IMPLEMENTATION AND EVALUATION OF A DECENTRALIZED MEDICAL DATA EXCHANGE SYSTEM BASED ON THE IOTA TANGLE AND APPROXIMATE ALGORITHMS FOR OPTIMAL DATA PLACEMENT

Facilitating the transfer of patient medical information across healthcare providers is crucial for ensuring high-quality care. However, this process encounters obstacles pertaining to privacy, security, and centralised control. This article outlines the creation of a decentralised system for exchanging medical data. The system utilises Distributed Ledger Technology, specifically the IOTA Tangle (open protocol (and network) for data and value transfer). This document outlines the structure and fundamental elements of a system designed for the secure and unalterable storage and transfer of medical records. The system employs masking and encryption methodologies to protect patient confidentiality while enabling healthcare practitioners to access complete information with patient authorization. The IOTA Tangle facilitates transactions without any fees and ensures the verification of data integrity through its Directed Acyclic Graph (DAG) topology. Simulation trials validate the system’s capability to securely communicate medical data on a large scale, while incurring lower resource costs than typical blockchain systems. The system demonstrates the feasibility of a decentralised and self-governing method for efficient and confidential sharing of medical data, utilising Distributed Ledger Technology (DLT). The secure data sharing platform facilitates the implementation of novel care and research frameworks, all while upholding patient confidentiality and adhering to healthcare ethical standards. Also, in the development of billing Online Transaction Processing (OLTP) systems, which are designed for input, structured storage and processing of information in real time, the use of cloud technology is proposed. The problems that arise and their relevance to the solution of an integer linear programming problem with Boolean variables are shown. Approximate algorithms for optimal data placement and mathematical models for optimizing the structure of a distributed database of a cloud system are proposed, taking into account the limitations on the amount of node memory, the available costs of renting cloud resources, and the number of replicas of fragments of the distributed database.

Keywords: electronic healthcare system, medical patient data, distributed ledger technology, IOTA Tangle, blockchain technology, billing OLTP system, integer linear programming with Boolean variables, distributed database.

Introduction

Problem statement. Currently, there is a surge in the use of distributed ledger technology across diverse sectors, including the healthcare industry. It is not unexpected that the same blockchain is an immutable, transparent, and decentralised database [1]. Implementing blockchain technology in healthcare systems will render medical data immutable. In the past, information was only documented on paper, making it susceptible to alterations. Privacy and security issues are already prevalent in contemporary medical systems [2]. Insufficient security and privacy measures might lead to people being hesitant to provide their sensitive information or decline receiving treatment [1]. The implementation of DLT in healthcare can address issues such as access control, data integrity, and dependability [2]. It is important to address health challenges related to inadequate integration of medical systems, fragmented data, and insufficient patient engagement [3]. Implementing Distributed Ledger Technology in the healthcare industry has the potential to revolutionise the way data is stored and shared, resulting in enhanced safety and efficiency of procedures. Due to its key attributes of openness, traceability, dependability, and decentralisation, the use of Distributed Ledger Technology in diverse healthcare systems will mitigate issues pertaining to security, privacy, and compatibility [1]. Blockchain is currently employed in several healthcare systems. In [4] outlined the primary domains where blockchain technology may be applied, including telemedicine, diagnostics, data governance and trade, and supply chain surveillance. Nevertheless, the majority of these initiatives are characterised by prototypes or small-scale endeavours that have a limited number of users. Furthermore, the blockchain has not yet achieved its ideal level of maturity. The technology still possesses deficiencies that remain unresolved. The primary factors include scalability, bandwidth, power consumption, and transaction costs. Given the circumstances, IOTA Tangle serves as a viable alternative to the blockchain, as it enables the elimination of these aforementioned drawbacks.

Analysis of the latest research and publications. Ensuring the confidentiality and protection of patients’
medical information is a persistent concern, prompting researchers to seek the development of a system capable of preventing the unauthorised access or disclosure of patient data. The paper [5] introduces a decentralised medical system that utilises IOTA Tangle to safeguard patients’ medical information and medical Internet of Things (IoT) equipment. As part of this project, four prototype applications were created to showcase the suggested solution: a web recording application, a patient application, a doctor application, and an application for a remote IoT medical device (internet of things). The findings demonstrate that the suggested architecture has the capability to enhance healthcare services through the provision of patient health records that are immutable, secure, scalable, dependable, self-managed, and traceable. This empowers patients with full authority over their medical information.

The convergence of distributed ledger technology with the Internet of Things has created novel prospects for advancement in the field of medical data management. Distributed ledger technology has the capability to address a range of problems, including security breaches, privacy breaches, and data fragmentation. In [6] the authors examine 10 scholarly publications published between 2018 and 2021 and propose using the IOTA Tangle as a solution to current challenges. The findings indicate that IOTA Tangle is a highly suitable option for handling medical data and that it has been effectively deployed as a proof of concept. This serves as the foundation for subsequent investigations on the appropriateness of utilising the IOTA Tangle for the management of medical data. In [7] the authors conduct an analysis of works published between 2017 and 2023 that utilise blockchain technology for the purpose of exchanging medical data. The findings indicate a significant increase in the advancement of blockchain technology and its application in facilitating the transfer of medical information. The majority of research propose a distinct framework, structure, or approach for the dissemination of medical data using blockchain technology. In [8], a proposal is made to conduct a systematic assessment of the literature in order to analyse current blockchain-based methods that aim to enhance privacy and security in electronic healthcare systems. A total of 51 papers, published from 2018 to December 2022, were subjected to analysis. The study provides a comprehensive analysis of the key concepts, blockchain types, assessment criteria, and utilised techniques for each chosen article.

The CoviReader architecture, which is built on IOTA Tangle, is introduced in [9]. It has been specifically designed for managing medical information in order to address the COVID-19 pandemic. This technology enables the safeguarding of citizens’ privacy and their health data by preventing unwanted access. The CoviReader design, as presented, offers both accessibility and stringent control over data processing.

An authentication architecture that employs triple encryption is proposed in [10]. This design aims to facilitate the secure and convenient sharing of personal medical information between patients and medical workers. The transmission of records is safeguarded by an encryption method using CEDA (Compact Energy and Delay-Aware Authentication), while the accuracy of records is verified using both the hash value and the blockchain. This is because information stored in the blockchain is immutable and cannot be altered or removed. Employing this triple safeguard ensures the attainment of utmost confidentiality and security for medical records.

In [11], a proposal is made for a medical system that utilises blockchain technology to facilitate the storage and sharing of medical information. This system is a sophisticated and collaborative management system that operates across several nodes. Its primary function is to prevent the fabrication of medical data and the unauthorised disclosure of information. It has the capability to address issues related to the administration of health data.

DLT is suggested in [12] as a solution for addressing issues about the security and privacy of medical data in the context of emerging health systems. Specifically, the suggestion is to utilise MAM (Masked Authentication) for the purpose of ensuring safe data transmission throughout the healthcare system. The authors suggested a concept based on the IOTA Tangle to provide secure and secret storage and interchange of information.

In order to address issues pertaining to the security of medical data and patient confidentiality, the authors in [13] suggest the implementation of a novel system utilising blockchain technology. This system enables the preservation of medical data confidentiality by offering patients methods to manage their personal information, empowering them to autonomously give access privileges to their medical data.

The literature analysis reveals that health organisations are becoming more interested in the potential of worldwide adoption of distributed ledger technology, particularly in light of data insecurity concerns. The utilisation of blockchain technology is already prevalent throughout several domains within the healthcare industry, encompassing the safeguarding of patient information as well as the administration of the pharmaceutical supply chain. Blockchain enables the safe transmission of medical data, a feat previously deemed unattainable. Nevertheless, distributed ledger technology is not static, and alongside the blockchain, other forms of DLT have emerged. The IOTA Tangle serves as another prominent illustration of Distributed Ledger Technology. Nevertheless, the adoption of the IOTA Tangle is presently limited. Given the numerous benefits of IOTA Tangle over blockchain, it has the potential to signifi-
cantly enhance the quality of medical treatment. Consequently, it is crucial to focus on developing systems that use IOTA Tangle in the healthcare industry to guarantee safe data exchange.

The objective of the article is to create a medical system utilising IOTA Tangle to facilitate the safe transfer of medical information among patients, healthcare providers, institutions, and organisations within the healthcare system. To achieve this goal, it is necessary to solve the following tasks:

- evaluate the conventional healthcare model and propose an alternative model utilising IOTA Tangle,
- elucidate the fundamental principles of the new model and explain their interplay;
- construct a decentralised system for storing, processing, and managing medical data using IOTA Tangle technology, outline the primary approaches for implementing the system.

**Summary of the main material**

Figure 1a depicts the conventional healthcare model. The central authority, which is a medical institution, stores all medical data. Deliberate manipulation or inadvertent hacking of the central organ can result in substantial harm to the medical system.

![Figure 1. Traditional Model (a) and IOTA Tangle-Based Model (b)](image)

The IOTA Tangle is a decentralised database that significantly eliminates the need for a central authority. The IOTA Tangle-based paradigm, seen in Figure 1b, offers much enhanced security compared to the conventional model, and it operates without the need for an intermediate.

The IOTA Tangle-based architecture achieves decentralisation by disseminating copies of data to all users in the network, hence eliminating the need for a central authority. The IOTA Tangle-based paradigm, seen in Figure 1b, offers much enhanced security compared to the conventional model, and it operates without the need for an intermediate.

The proposed model is characterised by three main entities: client, IOTA node, and IOTA Tangle (Figure 2).

![Figure 2. Model Entities](image)

Clients refer to individuals utilising a medical system, who have the capability to transmit transactions (in the form of medical data) to nodes.

A node is a device that is linked to other devices to create an IOTA network. It has the responsibility of adhering to the underlying protocol.

The IOTA Tangle is a decentralised database that securely records unchangeable transactions. Figure 3 illustrates the interplay between these components.

The patient produces transactions including their medical data that they wish to transmit to the doctor. Patient transactions are initially forwarded to the Tangle node, from which they will subsequently be relayed to the Tangle network. Upon verification of the transaction, patients are sent to the doctor’s node and then to the doctor’s system.

The transaction lifecycle starts when a patient or doctor initiates a request for consultation with another doctor or patient. In order to transmit a transaction to the IOTA network, it undergoes the subsequent stages:

1) The sender completes the relevant form, which may include information on symptoms, medicines, and diagnosis. This data is used to generate individual transactions.

2) The subsequent process involves consolidating these separate transactions into a fundamental component of the IOTA network known as a bundle. Each transaction inside a package is separately indexed and includes data on the total number of transactions within the package. After finishing, incoming transactions within the package must be signed in order to verify ownership. The system generates public and private keys in order to authenticate transactions. Keys are derived from a distinct access key known as a seed. The seed is generated within the designated field in the profile settings.

3) In order to transmit transactions to the network, it is necessary to validate the preceding two transactions. In order to do this, a solicitation is sent to the IOTA network node to choose two unverified transactions. The weighted random walk technique is employed for the purpose of selecting two unverified transactions.

4) In order to participate in Tangle, every transaction within the bundle must own a nonce. Nonce is the outcome of the Proof of Work (PoW) process. The computation of PoW confirmation needs to be carried out individually for each transaction, thereby resulting in a longer duration as the number of transactions in the package increases. The intricacy of the computation is also contingent upon the MWM (minimum weight magnitude) established by the network. The PoW computation is performed locally on the user’s device and may require a significant amount of time.

5) The final stage is resolving the packet for the network. Nodes will propagate transactions over the network and store them in their respective local databases.
The act of generating transactions and transmitting them to the network is depicted using the IDEF0 notation. Figure 4 displays the context diagram. The primary distinction is in the fact that the doctor, upon evaluating the patient’s symptoms, completes the diagnostic form.

In addition, the doctor has the ability to complete other forms, such as issuing a prescription or prescribing medical exercises. After the transactions have been included in Tangle, they will be designated as unverified. In the future, more transactions included into the Tangle will be linked to the transactions of the senders. The magnitude of these transactions directly correlates with the overall magnitude of their weight. As the overall weight of transactions increases, the probability of their confirmation also increases.

According to points 3 and 4 of the transaction lifecycle, it is stated that while transmitting transactions to the network, it is necessary to locate two transactions for verification and compute the PoW. Figure 5 illustrates the process of adding a new transaction to Tangle by choosing two unconfirmed transactions.

**Approximate algorithms for optimal data placement**

Traditionally, the bottleneck of an automated information management system (AIMS) is a decrease in performance with increasing workload (increasing number of users), accumulation of information over a long period of time, and high fragmentation of stored data, which is typical for transactional systems. This is especially critical for the OLTP solutions market, which are designed for real-time data entry, structured storage, and processing [14–17].

In addition, for the same reason, they have significantly limited capabilities to perform functions such as generating accounting and analytical reports in different sections and with different levels of detail. To solve this problem, service companies are forced to purchase expensive equipment, customize it, and constantly use the services of highly paid specialists. In this regard, it is proposed to use cloud technology as a basic architecture when developing billing OLTP systems, which will allow replacing large capital expenditures for the implementation of such a system with operating costs.

The ideology behind this approach is to move computing, processing, and data storage largely from personal computers (PCs) to Internet servers. In this case, the key task is to optimize data distribution in the cloud. This approach can significantly reduce costs and increase system speed. In most cases, such systems are built without taking into account efficiency criteria and with a large margin of scalability.
Suppose there is a network with an arbitrary topology (the cloud) connecting nodes (servers) and a local area network with a regular structure, all of whose PCs have access to the network with an arbitrary topology. In addition, there is a database distributed across the cloud nodes. A query that comes to any node of a network with an arbitrary topology provides access to a certain fragment of the distributed database, and all queries to the same fragment have different lengths and require different amounts of data to answer.

The request processing scheme is as follows. A request initiated on a node that is part of a regular network enters the input queue of a node in a network with an arbitrary topology. The PC processor processes requests in the order they are received. If the required fragment is contained in the local database of the node to which the request was received, the request is processed and the result is sent to the PC that initiated the request. If the required fragment is located in another node, the request is forwarded to that node, processed there, and the result is sent to the original node.

From the described scheme of query processing in the system, it can be concluded that in the course of service, a certain amount of data is sent over communication channels during each unit of time. The total value of the selected amount of data sent over the communication channels in the cloud structure depends on the distribution of fragments across the local databases of the network with the cloud structure. The smaller the average amount of data sent over the network channels per unit of time, the faster the query processing speed and the lower the total cost of traffic.

This volume will be minimal if each node has a complete set of fragments of the distributed database. For large databases, this is practically unattainable, since the storage capacity of nodes is limited. Therefore, the task of optimal placement of database fragments on cloud nodes arises, taking into account the restrictions.
on their available disk space.

Due to the fact that cloud technologies use a pay-as-you-go business model, and the cost of storing information arrays is a linearly increasing function of their volume, given the need to increase the availability and reliability of data storage, the urgent task is to determine the optimal number of copies (replicas) of database fragments and obtain a variant of their placement so that the total value of the replicas is maximized, and the total cost of renting hardware resources does not exceed the specified limits, and the restrictions are met.

This type of problem refers to the solution of an integer linear programming (ILP) problem with Boolean variables (BV). Currently, combinatorial methods occupy a dominant place in the methods of solving such problems. These primarily include methods of full search, branches and boundaries, dynamic programming, and local algorithms. The practical application of these methods is complicated when solving problems of high dimensionality.

Approximate algorithms for optimal data placement and mathematical models for optimizing the structure of a distributed database of a cloud system are proposed, taking into account the limitations on the amount of node memory, the available costs of renting cloud resources, the number of replicas of distributed database fragments, which differ from the existing ones in that they take into account the features of cloud computing technology [14–20]:

- model for placing fragments of a distributed database in the network nodes of the cloud structure according to the criterion of maximizing the total value of fragment replicas;
- model of distributed database fragments placement in the network nodes of the cloud structure according to the criterion of minimum traffic price;
- model for placing fragments of a distributed database in the network nodes of the cloud structure by the criterion of minimum average data transfer.

**Implementation and evaluation**

The IOTA Tangle consists of confirmed and unconfirmed transactions and tips. Each transaction can be represented as the vertex of a graph. Each time a new transaction is created, the node selects two other transactions using the WRW algorithm.

The algorithm goes through the tangle and selects the vertices that have the highest total weight. Once a node is sure that the selected transactions are not conflicting, it solves a cryptographic puzzle called nonce search. After that, the transaction is added to the tangle and becomes a new vertex [1]. The process of finding new transactions for confirmation is shown in the activity chart (Figure 7).

![Fig. 7. Tips Selection Algorithm](Source: obtained by the authors.)

The chart shows that the initial tx0 transaction is selected first, which will start searching for unconfirmed transactions. Then, for each transaction (Tx1 and Tx2—these transactions directly confirm the tx0 transaction), the probability of passing $P$ is calculated. Next, select the branch of the transaction that has a higher probability of $P$. If the probabilities of both transactions are equal, either of these transactions is selected. If there are
no more transactions in the branch, the last transaction will be a new confirmation transaction. If the branch still has transactions, then we return to calculating the probability of subsequent transactions.

Converting medical data to an array of bytes based on this array, we calculate the hash using the BLAKE2b-256 hash function and convert it to trits. After that, we take an arbitrary Nonce value and add it to the hash trits. The resulting value is hashed using the Kerl hash function. After that, we count the number of zeros in the hash. If the number 0 corresponds to MWM, the transaction is valid. If the number 0 corresponds to MWM, then the Nonce value increases by 1, and the process repeats. Prior to transmitting any data, the user (either a patient or a doctor) is required to authenticate themselves by logging into the system. Consequently, upon first access to the system, the doctor or patient is required to complete the form by providing the relevant information such as last name, first name, doctor/patient ID, and so on. In order to seek medical advice, the patient is required to input the specific field of expertise of the doctor they wish to communicate with into the search bar. Alternatively, you may select a specific medical specialisation from the provided list on the same webpage. Once the patient has chosen the suitable physician, they proceed to complete a form detailing the specific symptoms that are causing them distress. Using this data, transactions will be created and sent out to the network.

Figure 8 depicts the process of searching for a doctor using the IDEF0 notation. Figure 9 shows the PoW calculation process.

![Fig. 8. Finding a doctor in IDEF0 notation](source)

Initially, the patient must authenticate themselves into the system. In order to do this, the patient completes the relevant sections of the form. In the event that the patient fails to accurately maintain the data, the system will detect and report inaccuracies. Upon authentication, the patient proceeds to seek out a physician. Type the doctor’s area of expertise in the search field. The system will present a roster of physicians that you may reach out to for a consultation. Once a doctor has been chosen, the patient proceeds to specify the symptoms that are causing them discomfort. Subsequently, with this data, transactions are created and subsequently transmitted to the IOTA network.

Figure 10 illustrates a comprehensive concept of a decentralised system that utilises IOTA Tangle technology to store, analyse, and manage medical data. In order to get medical treatment, the patient is required to authenticate themselves on the medical system. By inputting personal identification information, the patient has the ability to look for a physician by defining a particular medical specialisation in the search field. The system will generate a roster of physicians capable of delivering medical treatment. Upon evaluating the offerings of each physician, the patient can select an appropriate specialty. In order to communicate the symptoms that are causing discomfort to the patient, it is necessary to complete the relevant form. Transactions are created or produced based on this data. Subsequently, these transactions progress through the respective steps that were previously outlined.

**Efficiency analysis**

When sending a transaction to the IOTA Tangle network, there are 3 main steps that take a lot of time to complete. These are: time to search for tips; PoW execution time; total time to create and link the bundle.
Fig. 9. PoW calculation
Source: obtained by the authors.

Fig. 10. Model of a decentralised system for storing, processing and managing medical data using IOTA Tangle technology
Source: obtained by the authors.
For testing, we will take 10 different diseases and their symptoms that the patient can send to the health care provider (Table 1). We will send the symptoms of these diseases to the doctor’s node. We will draw this text 20 times. Table 1 shows a list of diseases and their symptoms that patients send to doctors.

<table>
<thead>
<tr>
<th>No.</th>
<th>Disease</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>acute respiratory viral infection</td>
<td>weakness; increased fatigue; feeling of weakness; headache; drowsiness; difficulty nasal breathing; tickling and sore throat; fever; chills; weakness.</td>
</tr>
<tr>
<td>2</td>
<td>beriberi</td>
<td>peeling of nails and skin; poor hair condition; chronic lethargy and fatigue; apathy and depression; drowsiness; headache; decreased immunity and frequent colds.</td>
</tr>
<tr>
<td>3</td>
<td>asthma</td>
<td>wheezing; coughing; chest tightness and shortness of breath.</td>
</tr>
<tr>
<td>4</td>
<td>sinusitis</td>
<td>fever; sinus pain; difficulty in nasal breathing; loss of sense of smell.</td>
</tr>
<tr>
<td>5</td>
<td>flu</td>
<td>high fever; fever; headache; muscle and joint aches; general weakness; loss of appetite; runny nose.</td>
</tr>
<tr>
<td>6</td>
<td>pneumonia</td>
<td>shortness of breath; fever; cough; chest pain; impaired taste and smell.</td>
</tr>
<tr>
<td>7</td>
<td>poisoning</td>
<td>nausea; vomiting; general malaise and weakness; fever; fever; diarrhea.</td>
</tr>
<tr>
<td>8</td>
<td>chickenpox</td>
<td>formation of vesicles and papules on the skin; itching in the rash areas; appearance of new formations.</td>
</tr>
<tr>
<td>9</td>
<td>stroke</td>
<td>sudden weakness; numbness; paralysis of the facial muscles; speech disorders; dizziness and acute headache; loss of balance and sudden gait disorders.</td>
</tr>
<tr>
<td>10</td>
<td>allergy</td>
<td>chills; high fever; pale skin; low blood pressure; impaired consciousness.</td>
</tr>
</tbody>
</table>

Table 1

PoW execution time depends on the number of transactions in the bundle, since each transaction calculates its own PoW. The more transactions, the more time is spent at this stage. If we draw analogies with the blockchain network, then the transaction time interval depends on the network load. The average transaction time is between ten minutes and an hour, but when the network is overloaded, the transaction time increases.

<table>
<thead>
<tr>
<th>Disease number</th>
<th>Number of transactions, numbers</th>
<th>Search time, s</th>
<th>Execution time PoW, s</th>
<th>Total generation time and Link bundle, s</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>11.77</td>
<td>21.6</td>
<td>37.92</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>12.84</td>
<td>28.91</td>
<td>47.86</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>6.02</td>
<td>19.29</td>
<td>27.79</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>9.05</td>
<td>25.35</td>
<td>37.77</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>6.3</td>
<td>23.97</td>
<td>35.44</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>12.73</td>
<td>26.93</td>
<td>43.77</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>11.85</td>
<td>25.71</td>
<td>39.43</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>10.96</td>
<td>16.29</td>
<td>29.26</td>
</tr>
<tr>
<td>9</td>
<td>7</td>
<td>7.76</td>
<td>36.08</td>
<td>46.19</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
<td>9.53</td>
<td>31.69</td>
<td>44.46</td>
</tr>
</tbody>
</table>

Table 2

Source: obtained by the authors.

**Average Response Time**

Average response time is the most important indicator for understanding how a website works from the user’s point of view. Simply put, the average response time is the time spent passing a specific packet of information sent from the user’s browser to the server, and the time spent returning the packet back to the user’s computer. Other factors, such as the user’s geographical location and the complexity of the requested information, may affect the average response time for users and should be taken into account when evaluating the overall performance of the application. The researchers call the most acceptable response value 0.5 s. Taking into account geography, this value can be about (1–3) s. Figure 11 shows the average Response time value.

![Fig. 11. Average Response Time](image)

Source: obtained by the authors.
The figure shows that the average value is Avg.Response time does not exceed 3 s. From this we can conclude that Avg.Response time does not exceed the specified norm. Although the maximum value is 36.8 s. To reduce this value, we have changed the methods that are responsible for sending transactions, calculating PoW, and searching for confirmation transactions. After making changes, the average response time is 15.9 s. The Average Response time value dropped 2.3 times.

**Bandwidth**

One of the most important parameters of any decentralized application is its bandwidth, as this characteristic largely determines the performance and loading speed of the entire resource, which in turn affects the number of users of the site.

Bandwidth is the number of requests that a server can fulfill in one second. Bandwidth is measured in requests per second (RPS):

\[ B = \frac{NoR}{Tt} \]

where

- \( B \) – bandwidth;
- \( NoR \) – number of requests;
- \( Tt \) – total test time.

Several factors can affect bandwidth. These include the number of users, the complexity and frequency of user operations, caching, and the configuration of pages and web parts. Each of these factors can have a significant impact on bandwidth.

Figure 12 shows that, on average, the server processes 5 requests per second with a constant load of 25 users. Figures 12, 13 show the bandwidth under a load of 25 and 50 users respectively.

**Comparison to related system**

From the traditional healthcare model, we can conclude that it is outdated and requires the introduction of new technologies and solutions. Since the patient only plays a passive role in this model, consultations take place infrequently, and healthcare professionals use isolated systems, which causes data fragmentation. Table 3 shows a comparison of the traditional model and the proposed one.

The patient data is stored in a centralised manner, namely in systems that utilise a central database accessible exclusively by clinicians. Typically, all data is saved on a physical medical card, which is then kept at the family doctor’s office.

These circumstances give rise to several challenges related to the retrieval and transmission of information. Consequently, a proposition was put up to utilise IOTA Tangle, enabling the safe interchange of medical information while ensuring its integrity. Crucially, both medical professionals and those seeking treatment will be able to get this data.

The patient will consistently possess a comprehensive medical history, hence preventing any fragmentation of data.
The patient assumes an active part in such a system, enabling them to engage in ongoing discussions with the doctor. Tangle’s minimal resource demands make it well-suited for IoT devices largely employed in the healthcare sector.

Tangle technology effectively addresses two limitations of blockchain: scalability and transaction costs. Hence, this paper presents a system that utilises the IOTA Tangle to facilitate data flow between patients and healthcare professionals.

## Conclusions

Ultimately, this study shows the practicality of utilising Distributed Ledger Technology, especially the IOTA Tangle, to provide a decentralised platform for the secure and confidential sharing of medical information among healthcare providers. The provided system design enables patients to retain ownership of their medical history while effortlessly sharing it with authorised parties to facilitate coordinated treatment. Data privacy is maintained by the implementation of encryption and access controls. The asynchronous transaction style and lightweight consensus mechanism of IOTA Tangle are very suitable for decentralised medical applications.

Future work should focus on addressing difficulties related to patient consent management, key management, and ease of use. However, in general, the created system offers a fundamental framework for exchanging medical data that focuses on the security, privacy, and ease of access for patients.

In order to strike a balance between innovation and ethics, decentralised solutions will play a crucial role as healthcare becomes increasingly collaborative and data-driven. This study showcases the significance of Distributed Ledger Technology in safely accessing medical data to enhance health outcomes.

The use of cloud technology is optimal for the development of billing OLTP systems.

The article proposes approximate algorithms for optimal data placement and mathematical models for optimizing the structure of a distributed database of a cloud system, taking into account the limitations on the amount of node memory, the available costs of renting cloud resources and the number of replicas of distributed database fragments, which differ from the existing ones in that they take into account the features of cloud computing technology:

- model for placing fragments of a distributed database in the network nodes of the cloud structure according to the criterion of maximizing the total value of fragment replicas;
- model of distributed database fragments placement in the network nodes of the cloud structure according to the criterion of minimum traffic price;
- model for placing fragments of a distributed database in the network nodes of the cloud structure by the criterion of minimum average data transfer.

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Системи обробки інформації, 2023, випуск 4 (175) ISSN 1681-7710


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ВПРОВАДЖЕННЯ ТА ОЦІНКА ДЕЦЕНТРАЛІЗОВАНОЇ СИСТЕМИ ОБМІНУ МЕДІЧНИМИ ДАНИМИ НА ОСНОВІ IOTA TANGLE ТА НАБЛИЖЕНИ АЛГОРИТМИ ОПТИМАЛЬНОГО РОЗМІЩЕННЯ ДАНИХ

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Розроблена модель обміну медичної інформації на основі IOTA Tangle та наступних алгоритмів оптимального розміщення даних, що забезпечує безпеку та централізовану процедуру обміну. Система використовує технологію розподіленого реєстру для збереження і передачі медичних даних. Співробітники системи безпеки та централізованої процедур обміну медичними даними з використанням технології розподіленого реєстру. Безпека платформи обміну даними сприяє впровадженню нових методів інформації та зберігання збільшення кошторис у реальному часі. Також, з використанням блокчейну OLTP-систем, які призначені для введення, структурованого зберігання та обробки медичної інформації в реальному часі, запропоновано використання IOTA Tangle - технології розподіленого реєстру.

Ключові слова: електронна система охорони здоров'я, техніка розподіленого реєстру, IOTA Tangle, технологія блокчейн, білінгова OLTP-система, цілочислове зв'язане програмування з вузькими змінними, розподілена база даних.