Journal of Theoretical and Applied Information Technology
15th March 2024. Vol.102. No 5

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

BTSF: A BLOCKCHAIN TECHNOLOGY ENABLED SECURITY FRAMEWORK FOR STORAGE AND RETRIEVAL OF HEALTHCARE DATA BY INCORPORATING SMART CONTRACTS

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ABSTRACT

Blockchain technology enabled different real world applications to have secure storage and retrieval complying with desired security attributes. Of late, researchers focused on using blockchain for healthcare domain. Since health data is sensitive in nature and it needs technology-driven approach for data security and integrity. Many existing methods found in literature revealed their utility with blockchain integration. However, there is need for a comprehensive system with support for all operations controlled by smart contracts. Besides, the application should be user-friendly for user who does not know underlying technicalities. In this work, we suggested a framework named Blockchain Technology-enabled Security Framework (BTSF). Solidity language is used to define smart contracts. Two algorithms are proposed to realize the functionality of BTSF. They are known as Blockchain-enabled Security for Health Data Storage (BS-HDS) and Blockchain-enabled Security for Health Data Retrieval (BS-HDS). These two algorithms ensure secure healthcare data storage and retrieval. A prototype application is developed to evaluate our framework and underlying algorithms. Empirical study showed that BTSF is highly secure rendering non-repudiation and data integrity.

Keywords – *Security, Blockchain Technology, Smart Contracts, Healthcare Data Security, Secure Data Storage, Secure Data Retrieval*

1. INTRODUCTION

Blockchain technology, right from its inception, has been growing in serving diversified application domains beyond the cryptocurrency bitcoin. The technology enables a distributed ledger as repository of transactions in distributed peer-to-peer network [1]. At the same time, healthcare industry is growing rapidly and serving people across the globe. This industry needs secure data management which is one of the growing concerns in contemporary era. Traditional approaches to manage data in healthcare domain suffer from different problems for instance, single point of failure, privacy, and security due to centralized storage and underlying vulnerabilities. With blockchain technology in place, there is possible solution to the problem aforementioned. Blockchain is being used in different application domains due to its specific requirements like privacy, security, traceability, fault-tolerance and scalability. Literature has revealed many applications in healthcare that exploited blockchain.

Esposito *et al*. [2] investigated on cloud and blockchain ecosystem suitable for healthcare domain. Their findings revealed the significance of blockchain usage to safeguard healthcare data. Rehman *et al*. [9] discussed about healthcare 5.0 model for security. Rajawat *et al*. [10] discussed a methodology for IoT connected devices to be secured using blockchain. Improving content sharing experience in healthcare domain with the help of blockchain, according to Jabbar *et al*. [17], is possible besides achieving data integrity and interoperability. Architecture for healthcare data security using blockchain technology is explored in [18] while the difficulties in data exchanges between healthcare system and blockchain are discussed in [19].Many existing methods found in literature revealed their utility with blockchain integration. However, there is need for a

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

comprehensive system with support for all operations controlled by smart contracts. Besides, the application should be user-friendly for user who does not know underlying technicalities. The following are our contributions to this publication.

1. Presented a structure called Blockchain Technology-enabled Security Framework (BTSF) for protecting transactions using blockchain.
2. Two algorithms were proposed one for secure data storage and one for retrieval respectively. They are known as Blockchain-enabled Security for Health Data Storage (BS-HDS) and Blockchain-enabled Security for Health Data Retrieval (BS-HDS).
3. A prototype application is developed to evaluate our structure and underlying mathematical formulas.

Following is the framework for the remaining portion of the paper. The medical literature on blockchain security is reviewed in Section 2. The suggested method is described in Section 3. The outcomes of our prototype experiments are provided in Section 4. Part 5 provides guidance for future scope and conclusion of work.

2. RELATED WORK

This segment reviews literature on healthcare research that exploits blockchain technology. Israa *et al.* [1] explored benefits of using blockchain in different applications of healthcare domain. They investigated on utility of blockchain in terms of security and different modes operations. Similar kind of work was one by Hasselgren *et al.* [29] where the researcher elaborates health sciences that need blockchain support. Similarly, in [3], [15], [27], [28], the researchers established the need for blockchain technology for better possibilities in healthcare while advocating privacy and security. Esposito *et al.* [2] investigated on cloud and blockchain ecosystem suitable for healthcare domain. Their findings revealed the significance of blockchain usage to safeguard healthcare data. Farouk *et al.* [4] and Gokalp *et al.* [5] focused on industrial healthcare in terms of perceived vision and opportunities in future. Their investigation has resulted in the assertive propositions to healthcare domain to exploit blockchain and reap its benefits. Rathee *et al* [6] suggested a system that integrates blockchain and IoT for processing multimedia data with efficiency while Rehman *et al.* [9] discussed about healthcare 5.0 model for security. Gordon *et al.* [7] discussed how blockchain technology enables transition from current healthcare systems to patient-driven interoperability. Kumar *et al.* [9] investigated on different requirements of using blockchain and at the same time, when explored blockchain is to be used in healthcare, Specific difficulties include those related to standards on, security, privacy, and interoperability. Rajawat *et al.* [10] presented a blockchain-based security mechanism for IoT-connected devices.

Tanwar *et al.* [11] and Usman *et al.* [12] focused on electronic medical records and the importance of securing them using blockchain to reap benefits like immutability and non-repudiation. If there is importance of storage and accessing data through blockchain in healthcare, there is need for specific approach for efficient data accessibility as explored in [13] and [14]. Khan *et al.* [16] focused on smart grid and blockchain technology to be used in healthcare with possible security challenges ascertained. Improving content sharing experience in healthcare domain with the help of blockchain, according to Jabbar *et al.* [17], is possible besides achieving data integrity and interoperability. An architecture for healthcare data security using blockchain technology is explored in [18] while the difficulties in data exchanges between healthcare system and blockchain are discussed in [19]. Researchers in [20], [21] and [22] made diversified proposals that are useful for protecting healthcare data using blockchain. Importance of smart contracts [24], blockchain challenges [23], [25], privacy with blockchain [26] and a methodology for managing heterogeneous medical data using blockchain [30] are other important contributions found in the literature. Many existing methods found in literature revealed their need with blockchain integration. However, there is a need for a comprehensive system with support for all operations controlled by smart contracts. Besides, the application should be user-friendly for user who does not know underlying technicalities.

3. PRELIMINARIES

This section presents necessary preliminaries to understand the proposed framework, smart contracts and underlying algorithms.

3.1 Blockchain Technology

Blockchain technology uses a chain of blocks or nodes to store data. Each node is made up of the header and body are shown in Figure 1. Header

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

possesses metadata required to manage chain of blocks with ease. In other words, header contains information such as hash value of current node and its previous node Body, on the other hand, holds actual data pertaining to a transaction. Nodes are linked as contiguous blocks and they are distributed in a distributed network. The nodes have index and thus accessing data becomes easier [31].

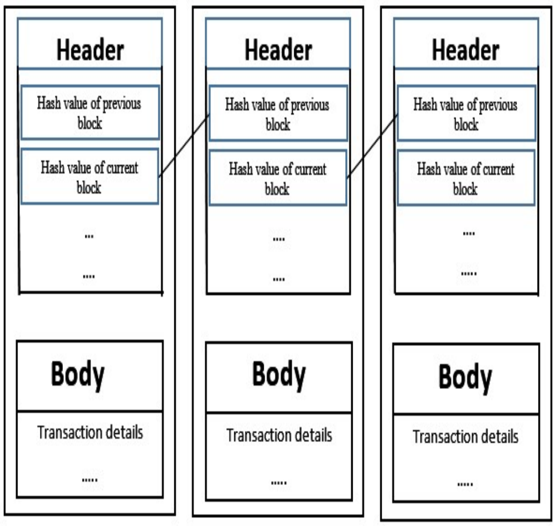

Figure 1: Typical Blocks In Blockchain And Their Connectivity

Nodes in a peer-to-peer distributed network maintain the interconnected blocks. Blockchain, then, is used to store data as a distributed ledger or as transactions. This study uses blockchain technology to store medical records. Additionally, blockchain technology facilitates platform interoperability. It allows for the storing of data of many kinds, and as blockchain data is immutable by default, it offers basic security for data storage.

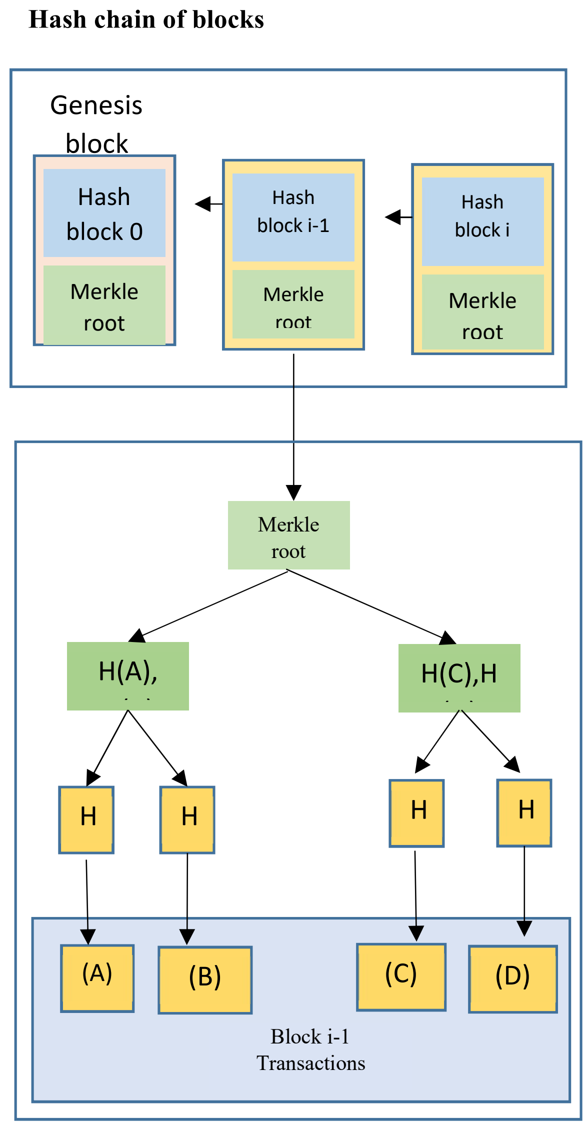

Figure 2: Merkle Tree Used By Blockchain For Efficient And Faster Validation Of Data

As presented in Figure 2, blockchain technology makes use of Merkle trees to validate data faster as they summarize data by using a root hash. Hashing pairs of child nodes until the root hash is obtained it reached Merkle root as discussed in [32].

3.2 Benefits of Blockchain in Healthcare

When blockchain is used in healthcare domain, there are many perceived benefits as illustrated in Figure 3. These benefits are associated with patients and also healthcare units. Benefits pertaining to patient include security to data, privacy to sensitive health information,

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

elimination of data leakage, data integrity, personalized authorization, ease of data retrieval and sharing, technology enabled health status monitoring and data access to only essential stakeholders like physicians. In case of emergence, data is being available to patients and doctors [33], [34].

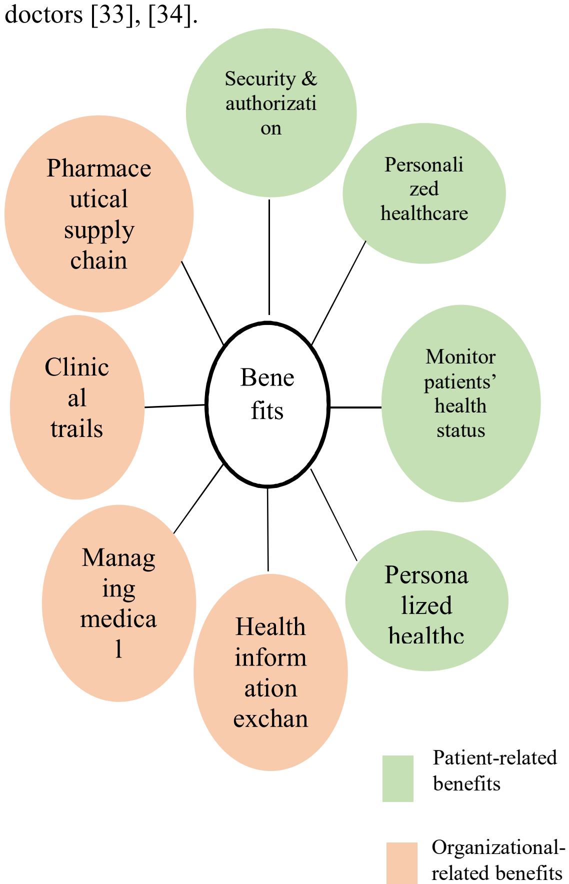

Figure 3: Perceived Benefits Of Blockchain To Patients And Healthcare Units

There are benefits to healthcare units as well when blockchain technology is used. As discussed in [35] and [36] benefits include health information exchange, ease in managing medical insurance dynamics, clinical trials and managing pharmaceutical supply chain. As patient information is required by different departments and branches, it helps in sharing information with ease. In other words, seamless patient information exchange is possible with blockchain enabled application. The information exchange can also be done with secure and reliable fashion. Blockchain also helps in managing clinical trials with integrity and transparency. With the help of blockchain clinical trials can be managed without privacy and security issues. In pharmaceutical supply management also blockchain is found to play crucial role. Medical insurance associated with patients can be managed without discrepancies.

3.3 Security Threats to Blockchain in Healthcare

Blockchain technology integration in healthcare domain also throws certain security challenges as illustrated in Figure 4. The security challenges are in the form of social, organizational and technological as explored in [37] and [38]. The technological threats include scalability issues of blockchain in terms of processing large volumes of transactions, energy efficiency to deal with transactions, security, susceptible to cyber-attacks and authorization. Attacks such as memory pool attack and DNS attack are possible. Other technical issues are linked to high energy consumption and low speed of processing

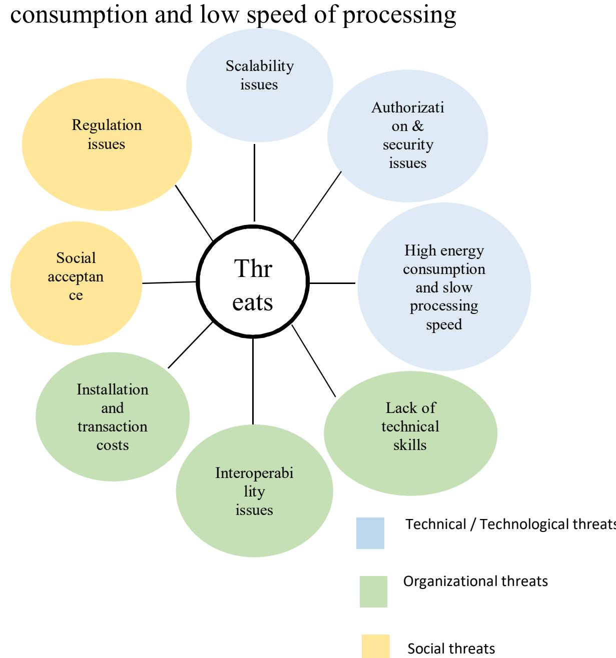

Figure 4: Different Kinds Of Threats To Blockchain In Healthcare

Social threats include the degree of social acceptance for blockchain in healthcare, trusted third parties, decentralization, legal authorities and legitimacy. There is lack of regulations and governance related guidelines for blockchain in healthcare. With respect to organizational threats, they are in the form of interoperability, lack of trust between different parties, lack of open standards for data exchange, maintenance of pharmaceutical data integrity and supply chain, cost and maintenance.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

4. METHODOLOGY OF PROPOSED SYSTEM

This section presents the proposed system and along with algorithms defined for secure data storage and retrieval.

4.1 Problem Statement

Developing healthcare application with smart contracts for secure data storage and retrieval using blockchain technology is the problem considered.

4.2 Proposed Methodology

The Proposed methodology named BTSF, is designed to achieve secure storage and management of healthcare data using Blockchain. Figure 5 shows its architectural overview of the framework. Its goal is to take use of Blockchain's underlying security protocols and technologies. Put differently, the goal of suggested solution is to guarantee correctness of data and its authorship in the healthcare ecosystem. Healthcare data is extremely sensitive, thus having these security measures is essential. Solidity is used to construct smart contracts that control the suggested system. It uses a support service to use blockchain and a traditional database to make transactions unchangeable. Correctness of data and its authorship are ensured by the service's provision of unchangeable proof of transactions. The owner of the data is guaranteed for high level of security while using the technology.

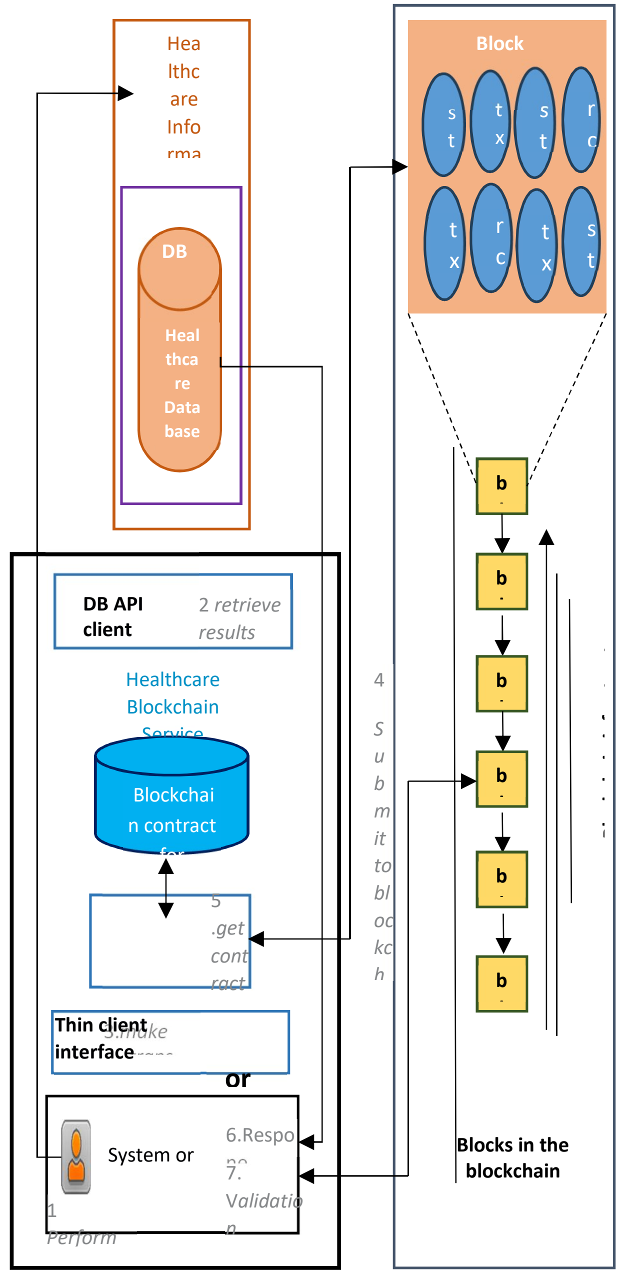

Figure 5: Proposed System Known As BTSF For Data Security Using Blockchain

The suggested service acts as a go-between for traditional databases and data users. A database with several relations is stored in the MySQL database system. There are three layers to the BTSF. End users use the first layer, referred to as the client application layer, to access the suggested system. Put otherwise, this layer offers a web-based user interface. A functional interface for database access is available in the second layer. The data associated with a transaction is stored in blockchain and that is made immutable.

The smart contract created to govern the application functionality is followed in carrying out the transactions. Every piece of data is coded into Merkle keeps trees in order to be safe. Data is stored in leaf nodes while number of child nodes is stored in non-leaf nodes. Put another way, each transaction's data is kept in a leaf node in accordance with the terms of the smart contract. The tree stores the changes made to the BTSF contract in the future and refers to the earlier tree for further information. Every transaction in the blockchain infrastructure is subject to a fee that is determined by the computational load at that moment. We refer to this fuel as "gas." Every transaction involves some petrol spending. The Ethereum blockchain, which is the subject of this article, uses a currency called ETH.

```
Algorithm: Blockchain-enabled Security for
Health Data Storage (BS-HDS)
    (id,pw)←getUserCredentials)
    IF (id,pw) correct Then
    data←getUserInputs()
      op←getUserOperation()
    account←getUserBCAccount()
      IF account is valid Then
        flag←verifySmartContract()
    IF flag is true Then
          block←generateNewBlock()
    tx←saveData(data, block)
    bhash←generateBlockHash(block)
          thash←generateTxHash(tx)
          gasLimit←updateGasLimit()
        End If
      End If
    End If
```

Algorithm 1: Blockchain-enabled Security for Health Data Storage (BS-HDS)

In Algorithm 1, user is allowed to perform intended action after due authentication. After authentication, system takes user's operation and inputs and then user's blockchain platform account is taken and verified. If the Ethereum account is valid, then the user's data is saved to a new block and block hash and transaction hash get updated. For every transaction gas is expended and the gas limit is updated.

```
Algorithm: Blockchain-enabled Security for
Health Data Retrieval (BS-HDR)
    (id,pw)←getUserCredentials)
    IF (id,pw) correct Then
      data←getUserInputs()
      op←getUserOperation()
      account←getUserBCAccount()
      IF account is valid Then
        flag←verifySmartContract()
        IF flag is true Then
    tx←retrieveData(data, block)
    block←generateNewBlock()
          bhash←generateBlockHash(block)
          thash←generateTxHash(tx)
          gasLimit←updateGasLimit()
          Display data
        End If
      End If
    End If
```

Algorithm 2: Blockchain-enabled Security for Health Data Retrieval (BS-HDR)

In Algorithm 2, user is allowed to perform intended action after due authentication. After authentication, system takes user's operation and inputs and then user's blockchain platform account is taken and verified. If the Ethereum account is valid, then the user's request for data retrieval is processed and a new block created. Then block hash and transaction hash get updated. For every transaction gas is expended and the gas limit is updated. The user operations are not allowed unless smart contract is satisfied. Solidity is the language used to define the smart contracts utilized in the application. Object orientation is supported by the high level programming language Solidity. The Ethereum Virtual Machine (EVM) is compatible with smart contracts written in Solidity. The healthcare application's operations are made possible by these contracts. These facts are stored in each block of the blockchain that has been produced. The hash values of the previous, current, and next blocks are included in the header of each block. The information related to the transaction is contained in the block's content.

5. EXPERIMENTAL RESULTS

A web-based interface is built for the application which uses Ethereum blockchain to construct the suggested solution. Smart contracts control how the system operates. The environment used for empirical study is provided here. Ethereum is the blockchain platform used. Web3 is used for required API. MySQL is used to store data in

Journal of Theoretical and Applied Information Technology
15th March 2024. Vol.102. No 5

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

relational format. Python is the language used to implement functionality. Truffle is used to develop smart contracts with ease. VS code is the IDE used for application development. Ganche is used as part of Truffle suit of tools for local blockchain development. The suggested system's definition of smart contracts is made up of structures for holding state of domain objects and functions that apply application's business rules. For instance, Hospital Record is a contract which contains different structures for maintaining hospital information, patient's treatment information and report. Functions used in the application are meant for hospital registration, obtain hospital information, manipulate hospital details and store and retrieve patient details.

Table 1: Performance Comparison Of BTSF With Existing Method

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

Cost which is accumulated for the blockchain-based healthcare framework, BTSF, is contrasted with the current system, which is also blockchain-based but not smart contract-governed, as shown in Table 1.

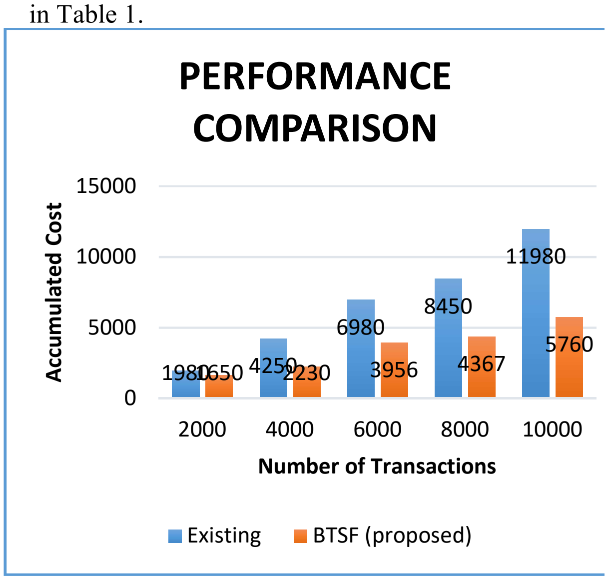

Figure 6:Analysing Performance In Relation To Total Expenses

The performance of the current system, which is not controlled by smart contracts, is contrasted with the proposed system, known as BTSF, as shown in Figure 6. The performance is assessed by comparing the total number of transactions seen with the cumulative cost. Better performance is indicated by a lower total cost. The suggested solution operates more quickly and requires less computing power since it includes robust support for smart contracts. It is the cause of the suggested system's improved performance. The current system costs 1980 when there are 2000 transactions, but the BTSF only needs 1650. In a similar manner, the total cost of the suggested method is 5760 when 10,000 transactions occur.

Table 2: Shows Latency Performance Against Throughput

Throughput(KBps)	Avg. Latency (ms)
150	6
370	8.2
500	6
600	7.8
750	6.2
890	6.3
990	8.1
1100	6.1
1200	10
1400	14.1

As presented in average latency of the proposed system activities are observed against the throughput associated. The amount of time needed to finish a transaction before it is recorded on a blockchain or to obtain data is known as latency. For each kind of operation, average of 10 transactions is computed to form average latency.

Journal of Theoretical and Applied Information Technology
15th March 2024. Vol.102. No 5
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ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

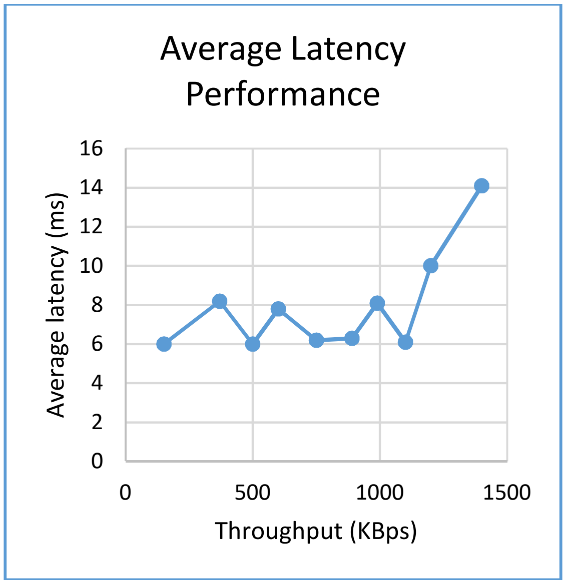

Figure 7: Shows Average Latency Against Throughput

Latency is the time required from the moment request is given in the system till the response comes after performing intended operation. With Apache JMeter latency is measured with different throughput values. As shown in Figure 7, average latency is changed for each throughput observation. When throughput is 1400 KBps, the average latency is highest with 14 ms.

Table 3: Throughput Performance Against Number Of Users

Number of users	Throughput(KBps)
100	230
200	490
300	520
400	660
500	830

As presented in Table 3, throughput observations are provided against number of users involved in the system.

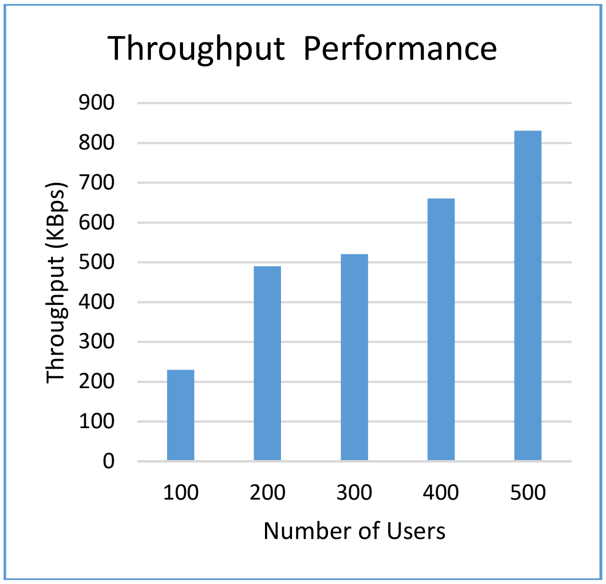

Figure 8:*Displays The System's Throughput Performance Vs The Total Number Of Users.*

As presented in Figure 8, experiments are made with the help of Apache JMeter to know how the proposed system performance with different quantity of users. According to the results, throughput is impacted by the number of users. The throughput greatly increases as the number of user's increases.

Table 4: Processing Time Comparison Against Number Of Blocks

Number of Blocks	Processing Time (seconds)	
	Bitcoin [20]	Proposed
10	2.3	2
20	2.7	2.3
30	3	2.5
40	3.3	2.7
50	3.6	2.9

As presented in Table 4, the processing time required by the proposed system and bitcoin against number of blocks is provided.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

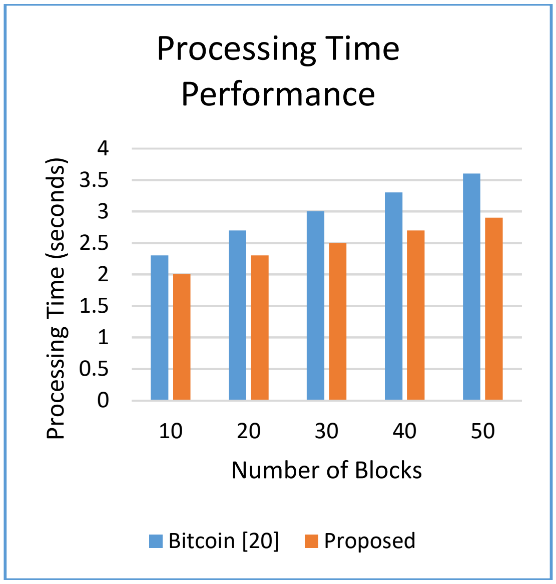

Figure 9:Processing Time Against Number Of Blocks

The processing time required by the proposed system is compared against the bitcoin system found in [20]. Increasing the number of blocks results in gradual increase in processing moment. However, when compared with bitcoin based system found in the literature, the proposed system showed better performance regarding processing duration.

6. CONCLUSION AND FUTURE WORK

This paper presents on framework Blockchain Technology-enabled Security Framework (BTSF). Solidity language is used to define smart contracts. The framework has mechanisms to exploit blockchain technology to protect all transactions and its data related to healthcare application. The framework has different layers to have client application, functional interface to blockchain in distributed ledger and data being managed securely using two algorithms are proposed to realize the functionality of BTSF. They are known as Blockchain-enabled Security for Health Data Storage (BS-HDS) and Blockchain-enabled Security for Health Data Retrieval (BS-HDS). These two algorithms ensure secure healthcare data storage and retrieval. A prototype application is developed to evaluate framework and underlying algorithms. This empirical study showed that BTSF is highly secure rendering non-repudiation and data integrity. Main contribution of this work is to define smart contracts based governance for secure blockchian based healthcare application. Future endeavour is to leverage BTSF with encoder and decoder functionalities for customized security mechanisms.

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