, E. R., 2019) the author had developed a patient-centric data sharing system based on the ripple environment. The machine learning algorithms had been implemented in order to detect the anomaly during the message passing. Once the attackers interpret the communication then the digital signature will be changed automatically which must be checked at the receiver side in order to find out the integrity of the shared message. In (Angraal, S., Krumholz, H. M., & Schulz, W. L., 2017) the authors developed a DApp on an open-chain environment based on the hash function, digital signature, and smart contract to deal with the insurance. The patient claiming for insurance should be verified in terms of digital signature with the help of a smart contract. Whenever the patient will go for an insurance claim then the smart contract will be invoked automatically to verify the identity.

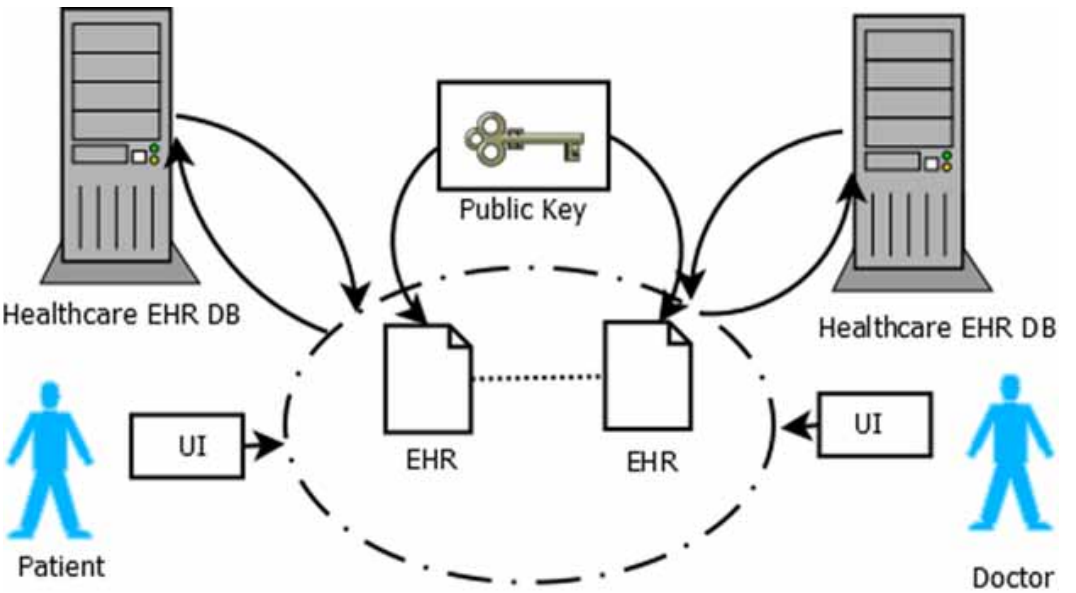
Dagher et al in (Dagher, G. G., et al, 2018) had proposed a payment portal based on the bitcoin environment. The node will choose the particular vendor who has successfully submitted the nonce in a minimal time period. Upon getting the result the patient will deal with that particular insurer for insurance claiming and the metamask payment wallet will be used to transfer the ether from one account to another. In (Dhagarra, D., et al, 2019) the author had tried to develop a DApp based on the digital ledger technology (DLT). Once the patient had been verified by one doctor then the records will

be stored in the used DLT which is accessible for every participant node present in the network. The main limitation present in this work is that the patient is unable to choose some particular participant for accessing the stored data. Every patient record is stored in the DLT with respect to its unique network. Dimitrov et al (Dimitrov, D. V., 2019) had developed a ripple-based SCM for sharing the patient record in which the uid will be a key attribute for sharing the information. Every patient and doctor is a part of the network thus having unique ids. Every patient has to store the diagnosis report in the provided public ledger from where the doctor can have access. The limitation present in this developed work is that the patient can not pay the doctor by using the blockchain wallet.

5. PROPOSED WORK

The purpose of this framework is to integrate blockchain technology for EHR first and then to enable secure electronic record storage for users of the proposed framework by creating granular access controls. Furthermore, by utilizing off-chain record storage, this framework overcomes the scalability issue that blockchain technology has in general. This provides the EHR system with the benefits of a scalable, secure, and integrated blockchain-based solution. The Healthcare EHR DApp is written in Javascript. This DApp provides an easy-to-use UI allowing the users to share and view the patient data. The developed system contains different modules such as the Registration and Login module, EHR uploading module, HER Accessing module. Figure 1 and 2 shows the block diagram and use case diagram of the proposed system. The developed application is deployed by using the Ganache EVM, Metamask, IPFS little server with a system having Windows OS, 256 GB SSD, 1 TB HDD, and i5 8th generation processor with 2.4-2.6 GHz clock speed.

Figure 1. Block diagram for the proposed system



Every user in terms of patient and doctor needs to register themselves for using the DApp. Before registering in the application, the users need to join the Ethereum network so that each can have their own key pair. The registration process will be done by using the user details such as the use case

Figure 2. Use case diagram for the proposed system

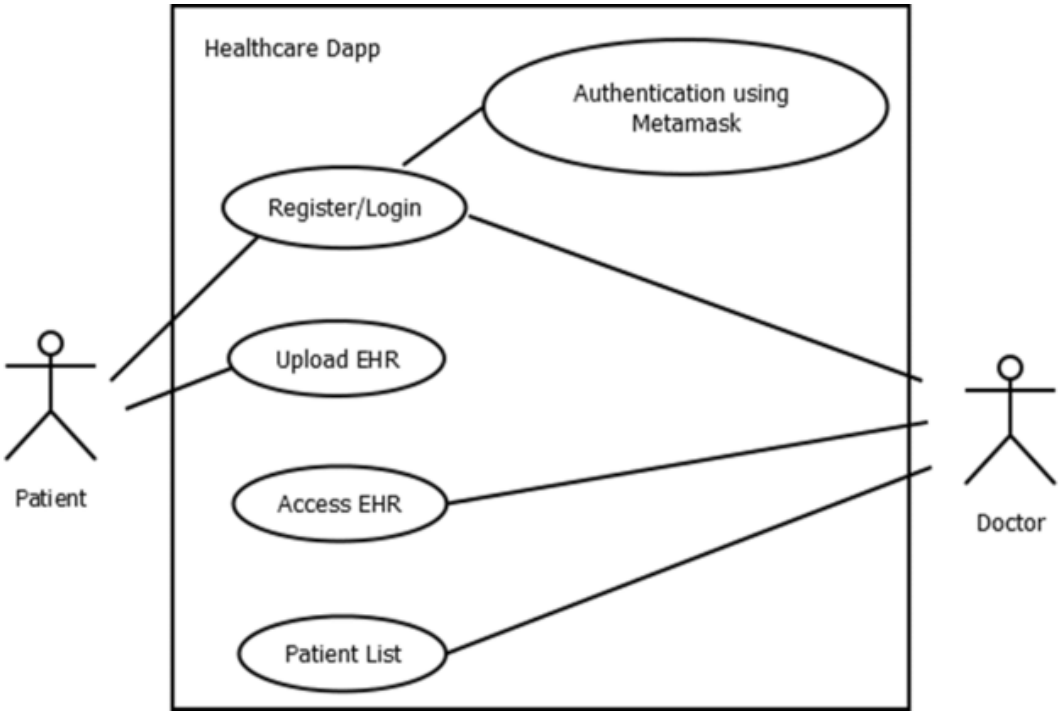


diagram for the name, age, the public key, and the activity for joining the application through the given UI. The attributes needed for registration are depicted in figure 3. After successful registration, the user needs to log in by using the provided public key.

After signing in the UI the patient has to choose the corresponding registered doctor for consultation. Once the doctor is making a diagnosis report then the report is considered as the HER that needs to be stored in the blockchain network which can be accessed by any doctor chosen by that corresponding patient. Figure 4 and 5 shows the patient and doctor portal in the developed DApp.

Figure 3. Attributes needed for the registration process

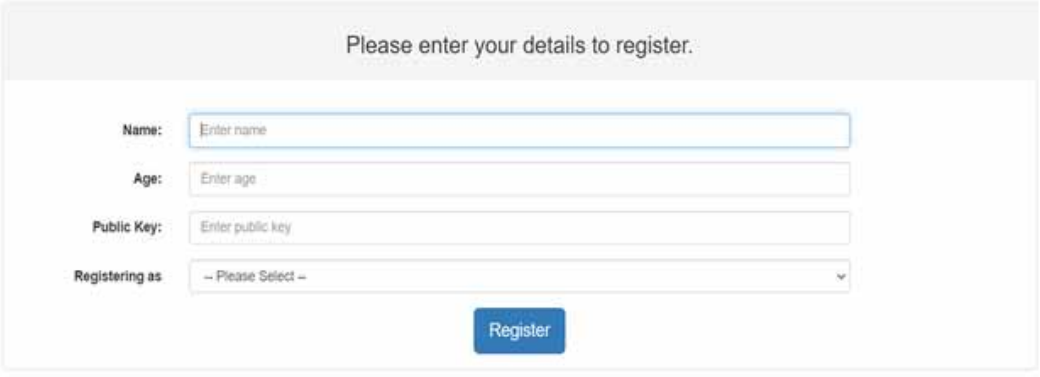


Figure 4. Patient dashboard for choosing the registered doctor

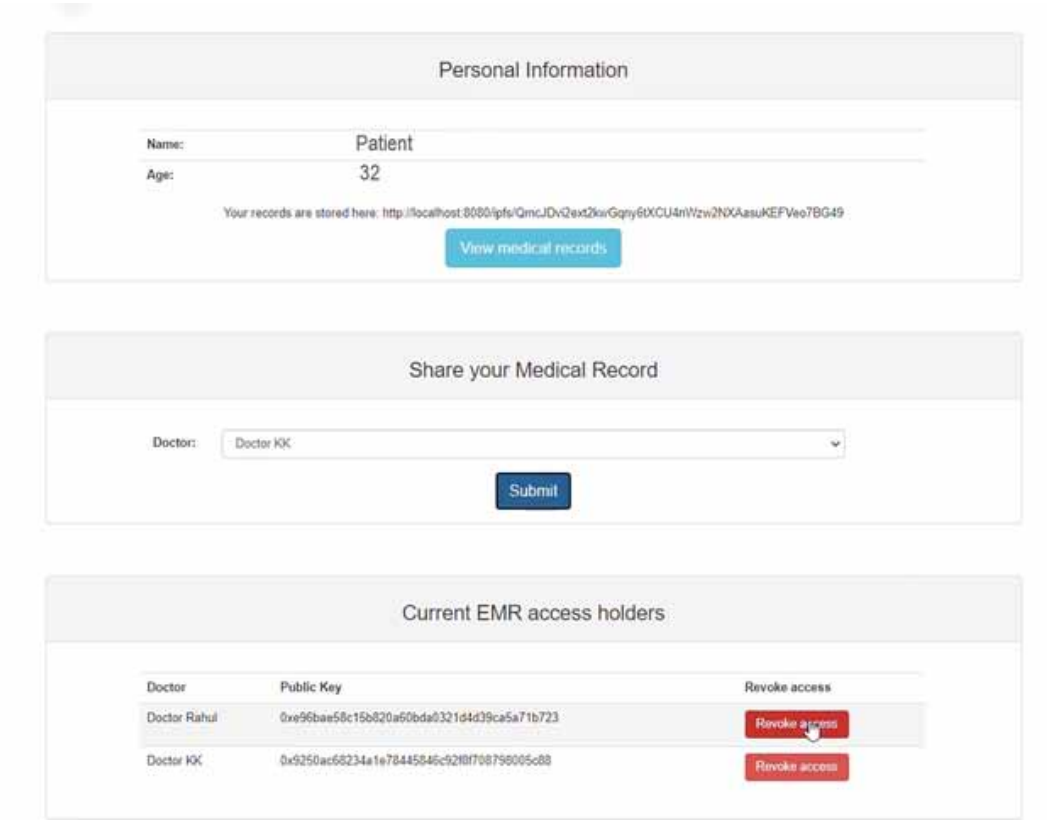
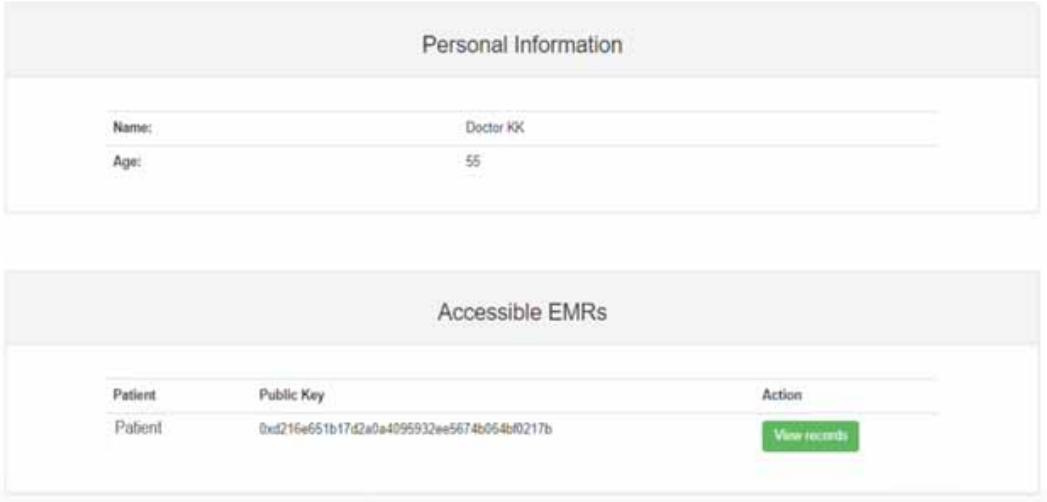


Figure 5. Doctor dashboard for diagnosing the registered patient



Once the registered doctor diagnoses the patient then the diagnosis report will be stored in the blockchain network in the off-chain storage manner. The patient can log in to the application to see the health diagnosis report and also can share the report with various doctors for further treatment. This process helps in avoiding the report storage at the patient side. These stored reports can be accessed by the doctor and the particular patient. Once the patient is diagnosed then it has to make the payment to that corresponding doctor. For that, each user is attached to metamask through their private key. Metamask helps the patient to transfer the fee in terms of ETH to the doctor by using the public key of the doctor. Once the money is transferred the remaining balance is updated in the blockchain account balance of the user. For sending the money the user needs to use an amount of gas which is provided by the EVM. For the current DApp development, the Ganache EVM is used. Figure 6 and 7 shows the EHR storage and metamask configuration for different users. For the current DApp two doctor entity has been taken as **Doctor** and **Doctor2** with one patient named as **Patient**.

Figure 6. EHR off-chain storage of the registered patient

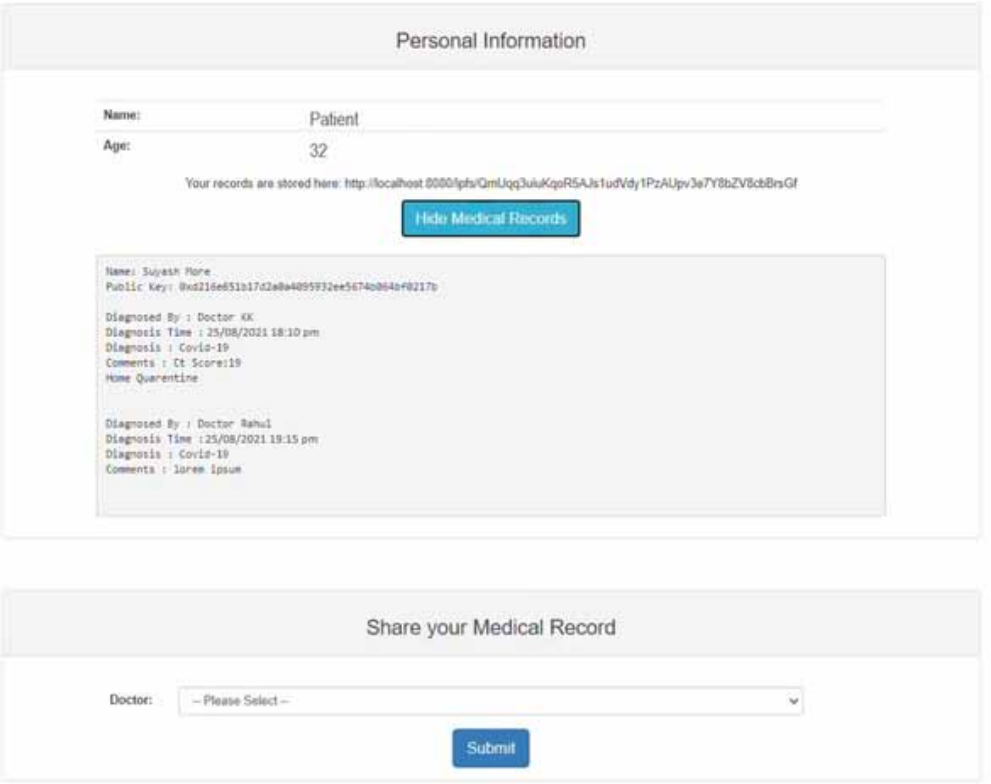
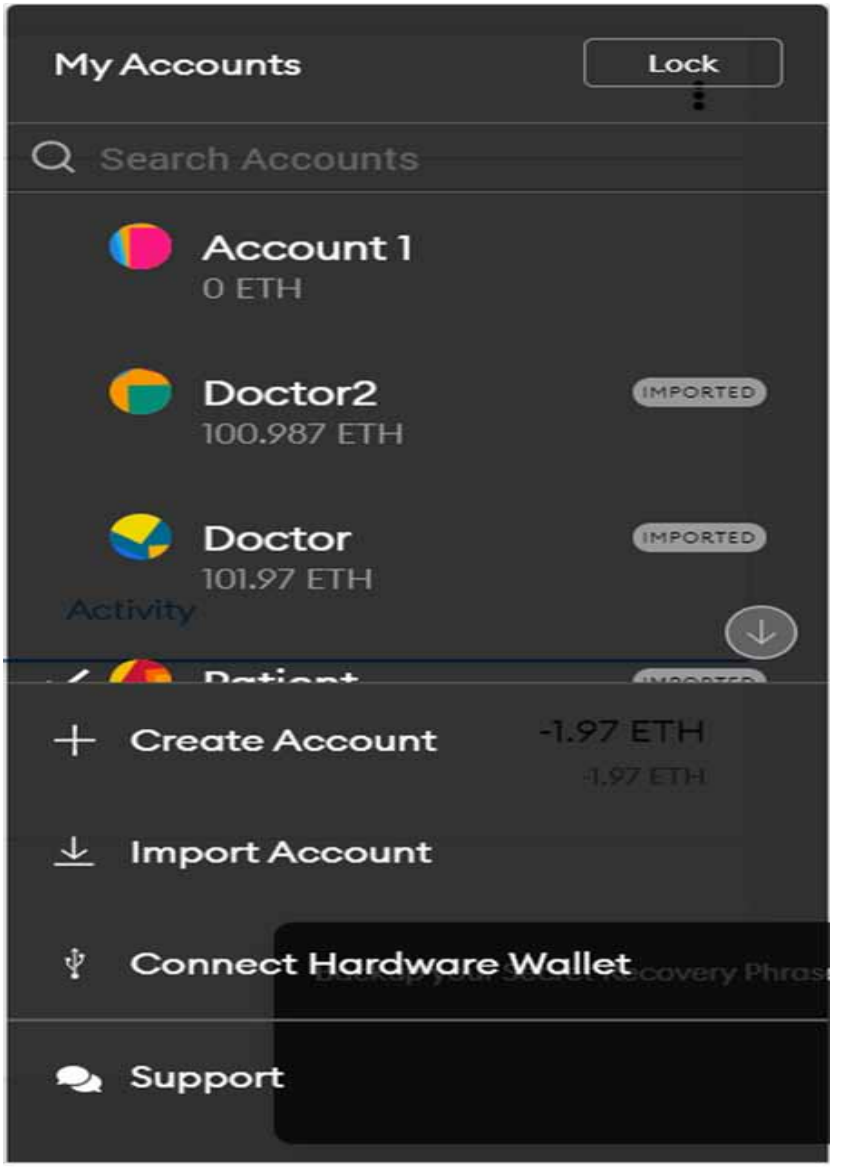


Figure 7. Metamask accounts for doctor and patient



The main benefit of the proposed DApp is the EHR sharing among the patient and doctor. The patient is able to share the previously diagnosed report with the desired doctor. The proposed model is compared with various existing models based on the adopted blockchain platform, key parameters, and payment options. Table 3 represents the comparative study.

Medrec (Azaria, A., et al, 2016) provides an Ethereum based platform for storing and sharing the patient medical data record. The limitation present in this work is that this model does not provide any mechanism to pay the consultation fee by using the Ethereum wallet. In MIstore (Zhou, L., Wang, L., & Sun, Y., 2018) a blockchain-based DApp has been proposed for data security. This model does provide any means to store and share the data. Remix (Latif, R. M. A., et al, 2020) is a Hyperledge based application system for storing and sharing the EMR but it does have any payment portal.

Table 3. Comparative analysis of proposed work concerning existing model

Model	Blockchain Platform	Use Case	Data Storage	Data Sharing	Payment Portal
Medrec (Azaria, A., et al, 2016)	Ethereum	EMR	Yes	Yes	NA
MIstore (Zhou, L., Wang, L., & Sun, Y., 2018)	Ethereum	Security	No	No	NA
Remix (Latif, R. M. A., et al, 2020)	Hyperledger	EMR	Yes	Yes	NA
Ancile (Dagher, G. G., et al, 2018)	Ripple	Insurance	Yes	Yes	Metamask
Proposed Work	Ethereum	EMR	Yes	Yes	Metamask

Ancile (Dagher, G. G., et al, 2018) is a Ripple-based application system for insurance claiming. This application only allows the patient to store the EMR and share the same with the vendor providing the insurance. The Metamask wallet is used for insurance payments. The proposed work aims to provide an Ethereum based DApp to store and share the data among the patient and doctor. The patient is free to make an appointment with any registered doctor and is also able to share the previously diagnosed report with the desired doctor. This application also allows the users to pay the consultation fee through the blockchain-enabled wallet metamask where the user has to create its account by using the obtained private key.

6. COST ESTIMATION

For deploying the DApp in the real world the implementation cost needs to be defined. The main goal is to create a solution that can provide a viable health care system by taking advantage of blockchain's capabilities. Network exploitation and other computational concerns are prevented by taking some fee for any kind of transaction executed in the platform and the fee is set as gas and ETH. On the Ethereum blockchain technology, gas refers to the payment or price value necessary for a successful transaction or contract execution.

For all kinds of computation done in EVM, the user needs to pay the fee. For every transaction initiated from different users, the gas limit needs to be set within which the user has to complete the transaction and the user has to return any unused gas to the network for which the user will be rewarded. If the user does not have sufficient balance in its account then it can initiate any further transaction. In EVM, ethers are used to buy gas, and users that are executing transactions can establish a gas limit for their account for that transaction. However, it is up to the miner to decide whether or not to allow the transaction. If a sender sets a higher gas price, it will cost them a lot of money to pay for the gas, while miners will gain a lot of money. The computation is then carried out by a miner to add this transaction to a block. A miner can then broadcast the new block into the network after all transactions have been completed successfully.

7. CONCLUSION

Blockchain system leverages the cryptography mechanism, P2P connection, consensus models, and smart contracts to build a decentralized communication and application. In this article, the blockchain evolution has been focused in terms of its application and feature. It is believed that the DApps based on the blockchain can bring a new era to the application domain. In this current research work, the

decentralized application using blockchain technology is developed for storing, sharing, and diagnosis purposes. The storage manner used in the current development is the off-chain one which helps in dealing with the blockchain storage constraint. The current Healthcare EHR DApp will let people to freely and securely share their medical records with various users inclusing the doctors, hospitals, insurance companies while maintaing the access controll and security over the medical records. Many of the current healthcare system's issues, such as data silos, legacy network unreliability, unstructured data-gathering obstacles, unreasonably high administrative costs, a lack of data security, and unsolved privacy concerns, have be addressed.

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