A Blockchain-Based Solution for Electronic Medical Records System in Healthcare

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Abstract. Healthcare has come out as an emerging field for technologies like IoTs, cloud computing, big data, etc. lately. However, keeping the healthcare records secure and private is still a big issue. Due to this, its widespread adoption is something that might take a few more years. For past few years, blockchain technology has shown its capability to be a preferred technology to provide better security and privacy. Recent breakthroughs in various technologies have improved medical transactions, health insurance claims, and secure records keeping, with the help of its decentralized and distributed nature. In this paper, several algorithms and methods are proposed to improve limitations in the current healthcare system using blockchain technology. It further proposes architecture and tools to measure the performance of the system. Finally, the results and future directions for the research in the healthcare domain are discussed.

Keywords: Blockchain · Electronic Medical Records · Healthcare · Ethereum · Binance Smart Chain · IPFS

1 Introduction

For past few years, the evolution of technologies like the Internet of Things (IoT), etc. has created a smart ecosystem where various entities interconnect to facilitate capturing, storing, sharing, and communicating the information. Technologies like Bluetooth, wi-fi, RFID, etc. have been a major catalyst in the transformation and improvements of traditional systems into smart systems [1–4]. With this advancement, all the major sectors like education, agriculture, transportation, etc. are shifting from transitional approaches to smart systems [5, 6]. Similarly, the healthcare industry is also developing into a Smart Healthcare System (SHS) where all the participants are interconnected to achieve holistic and ubiquitous healthcare facilities. This transformation has led to expansion in investments and awareness leading to becoming increasingly competent at enabling faster identification, handling large chunks of data, determining illness at a faster pace, with suggestions and treatment comparisons [7].

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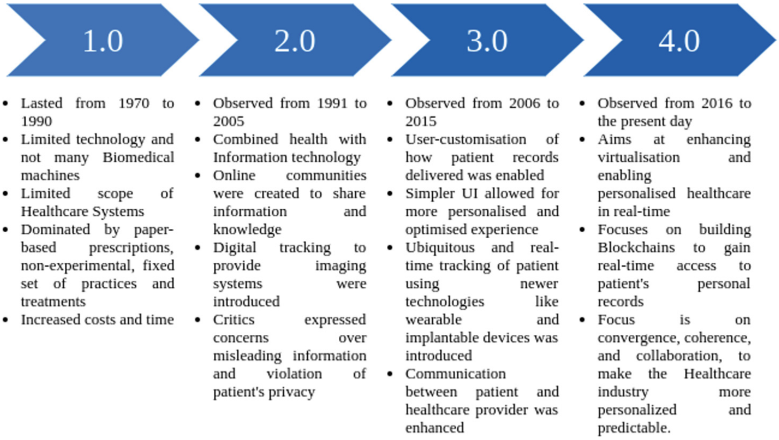
The Healthcare industry has come a long way over the years and has seen some major technological changes from Healthcare 1.0 to the current Healthcare 4.0 [8]. Started in the 1970 s the Healthcare industry has gone from using paper-based records to blockchain-enabled Electronic Medical Records (EMRs). The Fig. 1 shows the features of all 4 versions of the industry. The current era aims at enhancing virtualization and enabling personalized healthcare in real-time by building blockchains with a focus on convergence.

Healthcare data contains the private data of its patients, so it is obvious that it needs a high level of privacy and security. This requires a formation of standards and a trust among healthcare providers with the creation of agreed policies. Various security standards like Health Insurance Portability and Accountability Act (HIPAA), Digital Information Security in Healthcare Act (DISHA), and Control Objectives for Information and Related Technologies (COBIT) have been introduced to tackle this issue [8]. Healthcare security is of utmost importance to protect patient's private data. Access control management of the information, modification and removal of the previously stored data, and safety from unauthorized users, etc. are included in this [9]. With the increase in healthcare databases, the need for security mechanisms to safeguard the data has also been increased a lot.



1.0

- Lasted from 1970 to 1990
- Limited technology and not many Biomedical machines
- Limited scope of Healthcare Systems
- Dominated by paper-based prescriptions, non-experimental, fixed set of practices and treatments
- Increased costs and time

2.0

- Observed from 1991 to 2005
- Combined health with Information technology
- Online communities were created to share information and knowledge
- Digital tracking to provide imaging systems were introduced
- Critics expressed concerns over misleading information and violation of patient's privacy

3.0

- Observed from 2006 to 2015
- User-customisation of how patient records delivered was enabled
- Simpler UI allowed for more personalised and optimised experience
- Ubiquitous and real-time tracking of patient using newer technologies like wearable and implantable devices was introduced
- Communication between patient and healthcare provider was enhanced

4.0

- Observed from 2016 to the present day
- Aims at enhancing virtualisation and enabling personalised healthcare in real-time
- Focuses on building Blockchains to gain real-time access to patient's personal records
- Focus is on convergence, coherence, and collaboration, to make the Healthcare industry more personalized and predictable.

Fig. 1. Versions of healthcare industry

1.1 Blockchain Technology

In recent years, due to the increase in popularity of cryptocurrencies like Bitcoin [10] and Ethereum [11], research related to blockchain or the distributed ledger technology has gained worldwide popularity. Blockchain can be defined as a decentralized, distributed, and immutable ledger technology that provides data transparency and simultaneously, user privacy, removing middleman and not requiring a central dependency for checking transactions [12–14]. The concept of blockchain is based on the peer-to-peer system where the blocks (data) are connected to each other using chains (cryptographic techniques). There is an absence of central authority and the transactions or the immutable ledger is open to everyone connected to the network. All the valuable and invaluable information can be stored in the form of blocks where each block will have its own unique hash. These hashes are created on the basis of stored data inside them, therefore tampering is not possible since, with a change in data, the hash will also be changed [7].

1.2 Blockchain in Healthcare

The Healthcare sector, with this rapidly increasing data, is struggling with challenges like access to data, security, and access of the data outside the healthcare facility [8]. Blockchain can be one technology that can help in improving the verification and integrity of the data. Its decentalization, distributed, and immutable features can help healthcare industry transform.

The main contributions of this research are described as follows. Firstly, using distributed ledger technology, a Binance blockchain-based system to store EMRs in an immutable ledger form to provide better security, privacy, and decentralization is proposed. The proposed system works on patient-centric approach where the records can only be accessed by using the unique IDs given to the patients and at a registered medical facilities. The rest of the paper is organized as follows: Sect. 2 examines the previous works. Section 3 presents the proposed system architecture, followed by the proposed algorithms. Section 4 describes the results and analysis, and, finally, Sect. 5 provides conclusions and suggestions for future work.

2 Review of Existing Work

Quite a few schemes have worked on blockchain-based Electronic Medical Records systems and many have succeeded to some level. Vora et al. [15] presented a blockchain-based approach for efficient storage and transfer of EMRs. In their results, the authors found out a trade-off between complete encryption of patient's records and maintenance of ease of use and concluded that both cannot go hand-in-hand. Kaur et al. [16] proposed a solution and gave a future direction to store heterogeneous medical data in cloud environments on a blockchain-based system. The cloud environment is incorporated to mitigate the scalability issues which come with storing the data on the blockchain itself. Chen et al. [9] proposed a blockchain-based novel system for medical information sharing with a complete business process. In the proposed system, the information systems were combined with blockchain technology in which authorized users could jointly maintain the information in the network using a consensus mechanism. Li et al. [17] presented a novel data preservation system (DPS) that provides a reliable storage solution to ensure the stored data's primitiveness and verifiability while also users' privacy preservation. The proposed system could deal with situations of data loss and tampering.

Tripathi et al. [7] proposed a Secure and Smart Healthcare System (SSHS) framework, based on blockchain, to provide a healthcare system which is secure and private. The authors took the various IoT devices into consideration and proposed a framework to constantly monitor the patient's health and store the data in the blockchain.

Sun et al. [18] proposed a blockchain-based EMR system that enables doctors to add and encrypt patients' data with access policies and then upload the encrypted data to IPFS. For searching particular encrypted data records, keyword index searching is also employed. Tanwar et al. [8] proposed a distributed ledger system architecture and algorithms for a patient-centric approach to provide an access control policy to different healthcare providers. The authors were successful in eliminating the centralized authority and a single-point of failure in the system. Usman and Qamar [19] presented an EMR preservation system based on blockchain, providing efficient, reliable, and secure storage, to better the availability and accessibility of medical records. In the proposed system, patients can actively manage their records and control access to their data. Huang et al. [20] presented a blockchain-based scheme for privacy preservation. The scheme employs the secure sharing of healthcare or medical data between entities like patients, doctors, research institutions, and semi-trusted cloud servers. The main contribution to the research is the employment of Zero-Knowledge proof which helps in verification of whether the patient's medical records meets the requirements proposed by research institutions without revealing the patient's data or records to achieve data availability and consistency among both parties. Shamshad et al. [21] presented a novel blockchain-based protocol managing the privacy and security of patient's health records for improved diagnosis and efficient treatments in Telecare Medicine Information System (TMIS). Pandey and Litoriya [22] presented challenges faced during the implementation of healthcare services on a large scale (specifically India) and proposed AarogyaChain, based on blockchain technology. The authors employed Hyperledger fabric to form a model to store patient's EMRs and tested the throughput of the system analyzing the scalability of the system.

After extensive research, it was found out that blockchain is indeed a rising technology that can help in improving the healthcare sector to a significant level. Table 1 shows the comparison of the proposed model with existing models based on similar principle.

3 Proposed Methodology

In this section, a blockchain-based approach for EMR sharing is introduced. Consequently, the blockchain-based system architecture for EMR sharing is also proposed.

Table 1. Comparison of the proposed system with similar models

S. No.	Paper	Patient centric	Access control	IPFS used	Performance evaluation	Blockchain used
1	Sun et al. [18]	×	×	✓	✓	Ethereum
2	Vora et al. [15]	✓	✓	×	×	Ethereum
3	Tanwar et al. [8]	✓	✓	×	✓	Hyperledger fabric, Composer
4	Tripathi et al. [7]	✓	✓	×	×	Public and private blockchain
5	Usman et al. [19]	✓	✓	✓	×	Hyper ledger Fabric, Composer
6	Omar et al. [23]	✓	×	×	×	Not specified
7	Proposed system	✓	✓	✓	✓	Binance Smart Chain

3.1 System Architecture

In the proposed system, there are 3 main entities: (1) The deployer, (2) the doctor, and (3) the patient. Unlike the traditional system, where all the rights of adding, updating, and deleting the records were with the administrator of the system, here, the patient is the sole owner of his/her records. Whereas the deployer is responsible for deploying the smart contracts on the blockchain network, the doctors is responsible for adding new patients and records to the system. In the proposed system, underlying blockchain technology enables the EMR to be distributed with other entities. In the proposed system, various smart contracts are defined, which are: HospitalContract, and PatientContract.

The system workflow is easy to use and access. Doctors are registered in the network by the deployer using a password and the public address of the doctor. After registration, the doctor is then given the authority to create new patients and add/view records. Whenever a doctor creates a new patient, the initial data of the patient is added to the blockchain network returning back a unique ID (in a form of QR) which will be the permanent key of the patient.

Whenever creating a new record, the doctor can add multiple values which then are sent to the IPFS [24] which returns a unique hash which will, from here on, be used to access these stored records. The records will not be available to everyone on the network but can only be accessed using the patient's unique ID. The system architecture is shown in the Fig. 2.

3.2 Technology Stack

The public blockchain Ethereum-based framework, called Binance Smart Chain is used to develop the proposed electronic medical records system. Ethereum is an open-source, permissionless Distributed Ledger Technology (DLT). Ethereum provides transparency, security, and immutability to the system. Binance Smart Chain is a clone of original Ethereum blockchain, but provides better security,

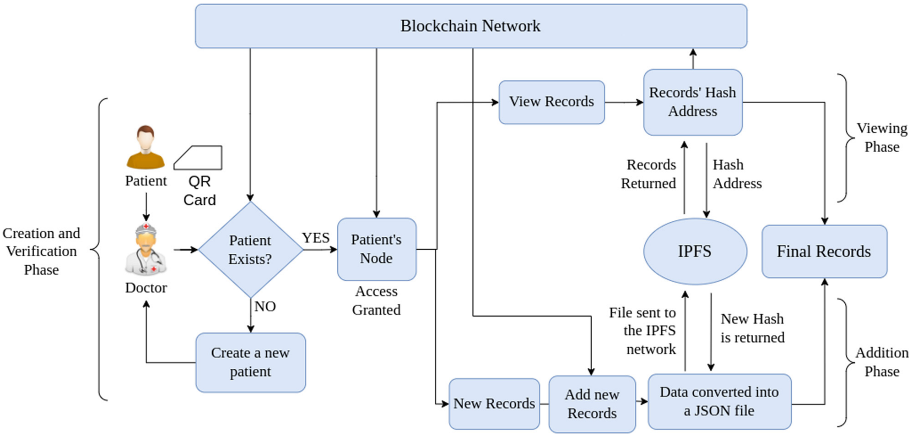


Fig. 2. Proposed system architecture

scalability, and lower transactional costs. The coin used in the BSC (Binance Smart Chain) is called BNB. The proposed system uses BSC as the main blockchain. To handle all the transactions and the functions in the proposed system, smart contracts are required. The proposed system uses Solidity programming language which is a high-level, an object-oriented language for implementing smart contracts and governs the behavior of accounts and nodes within the Binance state [25].

To perform any task on the Binance platform, the user has to call the function corresponding to the required action. If the function call results in a change of state on the blockchain network, then the function call is treated as a transaction. To mine a transaction into a blockchain network, some amount of BNB, in the form of gas, is required. Gas is a denomination of Ether or BNB, also known as wei (smallest denomination of BNB) and its value is 10^{-18} BNB. To handle all of these transactions effectively, a browser extension Metamask is used. Metamask is an Ethereum based wallet that helps in handling and signing transactions [26]. But since testing of the model requires a lot of transactions, using real BNBs doesn't sound feasible.

For the testing purposes, the proposed system uses Binance Testnet which provides us the capability to test our dApps without using real cryptocurrency. The proposed system uses Reactjs [27], a popular Javascript library to create front-end user interfaces, and web3.js [28], a collection of Ethereum Javascript API libraries that enables the front-end to connect to the smart contracts on the Binance blockchain. Since the proposed system is not tied to any particular storage system, IPFS is used to store patient's final records.

3.3 Proposed Algorithms

This section presents details of the algorithms proposed in the system. The precise execution and creation of the doctor is shown in Algorithm 1. The initial requirement for doctor creation is that the node registering the doctor needs to be the deployer. The main requirement for the doctor creation is the public node address. Every doctor needs to have a node address to get registered on the blockchain network. If every added information is up to the standards, the doctor will be registered as an authorized participant in the blockchain network.

$$authAddress[doctor'sNodeAddress] = true \tag{1}$$

The process to create a new patient in the blockchain network is shown in Algorithm 2. Here, the initial requirement is the authorization of the doctor's node. After granting access, the doctor now can input the basic details for the patient. Here, the algorithm uses the combination of the patient's name, blood group, age, current timestamp, and the current block difficulty to create a unique ID for the patient. The block difficulty is a metric that calculates the average time to create a block in the network. Here, these values are encoded and hashed using hashing algorithm, keccak256, to create a unique hash ID for the patient.

$$patient'sID = Keccak256(block.timestamp, block.difficulty, name, dob, bGroup) \tag{2}$$

Algorithm 1. Pseudocode to add a new doctor

```
BEGIN
if user == contract deployer then
    if doctor's ID does not exist then
        if password == entered password then
            enter doctor's initial infomation
            enter node address of the doctor
        end if password is incorrect
    else doctor already exists
    end if
else user needs to be the deployer
end if
New doctor created
END
```

From here on, the previous records of the patient can easily be accessed using the patient unique ID. The process to add new records to the blockchain network are depicted in Algorithm 3. For input, the patient provides his/her QR Code to the doctor which lets the doctor gain access to the patient's previous records. An authorized doctor can add a request to add new records to the patient's node. After adding, the data is converted into a JavaScript Object Notation (JSON) file and is sent to the InterPlanetary File System (IPFS). IPFS stores the data and returns the hash address to the system. This hash is then stored in the patient's node as a new record address.

Algorithm 2. Pseudocode to add a new patient

```
BEGIN
if doctor == authorized node then
    Enter patient's details
    Generate patient's unique ID using keccak 256
    Data stored in Struct
    map the patient's unique ID to his struct address
else patient cannot be created
end if
New patient is created
END
```

Algorithm 3. Pseudocode to add records

```
BEGIN
Enter patient's ID access patient's node
if the patient exists then
    Request to create new record created
    Add data to the patient's node
    Convert the entered data into a JSON format file
    Send the file to the IPFS and fetch the hash address returned
    Store the hash in the blockchain and show final records
else the patient doesn't exist
end if
New records added
END
```

4 Results and Discussion

In this section, the proposed system is evaluated and results are compared with the transaction costs of various functions involved in the system.

4.1 Simulation Settings

For the test runs, a dataset of 15 diseases is used. Every disease is given a serial number, a name, a summary, and cures prescribed by the doctor. Once the smart contracts are compiled, all the functions and variables are converted into low-level assembly opcodes which can be read by Ethereum Virtual Machine (EVM). These opcodes are then imported into the React framework using the web3 module allowing it to connect to the front-end of the application. Every transaction is recorded in Metamask and mined in the blockchain provided by Binance testnet.

4.2 Experiment

To get a better idea of the transaction costs or gas prices involved in the execution of the functions, gas requirements are obtained and then their costs are estimated. The experiment is performed on BNB testnet where the gas price to perform the transactions was 10 Gwei or 10^{10} wei. It must be noted that 1 Billion Gwei is equal to 1 BNB and the price of 1 BNB at the time of this experiment (November 2021) was around $634.

Table 2 represents functions, the gas costs, and the average transaction costs involved (in USD). Deploying the contract is a one-time process. In the test runs, the cost for deploying the contract came out to be an average of 0.017 BNB or $ 10.77. Adding the doctor is also a one-time process. For this, the deployer needs the public address of the doctor. In the test runs, the average cost for creating a doctor came out to be 0.000908 BNB or $0.57. Adding a patient is also a one-time task. In the test runs, the cost for adding a new patient to the network came out to be 0.009476 BNB or $6.003. Adding a new record to IPFS returns a unique hash that costs 0.0016 BNB or $1.01 to be saved on the blockchain. This means that a patient can get new records entered into his node with a minimal amount of 0.0016 BNB or $1.01, neglecting all the one-time functions.

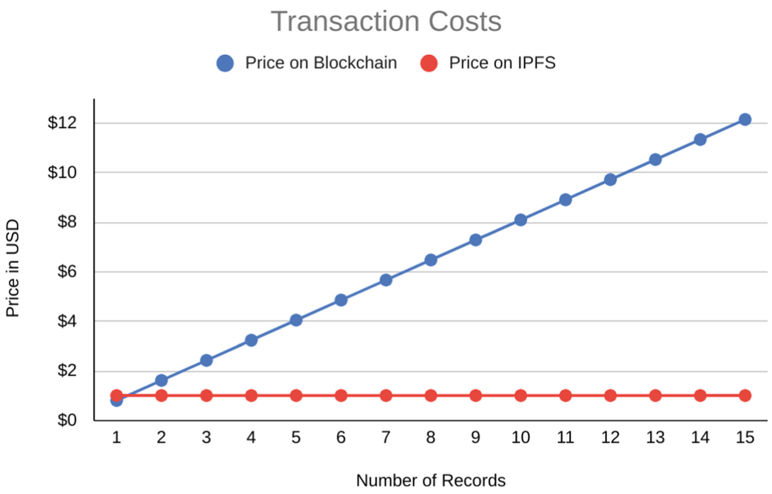


Fig. 3. Transaction costs comparison between blockchain and IPFS

Based on these gas costs, the proposed system is compared with the traditional systems where the data was stored on the blockchain itself. Table 3 shows the comparison of transactional costs between both of the scenarios. As there can be multiple tuples in a single record, the transaction cost in the Fig. 3 is increased proportionally to the number of tuples. But after using the IPFS, the transaction cost came out to be really low. In our results, we found out that for a record with 15 tuples, the transaction cost will remain the same as for the record with 1 tuple.

Table 2. Gas costs and transactions costs for the functions in the proposed system

S. No.	Function	Gas cost	Cost estimate (in BNB)	Cost estimate (in USD)	Number of times to be repeated
1.	Deploying the contract	1736649	0.017	10.77	One time
2	Add a new doctor	90823	0.000908	0.57	One time
3	Add a new patient	947639	0.009476	6.003	One time
4	Store the record hash from IPFS	144816	0.0016	1.01	Once for each record

Table 3. Gas costs and transactions costs for record storage comparison

Patient records	Gas cost	Cost estimate (in BNB)	Cost estimate (in USD)	Number of times to be repeated
On blockchain	129122	0.001291	0.81	Once for each tuple
On IPFS	144816	0.0016	1.01	Once per record

4.3 Discussion and Analysis

Blockchain has revolutionized the creation, storage, and management of data. Its decentralized, distributed, and immutable nature of storage provides a significant upgrade to the traditional centralized system of storage and can help in situations of catastrophic and disaster. This is a huge advantage, considering the fact that data can easily be lost in Medical institutions. In the proposed system, use of multiple contracts ensures improved privacy and security. Because of this, no unauthorized entity will be able to access records of the patient without going through initial contracts.

As discussed in Sect. 4.3, IPFS provides a significantly low cost for the storage of patient's records compared to the scenario where records are stored on the blockchain itself. Storing a hash address is cheaper than storing the whole record of the patient. IPFS also provides added security and avoids the reduced bandwidth problem in the blockchain network, as the major amount of data will be stored off-chain. Thus, IPFS provides a major advantage over the blockchain network.

5 Conclusion

Blockchain technology, combined with other modern technologies, plays an important role in medicine and can transform the current healthcare industry. In this paper, current challenges and issues faced by the healthcare industry are discussed. The proposed system defined algorithms and architecture for an EMR system that achieved privacy, security, and immutability of patient's data. The proposed system is implemented and evaluated using blockchain technology.

The involvement of blockchain eliminates the central authorisation or middleman from the system and is saves the network from single point of failure. The use of IPFS saves the bandwidth of the system and makes the transactions fast and cheap. For future works, researchers can include smart contracts to add more functionalities like billing, transportation, reports, etc. to create a full-fledged healthcare management system. The researchers should also focus on different blockchain technologies, like Ethereum 2.0 which is estimated to use very low transactional costs with faster mining on the network. Beyond this, researchers can also extend the proposed work by implementing it in a real-time environment by adding real participants to the system.

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