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Incentive Mechanism of Medical Data Sharing Based On Information Entropy in Blockchain Environment

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Abstract. With the rapid development and wide applications of information technology in the medical field, the data sharing of medical information has become one of the focus that has been received much attention by most researchers in recent years. At present, the scheme of data sharing based on blockchain has been becoming more and more mature, and it has the features of decentralized, secure and tamper-resistant to address the problem of data security in the process of data sharing, thereby improving the quality of medical service of citizens, reducing medical cost and cutting down medical risk. Obviously, information technology is not the main factor to hinder data sharing between medical institutions. Actually, the low enthusiasm of medical institutions was due to lack a comprehensive incentive mechanism of medical data sharing. Combining the medical field, this paper proposes an incentive mechanism of data sharing based on information entropy, which can effectively promote more medical institutions to participate in data sharing and enhance the enthusiasm of medical data sharing. Analyses show that the approach is efficient and effective.

1. Introduction

With the rapid development and wide application of information technology in the medical field, most hospitals have deployed medical information systems such as laboratory information system (LIS), electronic medical records (EMR) [1], which have realized the functions of information collection and storage of medical business data. Due to the widespread use of medical information systems, the potential sharing value of medical data has also attracted people's attention. Sharing data can support more medical research and improve the diagnosis of diseases [2]. By realizing the sharing of medical data between different hospitals, doctors can access all of a patient's electronic medical records in a short time, which not only helps medical staff to formulate optimal treatment plans, but also reduces unnecessary examination items for patients, thus reducing the cost of patients' treatment, improving the quality of medical service and reducing medical risks [3].

In recent years, the migration of medical records to cloud-based platforms has facilitated the sharing of medical data between hospitals and research institutions. The patient's data is stored on the cloud server by the medical institution, and the medical data is shared with other medical institutions through access rights. At present, there are many data sharing platforms based on cloud platforms, but there are still many problems in the process of sharing [5]. First of all, most medical data is electronic information that can identify an individual and contain personal privacy. If medical data is shared, it is bound to be accompanied by risks of disclosure of personal identity and privacy information [6, 7]. Second, the computing resources and storage of the cloud platform are provided by third-party providers [8, 9]. Once the shared data is separated from the cloud platform, the next user's operation on the data cannot be controlled [10]. The abuse of data has also become an important factor hindering the sharing of medical data. The development of blockchain technology has changed the pattern of medical data sharing. As a



distributed and verifiable public ledger, the blockchain has the characteristics of decentralization, trust, traceability, security [11], which can solve the above mentioned problems well. The blockchain guarantees the security and privacy of shared data [12-14].

It can be seen that technology is not the main factor restricting data sharing between medical institutions, especially for digital medical data, it is easier to share because of the convenience of delivery. Effective medical data sharing not only solves the problem of how to share, but also encourages more medical institutions to participate in medical data sharing. At present, many medical institutions join the medical data sharing system in order to obtain data that provided by others, they are not willing to share their own medical data. The main reason is that it is impossible to measure the contribution of a medical institution in data sharing, and data sharing cannot bring corresponding benefits to medical institutions [15]. Therefore, in order to encourage medical institutions to participate in data sharing, the most effective measure is to establish a medical data sharing incentive mechanism to balance the benefits and resources shared by each medical institution. Considering the above mentioned problems, an incentive mechanism of medical data sharing is proposed, which adopts blockchain technology to protect the security and privacy of medical data, and information entropy is used to quantify the value of medical data. After quantifying the value of the data, the data value can be converted into the value of points, and the medical data provider and the consumer can trade by this points. In the later stage, the points can be transformed into other interests, thereby encouraging the medical institution to share the medical data.

2. Formatting the Title, Authors and Affiliations

The blockchain concept originated from a paper "Bitcoin: A peer to peer electronic cash system" published by Satoshi Nakamoto in Bitcoin Forum in 2008, which is one of the underlying support technologies of Bitcoin. The article describes in detail how to establish a new, decentralized trading system that does not require a trust foundation. Its achievability has been proven by Bitcoin, which has been in operation since 2009. In recent years, there have been many more comprehensive elaborations of the concept of blockchain in the academic field. For example, Decker et al. pointed out that the blockchain is derived from the distributed technology of Bitcoin. It is an open ledger system based on bitcoin protocol in which different nodes participate together. It is a new application mode of computer technologies such as mass data storage, decentralized terminal transmission and crypto cryptography [16]. After several years of development and improvement, the blockchain has gradually become a new technology with decentralization, trustworthiness and high reliability [17]. The blockchain has gradually separated from Bitcoin, which has become a hot spot for technological innovation and has created a new data distribution storage technology.

The unique advantages of blockchain bring new ideas to data sharing. The application of blockchain technology to data sharing has significant research significance and real economic value, especially medical data containing personal privacy. First of all, the blockchain uses timestamp technology to add a time dimension to medical data. Blockchain records the sequencing of shared medical data for ease of monitoring and tracking. Secondly, asymmetric encryption technology encrypts data to ensure the security of medical data. Finally, medical institutions conduct transactions in an anonymous manner, which greatly protects the privacy of patients. A medical data sharing incentive mechanism is proposed, which adopts blockchain technology to protect the security and privacy of medical data, and information entropy is used in this mechanism to quantify the value of medical data in the diffusion process.

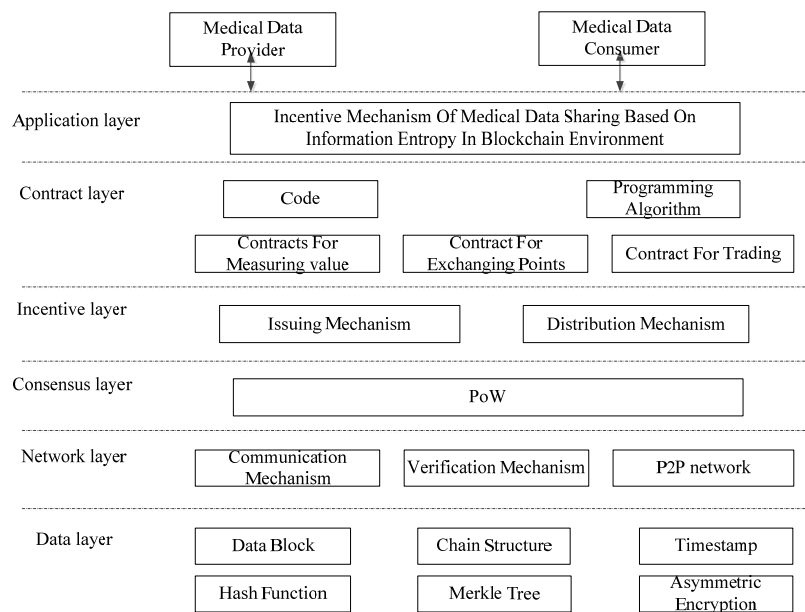


Figure 1. Figure with the platform frame of this paper

3. Blockchain Data Sharing Incentive Method Based on Information Entropy

Currently, blockchain has drawn wide attentions as a kind of decentralized, distributed and public digital ledger. It is used to record transactions across many computers so that the record cannot be altered retroactively without the alteration of all subsequent blocks and the consensus of the network. Aiming to enable medical data sharing and finally facilitate medical institutions to participate as far as possible, the paper introduces blockchain into data sharing. A mechanism for sharing medical data, supporting data trades is proposed. Information entropy is used to quantitatively measure the value of medical data in the process of dissemination in this mechanism, and the medical institutions trades according to this value. The blockchain technology is use to protect the right and privacy of medical data owners, and the mechanism also proposes an incentive mechanism for data sharing to ensure that data providers gain revenue after sharing medical data ,thereby motivating participants to sharing more data.

3.1. Measuring the Value of Medical Data Based on Information Entropy

In the data sharing process, participants would prefer to get data through shared platform rather than share their own data. Therefore, the most effective way for participants to share their own data is to establish incentive mechanism. First, we must accurately measure the contribution of the participants to the data sharing platform by using the incentive mechanism, and then give corresponding rewards to participants according to this contribution. At present, in many existing incentive mechanism, participants were rewarded based on the size of the data they uploaded, or were gained different services based on the size of the data they uploaded [18]. Problems caused by such incentives are participants in order to get more rewards or better services, shared unpopular or useless files, and the quality of the data cannot be guaranteed. In view of the present situation, we'll have to propose new methods. We propose an incentive mechanism for medical data sharing based on information entropy and blockchain, which ignores the size of the data and the rewards obtained by the participants are determined by the information entropy of the medical data. On the one hand, the mechanism improves the enthusiasm of data sharing, and on the other hand guarantees the availability of shared data content.

Entropy, an idea inherited from thermodynamics, a very important notion for measuring uncertain information, has received great attention in the past decades. The concept of information entropy is proposed by Shannon in 1948. The smaller the amount of information contained in a variable, the higher its uncertainly and the greater its entropy and this variable is also difficult to explain.

Suppose X is a discrete information source, which is a random variable whose element set is $X = \{x_1, x_2, \dots, x_k\}$. Given element x_1, x_2, \dots, x_k occurring with probabilities p_1, p_2, \dots, p_k . The information

amount $I(x_i)$ of the element is the logarithm of the reciprocal of the probability p_i in which it appears, it is defined as:

$$I(x_i) = \log \frac{1}{p_i}, \text{ and } \sum_{i=1}^k p_i = 1, (i = 1, 2, \dots, k) \quad (1)$$

As can be seen from the expression of the amount of information, the amount of information of element (x_i) may be inversely proportional to the probability of its occurrence. And the average amount of information can be measured from the perspective of mathematical expectation, which can be defined as the information entropy $H(X)$ of the information source:

$$H(X) = E[I(x_i)] = - \sum_{i=1}^k p_i \log p_i, (i = 1, 2, \dots, k) \quad (2)$$

In the above definition, i is the serial number of information, p_i is the probability of information i appeared, and $\sum_{i=1}^k p_i = 1$. This formula represents the average amount of information provided by each message after the information source is output. In general, the higher the probability that a information appears, the more widespread it is spread, or the richer the information content. We can think that from the perspective of information transmission, information entropy can represent the value of information and can be used as a standard to measure the value of information.

Measure the value of medical data as a basis for transactions between producers and consumers of medical data. Combining the theory of information entropy, this paper uses the information entropy of medical data as a measure of the value of the medical data. It is assumed that H is the information entropy of medical data, N is the medical institution participating in data sharing in the blockchain, D is one of the medical data, and abstracts all the medical data participating in the sharing into one data set S .

For the data set S with m medical data, the information entropy of a piece of medical data D_i is:

$$H(D_i) = - \sum_{i=1}^m p(D_i) \log p(D_i), (i = 1, 2, \dots, m) \quad (3)$$

In the above formula, D_i represents the i -th medical data in the data set S , $H(D_i)$ represents the information entropy of the medical data D_i , and $p(D_i)$ represents the probability of occurrence of the i -th data in the medical data set S . The information entropy of medical data is quantitatively measured by formula (3). According to the analysis of information entropy theory, it is not difficult to see that the value of medical data is inversely proportional to the information entropy, that is, the higher the frequency of medical data, the lower the information entropy, and the higher the value of medical data. Supposing $P(D_i)$ is the value of the data. As shown in formula (4):

$$P(D_i) = \frac{1}{H(D_i)} \quad (4)$$

3.2. Exchanging Points

In the above method, if the frequency of a certain medical data can be obtained, the information entropy of that medical data can be calculated and the value of medical data can be measured in this way. In the incentive mechanism proposed in this paper, the data transaction parties trade according to the points, and the data value needs to be converted into transaction points. In the later stage, points can be converted into other benefits through other means, so as to encourage medical institutions to share medical data in this way. The value of the medical data is mapped to obtain the corresponding points, assuming that the points are represented by C . As shown in formula (5):

$$f: P(D_i) \rightarrow C \quad (5)$$

When medical institutions use medical data provided by other institutions, the information entropy of the data is first calculated according to formula (3). After information entropy is obtained, information entropy is converted into medical data value according to formula (4). According to (5), the points that need to be paid for using the medical data are calculated, and the medical data producer and the user perform the transaction through the points.

3.3. The Process of Incentivizing Data Sharing

Medical institutions need to record patient data and upload data according to predefined formats. The consensus node broadcasts the medical data, and after obtaining more than 50% of the network node verification, the newly generated medical data is written into the blockchain, and finally the block information is returned to the medical data provider. The format of the data we define is shown in Table 1. There are three types of data in this mechanism, summary data, transaction data and complete medical data. Due to the limited storage capacity of the blockchain, the complete medical data is stored in the cloud storage under the chain, and only the transaction data and summary data are retained in the blockchain.

Table 1. The table of data format

type of data	Attributes	Meaning of attributes
Summary data	Hash values for patient ID	Used to uniquely tag the medical data owner, such as personal identification ID, name, mobile phone number, etc.
	Hash values for medical data	The medical data provider will use a hash function to get a hash value for a complete medical data, used as a digital signature.
	Timestamp	Used to indicate the time of medical data generation.
	The address of the data access	The medical data provider records the address where the data provided is stored.
	Version	Because the same raw data provided by the medical data provider changes over time, the version number is used to distinguish.
	Signature of the data provider	Equivalent to the Bitcoin wallet address, used to uniquely identify the data provider on the platform;
	The ID of the data provider	Used to uniquely identify the medical data provider with in the platform;
Transaction data	The ID of the data consumer	Used to uniquely identify the medical data consumer within the platform;
	Hash values for medical data	The medical data provider will use a hash function to get a hash value for a complete medical data, used as a digital signature.
	The timestamp of transaction	Time of the transaction
	Trade points	The information entropy is used to calculate the value of the medical data, Points that data consumers need to pay when using data
	Signature of the data provider	Equivalent to the Bitcoin wallet address, used to uniquely identify the data provider on the platform;
	Signature of the data consumer	Equivalent to the Bitcoin wallet address, used to uniquely identify the data consumer on the platform;
	Hash values for patient ID	Used to uniquely tag the medical data owner, such as personal identification ID, name, mobile phone number, etc.
Medical data	Time to store data	
	The ID of the data provider	Used to uniquely identify the medical data provider with in the platform;
	Hash values for patient ID	Used to uniquely tag the medical data owner, such as personal identification ID, name, mobile phone number, etc.

When the medical data consumer needs a patient's medical record, he first queries the data layer of all nodes in the blockchain according to the unique index of the patient. The node returns the queried record and the points that need to be paid for using the record to the medical data consumer. The consumer sends an access request according to interface obtained in medical record. After the medical data provider receives the request to access the data, after the data provider obtains request to access the data, the provider counts the frequency at which the data appears in all transactions, and the provider

also needs to calculate the value of the medical data, and then convert the value into transaction points. Finally, the provider generates a smart contract that includes complete data, transaction points, signatures, etc., and then sends the smart contract to the consumer. The consumer confirms the points that need to be paid to the data provider, and the smart contract is signed with the private key and then posted to the blockchain network. When the medical data provider and the user agree to the transaction, the transaction data is generated in a predefined format, and the transaction data is published to the blockchain network. All nodes of the whole network selected to do consensus verify the transaction data, when nodes achieve consensus on this transaction, the transaction information is written into the block. At this point, the smart contract function is invoked, and the points to be paid are automatically transferred from the consumer account to the corresponding medical data provider, and the medical data requester obtains complete medical data and the transaction is completed.

4. Evaluation

4.1. Methods to Evaluate

This part analyses the method proposed in this paper from the aspects of permission protection, privacy protection and so on, and compares it with the existing research results to comprehensively evaluate the method. The results of the evaluation are shown in table 2

Table 2. The results of the evaluation

	Privacy protection	Rights protection	backtracking	Facilitating data sharing
Data sharing method in cloud environment [4]	Weaker	Weaker	Weaker	Weaker
BBDS[12]	Stronger	Stronger	Stronger	Weaker
The method proposed in this paper	Stronger	Stronger	Stronger	Stronger

From the above four aspects to evaluate the method proposed in this paper, we can see that the method has certain advantages as a whole.

4.2. Advantages of Method

Using the method evaluation in the previous section, combined with the current problems in medical data sharing, comprehensive analysis of the advantages and impacts of the proposed method.

- Protecting patient privacy: On the one hand, both sides of the medical data transaction participate in the transaction in the blockchain in an anonymous manner. On the other hand, the patient's medical data is encrypted and stored in the cloud storage under the chain, and only the summary information of the medical record is saved in the blockchain. Therefore, the method proposed in this paper protects the privacy of patients.
- Guaranteeing the rights of the data provider: Blockchain not only can provider user a trustworthy and reliable environment, but also the rights and interests of data providers can be guaranteed. That's to say the data transactions can't change the data ownerships. At the same time, the contributions of participants in data sharing can also be evaluated using transaction records.
- Facilitating data sharing: The incentive mechanism of medical data sharing is proposed to ensure that data providers can obtain benefits after sharing medical data, and to encourage participants to actively share more data.
- Guaranteeing the availability of data content: The incentive mechanism proposed in this paper does not consider the size of the data, and the points paid by the consumers are determined according to the information entropy of the medical data.

5. Related Work

The direct purpose of the incentive mechanism is to mobilize the enthusiasm of the data sharing participants. Any useful data sharing scheme needs to incorporate an incentive or reputation mechanism

to encourage users to cooperate for effective information sharing [21] [22]. We summarize and analyze the current research results on incentive mechanisms and find that they have a common guiding principle. The ability of the participants to enjoy the service is determined based on the contributions made by the participants. In other words, the less contribution of the participant, the weaker his ability to enjoy the service [23]. This is consistent with the idea of incentive mechanism proposed in this paper. At present, a large number of scholars have proposed many incentive mechanisms for different application scenarios to encourage effective data sharing among participants, especially in the context of P2P data sharing, the incentive mechanism has been widely used [24]. Existing incentives can be divided into the following categories: payment-based incentives [22, 26], reputation-based incentives [26-28], and differential service-based incentive scheme [29, 30].

The payment-based incentive mechanism is to imitate economic activities in the market in real society, using a virtual currency to stimulate data sharing between participating entities [31]. In the method based on payment [25], the author analysed the free-rider problem in the traditional P2P network. In order to solve this phenomenon, a micro-payment mechanism is proposed, in which each user can be rewarded for uploading data, and the user can use these rewards to download the required data in the later stage. In addition, the author construct a formal game theoretic model of the system and analyse equilibria of user strategies under several novel payment mechanisms, that is, the resources obtained by the user from the system are balanced with the resources contributed by the users. Wu, T., et al., by considering users' bandwidth, computing power and the contributions of the sharing platform, they proposed system architecture gives users corresponding counters, which are stored and managed by the server. Users can use their counters to participate in the auction and bid on the admission of high-quality resources [22].

The reputation-based incentives rely on the historical of participant's contribution to data sharing. The overall reputation of the participant refers to the comprehensive evaluation of other participants who have interacted with each other. Reputation of peers is proportional to their overall resource contribution, and peers with higher reputation are rewarded with better performance. The participants are allowed to download files only from others with a lower or equal reputation [32]. This incentive mechanism motivates participants to increase their reputation by continuously contributing to the system in order to gain access to more files. Liang et al. used a trust agent stored in a P2P network to calculate a participant's reputation. However, this scheme needs a secure and reliable agents for maintaining the reputation of participants, and such an agent can be expensive to operate.

The strategy of differential service-based incentive scheme is to provide each participant with a different quality of service. The quality of the service that the participant gained depends on his contribution and the amount of resources in the system [19]. Bit Torrent [33] adopts differentiated service scheme, and has become one of the most popular P2P file-sharing software. The strategy of this scheme is to encourage nodes to be seed nodes. The more upload services provided by nodes, the more priority the download service can enjoy. Richard TB et al. proposed that different services can be provided to nodes according to their services and contributions in the network. The purpose is to implement differentiated services based on the number of services provided by nodes, so as to motivate all nodes to share resources. However, there is an unfair phenomenon in the differentiated service scheme, because of it does not take into account nodes with poor service capabilities.

Therefore, payment-based incentives mechanism shows its advantages in motivating participants to share resources. Participants earn points or virtual currency by sharing resources, which are converted into other benefits through certain ways. At present, most payment-based incentive schemes determine the points that participants receive according to the number of sharing files or the size of participants' shared files. However, in this scheme, the availability of file's content shared by participants is unpredictable. In order to increase more points, enforce participates share a certain amount of files when they are downloading. However this may lead to share unpopular or even useless files, as a result others will not download files from them. The incentive mechanism proposed in this paper does not consider the size of the data, and the points paid by the consumers are determined according to the information entropy of the medical data. Therefore, in order to gain widely dissemination, data providers control the availability of data content, which largely solves the problem of maliciously sharing data.

6. Conclusion And Future Work

In this paper, an incentive mechanism of medical data sharing based on information entropy in a blockchain environment is proposed. In this mechanism, the blockchain is used for data sharing, blockchain is used for data sharing to ensure medical data encryption and non-tampering, which can protect the rights and privacy of medical data owners;

Considering the unique application value of blockchain and information entropy in the incentive mechanism of medical data sharing, and combining different data sharing applications, this paper will extend its application to other data sharing incentives.

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