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Health Block: A Blockchain Based Secure Healthcare Data Storage and Retrieval System for Cloud Computing

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Abstract— Data in healthcare domain is highly sensitive in nature. Besides, there is need for maintaining integrity of such data. Blockchain technology has emerged to solve the problem of data integrity and non-repudiation with immutable storage in distributed repository. Thus secure data storage and retrieval in cloud environments is made possible using blockchain implementation. There are many existing healthcare systems with blockchain integration found in the literature. However, there is need for a system that supports complete set of operations that are governed by smart contracts. Another important consideration is that end users should be able to operate healthcare system without the need for knowledge of blockchain technology. Towards this end, in this paper, we proposed a Blockchain based secure healthcare data storage and retrieval system known as HealthBlock for cloud computing environments. We defined smart contract with underlying structures and functions using Solidity language for Ethereum blockchain platform. We also proposed and implemented an algorithm known as Healthcare Transactions over Blockchain (HToB). This algorithm supports secure blockchain based data storage and retrieval governed by smart contracts. Our system is evaluated using user-friendly web based client application. The experimental results showed that our system is able to ensure data integrity and non-repudiation besides reaping all benefits of blockchain technology..

Keywords- Blockchain, Security, Healthcare, Cloud Computing, Secure Data Storage and Retrieval.

I. INTRODUCTION

Data in healthcare domain is highly sensitive in nature. Besides, there is need for maintaining integrity of such data. Blockchain technology has emerged to solve the problem of data integrity and non-repudiation with immutable storage in distributed repository. Thus secure data storage and retrieval in cloud environments is made possible using blockchain implementation. There are many existing healthcare systems with blockchain integration found in the literature. Blockchain technology is based on distributed network and it can be linked to cloud and distributed systems. Ngabo et al. [3] investigated on the possible integration of technologies such as IoT, fog computing and blockchain for seamless secure data storage of healthcare data in cloud. Blockchain can also be used in Mobile Cloud Computing (MCC) environments. Hguyen et al. [4] studied the possibilities of MCC linked to healthcare for integration with blockchain technology towards secure healthcare data sharing. There are many scenarios in which blockchain is integrated with healthcare applications for privacy and security of data besides efficient data sharing as discussed in [9] and [10]. From the literature, it is observed that there are many contributions in healthcare-blockchain integration. However, most of the works are conceptual and theoretical in nature. In this paper, we followed an empirical approach with healthcare application and smart contracts for secure storage and retrieval of electronic health records. Our contributions in this paper are as follows.

1. We proposed a Blockchain based secure healthcare data storage and retrieval system known as HealthBlock for cloud computing environments.
2. We defined smart contract with underlying structures and functions using Solidity language for Ethereum blockchain platform.
3. We also proposed and implemented an algorithm known as Healthcare Transactions over Blockchain (HToB).
4. We developed an application to realize HealthBlock framework and the underlying algorithm besides evaluating the system.

The remainder of the paper is structured as follows. Section 2 threw light on many existing systems that contributed to healthcare application using blockchain. Section 3 provides

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preliminary details needed to understand our proposed system. Section 4 presents the proposed system. Section 5 focuses on results of the proposed system. Section 6 concludes our work and bestows directions for future work.

II. RELATED WORK

This section reviews literature on the usage of blockchain for healthcare solutions. Esposito et al. [1] opined that blockchain technology is a panacea for securing healthcare data in cloud. It was important due to sensitive nature of healthcare data. Theodouli et al. [2] investigated on sharing of healthcare data in distributed environments. Then, their research could find the significance of blockchain for secure and efficient sharing of healthcare information. Ngabo et al. [3] investigated on the possible integration of technologies such as IoT, fog computing and blockchain for seamless secure data storage of healthcare data in cloud. Hguyen et al. [4] studied the possibilities of Mobile Cloud Computing (MCC) linked to healthcare for integration with blockchain technology towards secure healthcare data sharing. Sun et al. [5] proposed a methodology for storage and accessing of electronic medical records in a secure way in cloud with blockchain based solution. Omar et al. [6] viewed blockchain based solution for healthcare as privacy and security-friendly as it supports common security features in addition to immutable storage. Shen et al. [7] proposed a medical IoT system where blockchain based approach is followed to deal with medical images. In other words, the medical images are stored and retrieved with security and privacy.

Kollu et al. [8] investigated in blockchain and cloud technologies and their relevance to solve the problems in healthcare domain. Particularly, they focused on blockchain techniques to ensure secure data storage and retrieval. Omar et al. [9] proposed a tool named MediBchain which is meant for managing healthcare data with privacy preserved. Bhaskara et al. [10] also proposed a tool named fortified-chain which is a framework for dealing with medical data in a secure and privacy preserving fashion. Nagasubramanian et al. [11] proposed a methodology for usage of blockchain technology in e-Health application by exploiting keyless signature infrastructure. Benil and Jasper [12] thought of outsourcing security of e-health system with the help of blockchain. Arul et al. [13] considered IoMT environment where data dissemination is given important leading to multi-modal secure sharing of healthcare data. Xia et al. [14] proposed a system named BBDS which is meant for secure data storage in cloud with the help of blockchain. Shen et al [15] proposed MedChain where data storage and sharing are carried out using blockchain technology. Other significant contributions include smart contracts for healthcare [16], data gateways for healthcare intelligence [17], smart contract system for managing healthcare data [18], blockchain based data accessibility [19] and robust-healthcare using blockchain [20]. From the literature, it is observed that there are many contributions in healthcare-blockchain integration. However, most of the works are conceptual and theoretical in nature. In this paper, we followed an empirical approach with healthcare application and smart contracts for secure storage and retrieval of electronic health records

III. PRELIMINARIES

Blockchain is technology that is with immutable and shared ledger which supports immutable storage of business transactions keeping track of assets. Here asset may be of any valuable thing. As businesses run on information, it is indispensable to have security to information and transactions. Blockchain technology is found ideal for such requirement. It is the distributed ledger technology where participates can access the ledger and its record of transactions that are immutable in nature. Each transaction is stored only once. It does not support duplications in data. Once data is stored in blockchain, it is immutable and participants cannot change. If any record has error, there must be new transaction added in order to rectify the error and both error and correct transactions are visible. In order to speed up transactions, there is need for having set of rules known as smart contract. Smart contract is stored in blockchain repository and automatically executed as and when requested. Each transaction is stored in blockchain as a block. Each block is connected to its previous block and next block causing a chain of blocks. The blocks hold timestamp and transaction sequence. The blocks cannot be altered once created. Each block added to the chain improves the strength of blockchain. Thus blockchain improves trust, improves data security and enhances efficiency.

Sl. No.	Protocol	Advantages	Limitations
1	PoW	Highly scalable and support different kinds of blockchain applications	Probability of "51% attack"
2	PoS	Lightweight	Victim's transactions may be used by adversaries and PoS shows bias towards wealthy.
3	DPoS	Transparent	Partially centralized and vulnerable to attacks
4	TaPoS	Prevents transaction replay attacks	Not widely adopted still.
5	dBFT	Faster execution and transaction cannot be rolled back.	Partially decentralized and no anonymity.
6	Casper	Better security, minimizes risk of double spending attack, gets rid of	Vulnerable to "51% attack".

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		"nothing-to-stake" problem.	
7	PoI	Reduction in hoarding of coins and energy efficient.	Limited mining percentage
8	PoET	Improved transparency and provides equal chance of winning to everyone.	It needs specialized hardware and relays on trust of the hardware.
9	PoBr	Fair distribution of coins, support for long-term projects and reduction in coin circulation.	Not always transparent and frequent delay in miner's verification.

Table 1: Different consensus protocols, their pros and cons

Blockchain has a mechanism known as consensus. It is a fault-tolerant mechanism where consensus is achieved among distributed nodes so as to ensure data integrity. Table 1 shows different consensus protocols being used in blockchain technology.

IV. PROPOSED SYSTEM

We proposed and implemented a blockchain based secure healthcare data storage and retrieval system known as HealthBlock. Its architectural overview is presented in Figure 1. It is designed to exploit Blockchain technology, its underlying protocols and security mechanisms

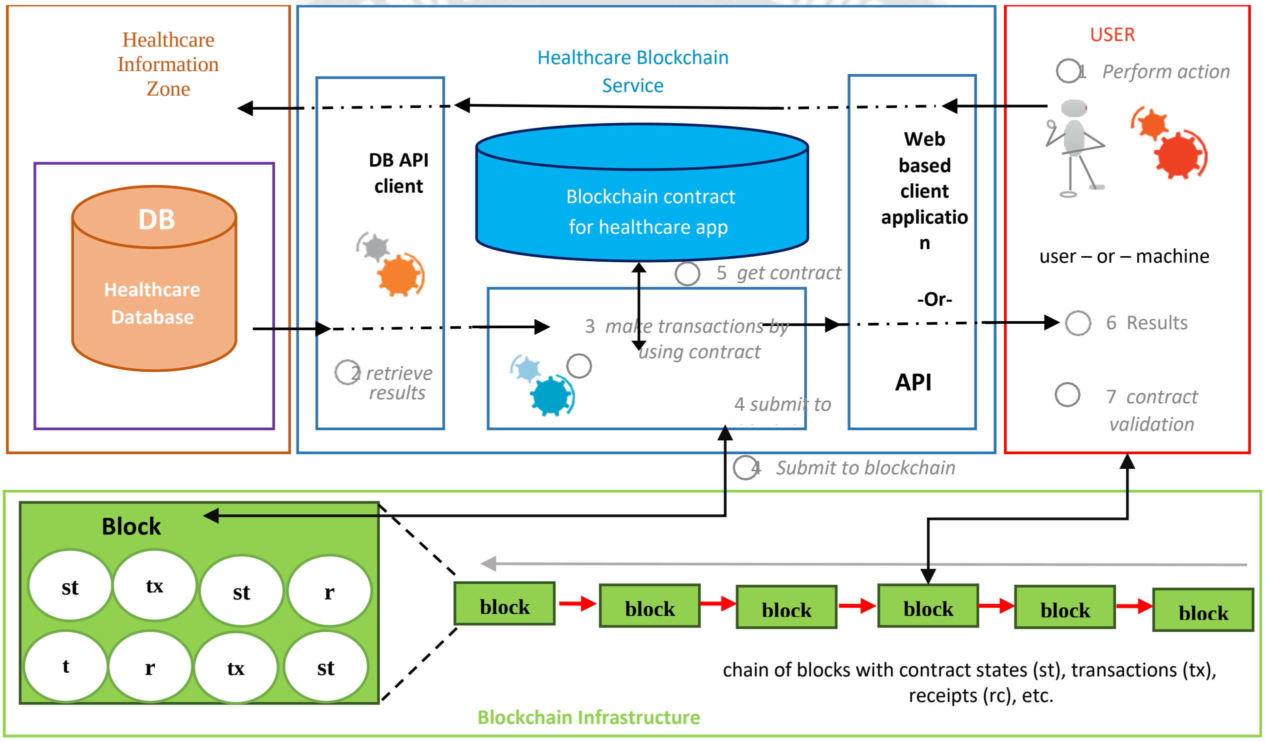

Figure 1: Proposed blockchain based secure healthcare data storage and retrieval system

In other words, our proposed system is meant for ensuring security features such as non-repudiation and data integrity in healthcare eco-system. Since healthcare data is very sensitive in nature, it is indispensable to have such security mechanisms. The proposed system is governed by smart contract defined using Solidity language. It has conventional database and a wrapper service to exploit blockchain technology for making transactions immutable. The service renders irrevocable proof of transactions thus leading to data integrity and non-repudiation. The data owner is assured to have highest level of security with blockchain implementation.

The HealthBlock is governed by a smart contract presented in Listing1 and Listing 2. The proposed service mediates between data user and conventional database. The database system used is MySQL with a database containing several relations. The HealthBlock has three different layers. The first layer is known as client application layer which is used by end users to utilize the proposed system. In other words, this layer provides web based user interface. The second layer has functional interface to have database access. The third layer is blockchain layer where the transaction details are saved with timestamp and they become immutable by default. The transactions are carried out as per the smart contract defined for the healthcare application.

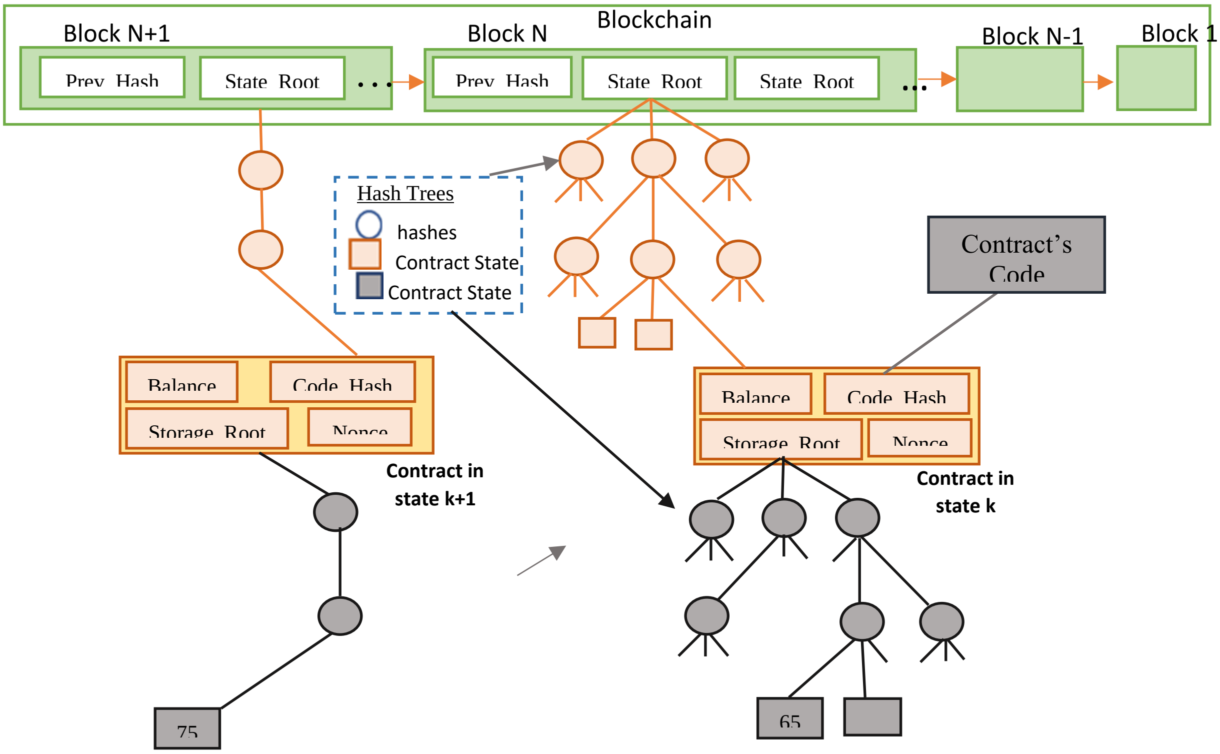

Figure 2: Blockchain implementation with smart contract

As presented in Figure 2, blockchain has chain of blocks that hold data of proposed HealthBlock transactions. The data is each block is coded into Merkle has trees for security reasons. The tree has root hash, leaf nodes that hold data and non-leaf nodes that hold has of child nodes. In other words, the data of each transaction is stored, as per the smart contract, in leaf node. When there is change in the HealthBlock contract in future, the tree holds the change and points to the previous tree for other details. In the blockchain infrastructure each transaction is charged a fee based on the computational burden at runtime. This fuel is termed as "gas". There is some expenditure of gas for every transaction. The currency expended in case of Ethereum (the blockchain platform used in this paper) is known as ETH.

Algorithm: Healthcare Transactions over Blockchain (HToB)

1. Begin
2. User logs into deployed ***HealthBlock*** system into Ethereum

Data Storage

3. User perform storage action (add hospital/add record/add report/add patient/add doctor)
4. User enters required data
5. User submits data
6. Data is stored in MySQL database
7. Sender account is verified by blockchain
8. IF account is valid Then
9. Blockchain verifies smart contract
10. IF smart contract and user operation are compatible Then
11. New block is created
12. Submitted data is stored in new block with timestamp
13. Block hash is generated
14. Transaction hash is generated
15. Gas limit is updated
16. End If
17. End If

Data Retrieval

18. User perform retrieval action (list of hospitals, patient records, reports)
19. User selects operation on dashboard
20. Data is retrieved from MySQL database
21. Sender account is verified by blockchain
22. IF account is valid Then
23. Blockchain verifies smart contract
24. IF smart contract and user operation are compatible Then
25. New block is created
26. Retrieved data is stored in new block with timestamp
27. Block hash is generated
28. Transaction hash is generated
29. Gas limit is updated
30. End If
31. End If
32. End

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Algorithm 1: Healthcare Transactions over Blockchain (HToB)

As presented in Algorithm 1, it supports both data storage and data retrieval over blockchain distributed repository. In case of data storage, the user operation is supported by client application to capture data from user. Then the data is stored in relational database. Afterwards, the transaction is recorded in blockchain for ensuring integrity and no-repudiation. In the process, user account is validated and the smart contract of the healthcare application is verified. If the user is valid and the smart contract is compatible with the operation, then a new block is created to hold the transacted data. Afterwards, hash is generated for transaction and also block. Gas limit is updated. In case of data retrieval, user operation is executed in MySQL database and the same is recorded in the blockchain after due verification of account and smart contract. The data retrieval is updated in blockchain besides generating hash for block and transaction. Then gas limit gets updated. These transactions are not allowed unless, they satisfy smart contract.

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

V. IMPLEMENTATION DETAILS

We implemented the proposed system known as HealthBlock with Ethereum blockchain repository and web based client application developed using Python language. The system is governed by smart contract provided in Listing 1 and Listing 2.

Contact: Code of the contract with important structures

```
pragma solidity ^0.5.11;
pragma experimental ABIEncoderV2;
contract HospitalRecord{
    struct HospInfo{
        string name;
        string cnpj;
        address hospAdd;
    }
    struct Record{
        HospInfo responsibleHospital; // hospital that made/updated the record
        string treatments; // previus patient treatments
        string medicationHistory;
        string allergies;
        uint256 date; // register date;
    }
    // doctor report for a hospital visit
    struct Report{
        HospInfo responsibleHospital; // name, CNPJ and address
        string doctorName; // name of the doctor
        string description; // doctor observations
        string exams; // requested exams
        string medicines; // medicines
        uint height; // patient height
        uint weight; // patient weight
        uint bodyTemperature;
        string bloodPressuare;
        uint256 date; // register date
    }
}
```

Listing 1: Solidity code of the contract with important structures

As presented in Listing 1, the Solidity code that contains different structures which are essential for blockchain implementation for healthcare application.

Contract: Code of the contract with important functions

```
contract HospitalRecord{
    // Register a new hospital to the network
    function registerHospital(string memory name, string memory cnpj, address hospAdd) public isOwner(msg.sender) notRegistered(hospAdd){
        registeredHosp[hospAdd].name = name;
        registeredHosp[hospAdd].cnpj = cnpj;
        registeredHosp[hospAdd].hospAdd = hospAdd;
        hospitals.push(hospAdd);
    }
    // Get hospital infos based on their PK
    function returnHospital(address hospAdd) private view isRegistered(hospAdd)
    returns (HospInfo memory h){
        h = registeredHosp[hospAdd];
    }
    // Get hospital infos based on their PK
    function getHospital(address hospAdd) public view isRegistered(hospAdd)
    returns (string memory _name, string memory _cnpj){
        _name = registeredHosp[hospAdd].name;
        _cnpj = registeredHosp[hospAdd].cnpj;
    }
    // Remove a hospital from the network
    function removeHospital(address hospAdd) public isOwner(msg.sender){
        // find the hospital to be deleted and do it
        // move the last element to the deleted position so it does not leave a gap
        for (uint i = 0; i < hospitals.length; i++){
            if (hospitals[i] == hospAdd){
                hospitals[i] = hospitals[hospitals.length-1];
                delete hospitals[hospitals.length-1];
                hospitals.length--;
                break;
            }
        }
        delete registeredHosp[hospAdd];
        emit removed(hospAdd);
    }
```

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```
    // Lists all the participant hospitals
    function listHospitals() public view returns(address[] memory){
        return hospitals;
    }
    // Creates a new record for a patient
    function setRecord(string memory patientID, string memory treatments, string memory medicationHistory, string memory allergies, uint256 date)
    public isRegistered(msg.sender){
        HospInfo memory h = returnHospital(msg.sender);
        patientRecord[patientID] = Record(h,treatments,medicationHistory,allergies,date);
    }
    // Get the record infos
    function getRecord(string memory patientID) public view returns(Record memory){
        return patientRecord[patientID];
    }
}
```

Listing 2: Solidity code of the contract with important functions

As presented in Listing 1, the Solidity code that contains different functions which are essential for blockchain implementation for healthcare application..

VI. EXPERIMENTAL RESULTS

We evaluated the proposed blockchain based execution system known as HealthBlock. It is implemented and testing using the different software requirements as listed in Table 1

SL. NO.	Software	Description
1	Ethereum	Open source blockchain technology
2	Web3	Supports Web 3.0 technologies for decentralization and blockchain.
3	My SQL	Relational database management system
4	Python	Programming language
5	Truffle	Set of tools for smart contract development
6	Ganache	Development tool for local blockchain. It is part of Truffle suite.
7	VS Code	Visual Studio Code is an Integrated Development Environment for which Truffle extension enables blockchain development and usage.

Table 1: Shows different software used in this paper for developing blockchain healthcare application

As presented in Table 1, the software used in the implementation of the proposed system and the description are provided.

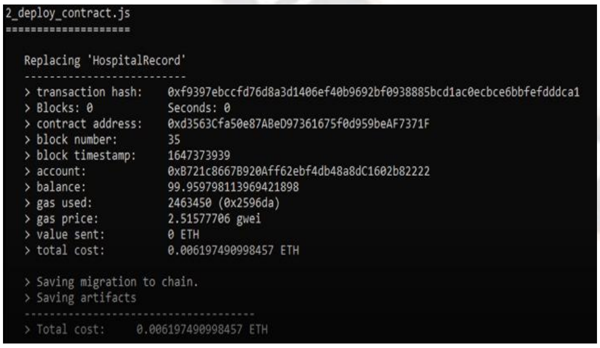

Figure 3: Execution result of deployment script for “Hospital Record” project

The healthcare application is deployed into Ethereum platform using Triffle which is configured as an extension to Visual Studio Code IDE. “HospitalRecord” is the deployment name of the application. On deployment, the number of blocks is zero and gas price is 2.51 gwei and the gas required for deployment is 2463450. The total cost of deployment is 0.006197490998457 ETH. The initial current associated with the deployed system is 100 ETH. With every transaction, this money gets expended based on the computational burden on the blockchian system.

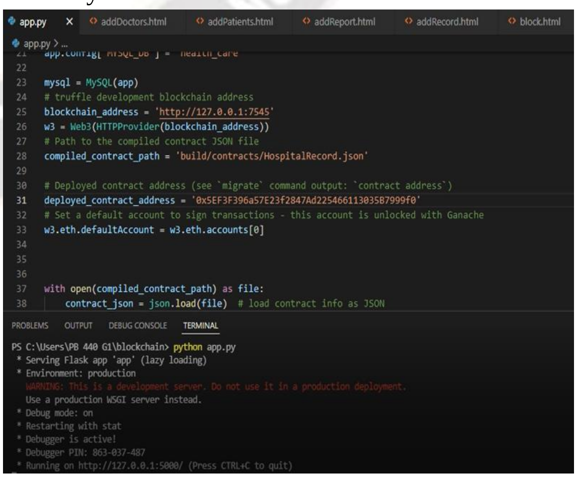

Figure 4: Running front end web application through Visual Studio Code IDE

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As presented in Figure 4, the web based client application is opened in browser using python app.py command in VS code IDE. The web application is run with the URL http://127.0.0.1:5000/. The web application provides user dashboard that makes it easier for user to perform various operations associated with the healthcare application. The end user's experience does not depend on the knowledge of blockchain. The Truffle tool helps in connecting to Ethereum blockchain with address http://127.0.0.1:7545/.

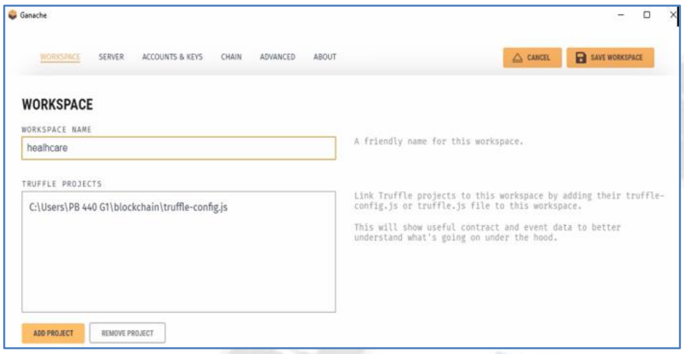

Figure 5: Configuration of healthcare blockchain project to Ganache Workspace

As presented in Figure 5, Ganache tool is used to configure blockchain healthcare application. This will enable the user to view blocks in blockchain besides the transaction dynamics, temporal details and transactions cost dynamics. The HealthBlock system developed in this paper is configured in truffle-config.cs. The path of this configuration file is given while new workspace configuration in Ganache. The workspace name is given as "healthcare".

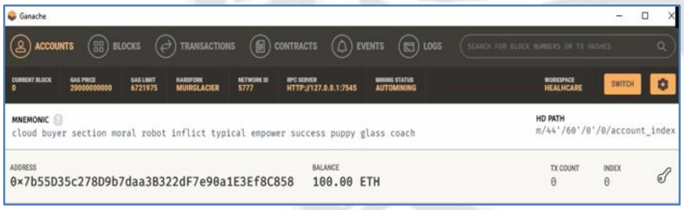

Figure 6: Initial ETH balance for deployed Healthcare blockchain application

After successful deployment of the healthcare application, it can be viewed in Ganache interface. It shows the name of the workspace, gas price, gas limit, accounts, blocks, contracts, transactions besides the balance of the money associated with the deployment. The current balance amount is 100 ETCH which is expended for any transaction made based on the computational burden on the system.

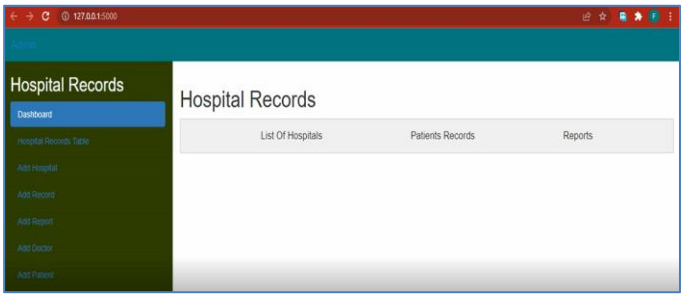

Figure 7: User dashboard of the client application

The healthcare application when launched using python app.py command in VS code IDE results in the user dashboard shown in Figure 7. It has provision to view hospital records in terms of list of hospitals, patient records and reports. Besides the UI enables the user to perform transactions such as adding new hospital to the HealthBlock system, adding records, adding reports, adding patients and adding doctors.

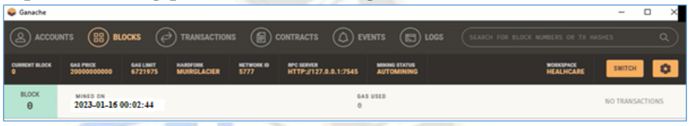

Figure 8: Showing Block 0 prior to making blockchain transactions

As presented in Figure 8, the Ganache interface is provided with BLOCK tab selected. It reflects that there are no transactions done yet for the deployed HEALTHCARE application. Therefore, the gas used in 0 and the it is Block 0 before adding any transactions to the blockchain application. The block is mined on 2023-01-16 00:02:44. Once new transactions are performed by end user a new block is created for each transaction. Then it is possible to view updated blocks using Ganache interface.

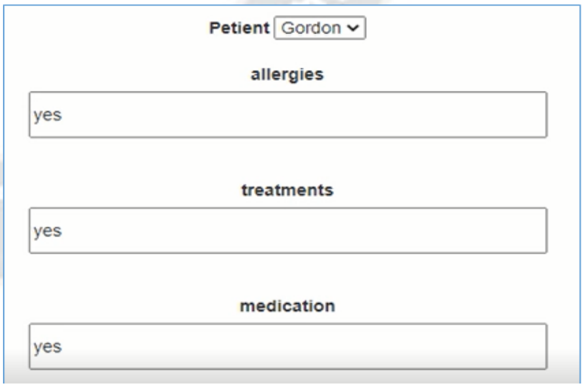

Figure 9: Adding patient record

As presented in Figure 9, patient record is added as a new transaction. It enables user to provide different inputs and add the record. Once the record is added, the proposed algorithm known as HToB is executed in order to have a secure approach to save the record to database and add a new block to the blockchain application deployed in Ethereum.

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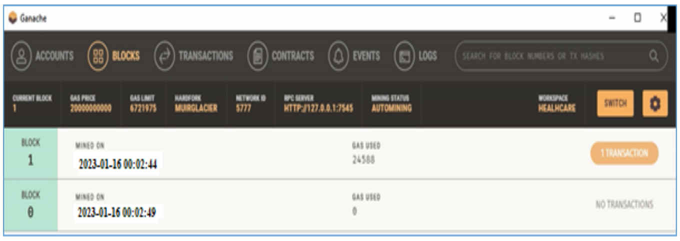

Figure 10: Ganache reflecting new block in the block chain after successful transaction

As presented in Figure 10, when new transaction is added for the first time after deployment of the healthcare application, it is observed in Ganache that a new block known as BLOCK 1 is created. And it shows the number of transactions as 1. Block 0 is initial block without any transaction. After adding new transactions BLOCK 1 is created. When one more transaction is added, then a new block named BLOCK 2 gets created.

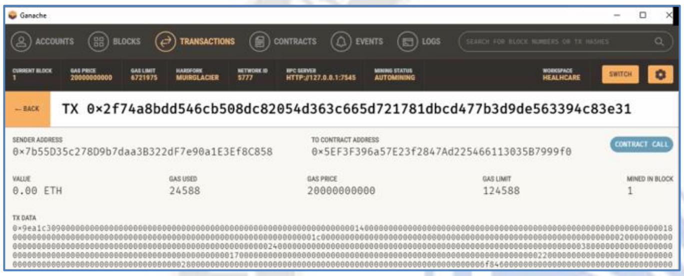

Figure 11: Detail of block 1

As presented in Figure 11, the current block is 1 and its transaction has is provided. It also provides all details of the transaction. It shows the gas used for this transaction, the transaction data, gas price and gas limit. It also shows the sender address.

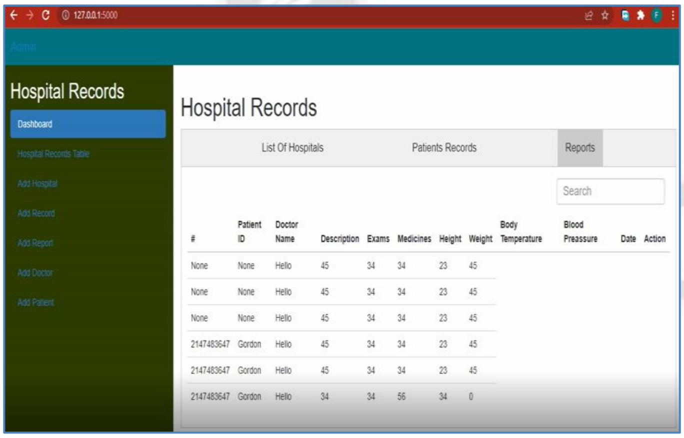

Figure 12: Shows hospital records obtained from repository

As presented in Figure 12, the hospital records tab is showing the records. It shows different patient records retrieved from database.

Number of Requests	Accumulated Cost	
	Existing	*HealthBlock* (proposed)
2000	1980	1650
4000	4250	2230
6000	6980	3956
8000	8450	4367
10000	11980	5760

Table 2: Shows performance of the proposed system in terms of accumulated cost

As presented in Table 2, the accumulated cost of the proposed blockchian healthcare application HealthBlock is compared against existing system that is blockchain based but not governed by smart contract.

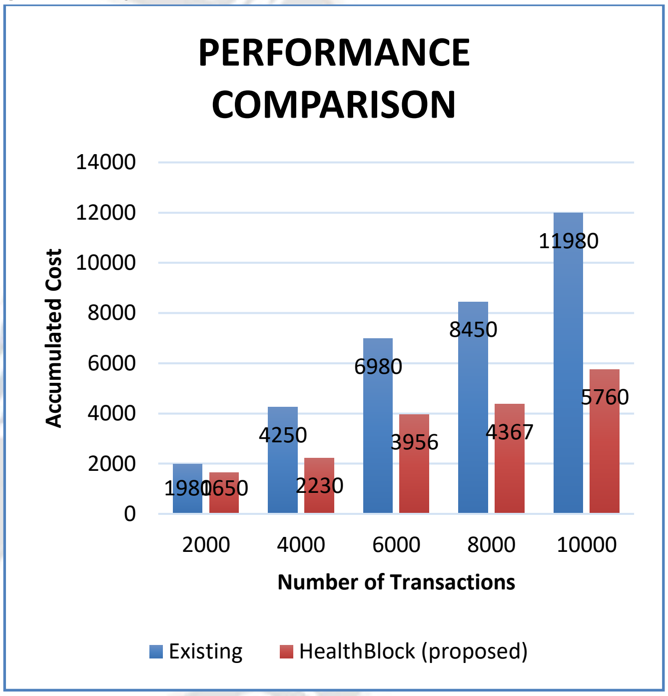

Figure 13: Performance comparison in terms of accumulated cost

As presented in Figure 13, the performance of the proposed blockchain based healthcare system known as HealthBlock is compared against existing blockchain based healthcare system that is not governed by smart contract. The performance is evaluated in terms of accumulated cost against number of transactions observed. Less in accumulated cost indicates better performance. Since the proposed system has strong support for smart contract, its operations are faster relatively and cause less computational burden on the system. It is the reason behind the performance improvement of the proposed system. When number of transactions is 2000, the existing system costs 1980 while the HealthBlock required 1650 only. In the same fashion, when number of transactions is 10000, the accumulated cost of proposed system is 5760 which is much lesser than that of existing system that costed 11980. Thus the proposed system outperforms existing one.

VII. CONCLUSION AND FUTURE WORK

In this paper, we proposed a Blockchain based secure healthcare data storage and retrieval system known as HealthBlock for cloud computing environments. We defined smart contract with underlying structures and functions using Solidity language for Ethereum blockchain platform. We also proposed and implemented an algorithm known as Healthcare Transactions over Blockchain (HToB). This algorithm supports secure blockchain based data storage and retrieval governed by smart contracts. Our system is evaluated using user-friendly web based client application. The experimental results showed that our system is able to ensure data integrity and non-repudiation besides reaping all benefits of blockchain technology. Our implementation of the system has provision for various healthcare operations that enable end users to operate with ease without having any knowledge on blockchain technology. In future we improve our system with encoding and decoding schemes towards improving security further in data storage and retrieval.

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