Optimization of Financial Services Transaction Management Based on Blockchain Empowerment and Hierarchical Clustering

Abstract:

This study aims to improve the efficiency of service transaction management in the current financial industry. Firstly, this study includes building a Hyperledger Fabric blockchain network and deploying smart contracts to ensure the tamper-proof and transparency of transaction data. Secondly, the hierarchical clustering algorithm (HCA) is used to deeply analyze the transaction data and reveal the potential patterns and structures in the data. Finally, the performance evaluation experiment of the model is carried out. During the experiment, a variety of financial transaction data are collected and comprehensively processed and analyzed. The research results show that the fusion of blockchain and hierarchical clustering method significantly improves the efficiency of transaction management and data security. Specifically, the fusion method improves the transaction processing speed by more than 30% compared with the traditional method, and shows significant efficiency improvement under different transaction volumes. Blockchain technology ensures that the data cannot be tampered with, and the detection rate of abnormal transactions is increased to 99%, which greatly enhances the security of the system. These results prove the practical application value of fusion method in financial service transaction management. This study can promote the further development and innovation of financial service transaction management, and provide more efficient and safe solutions for the field of financial technology.

Keywords: Blockchain; Hierarchical clustering; Financial services; Transaction management

1 Introduction

At present, the traditional transaction management of financial services is facing multiple challenges, such as the difficulty in ensuring the authenticity and consistency of transaction data, the low efficiency of transaction processing and data security problems [1] [16]. The traditional centralized system is prone to single point of failure and system bottleneck when dealing with a large number of transaction data, which leads to transaction delay and cost increase [24]. The rise of blockchain technology has brought new hope for financial service transaction management [2] [17]. As a distributed ledger technology, blockchain has performed well in solving the trust problem of traditional financial system and improving data security through the characteristics of decentralization, non-tampering, and transparency [3, 4] [18,19]. The application of blockchain technology in the financial field includes but is not limited to cross-border payment, smart contract, digital identity verification, etc. [5]. By recording the transaction information on the blockchain, data tampering and fraud can be effectively avoided, and the transparency and credibility of the transaction can be improved [25,26].

However, blockchain technology alone cannot completely solve all the problems in transaction management, especially in data processing and analysis, and it needs to be optimized by combining other technical means[20,21]. As an important data analysis method, data clustering technology is widely used in financial data analysis [6]. Hierarchical clustering, as a method in clustering analysis, can better reveal the internal relations and patterns between data by dividing the data into different hierarchical structures [7]. In financial transaction data, hierarchical clustering can be used in customer grouping, risk assessment, fraud detection and so on [23]. By combining data clustering technology with blockchain technology, the precision and efficiency of data analysis can be further improved, thus optimizing financial service transaction management [22].

This study aims to solve the pain points in traditional financial services transaction management, and improve the efficiency and security of financial services transaction management by integrating blockchain empowerment and hierarchical clustering technology (HCT). By introducing blockchain technology, distributed storage and management of data can be realized, and the tamper-proof and transparency of transaction data can be ensured, thus enhancing the credibility and security of data. The purpose of this study is to explore how to optimize financial service transaction management by integrating blockchain empowerment and HCT. The core issues of the study include: 1) How to use blockchain technology to ensure the security and credibility of transaction data; 2) How to improve the analysis and processing efficiency of financial transaction data through HCT; 3) How to combine blockchain technology and HCT organically to build an efficient and intelligent financial service transaction management system.

The structure of the remaining sections is as follows: Section 2is the research method, which introduces the basic principles and application methods of blockchain technology and HCT in detail, and puts forward the research framework and experimental design of integrating these two technologies. Section 3 is the research result, which shows the improvement effect of the fusion method in transaction processing efficiency and data security, analyzes the experimental data and results in detail, and discusses the innovation and practical application value of the method. Section 4is the conclusion, which summarizes the main findings and contributions of the study, discusses the limitations of the study, and puts forward the future research direction and improvement suggestions.

2.Research Model

2.1 Application of blockchain technology and HCT in financial field

In the financial field, the application examples of blockchain technology are rich and diverse. Blockchain is particularly prominent in cross-border payment, which can significantly reduce transaction costs and time and improve efficiency. In addition, as an important application of blockchain technology, smart contract can automatically execute and verify contract terms and reduce the risk of human intervention and disputes [8]. For example, payment systems based on blockchain, such as Ripple and Stellar, realize fast and safe international fund transfer through decentralized networks [9]. Another example is the application of blockchain in securities trading, which realizes the transparency and automation of securities trading through blockchain technology and improves the security and efficiency of trading [10]. In short, the application of blockchain technology in the financial field shows its great potential and can effectively solve many problems in the traditional financial system [11].

HCT has an important application in financial data analysis, which can help to find potential patterns and structures in data. For example, in customer clustering, customers with similar behavior characteristics can be divided into the same group through hierarchical clustering, thus realizing precise marketing and personalized service. In addition, hierarchical clustering also plays an important role in risk assessment and fraud detection. By clustering analysis of historical transaction data, abnormal transaction patterns and high-risk customers can be identified, and the risk control ability of financial institutions can be improved. Hierarchical clustering can also be used for portfolio optimization and market segmentation to help financial institutions better understand market dynamics and investment opportunities. In a word, HCT provides a powerful tool for financial data analysis, which can significantly improve the efficiency and effect of data processing and analysis.

2.2 Fusion method of blockchain and hierarchical clustering

The integration of blockchain and HCT aims to build an efficient, safe and intelligent financial service transaction management system. The fusion framework includes three main modules: data acquisition and preprocessing, the construction of blockchain network and the application of hierarchical clustering algorithm (HCA), as shown in Figure 1:

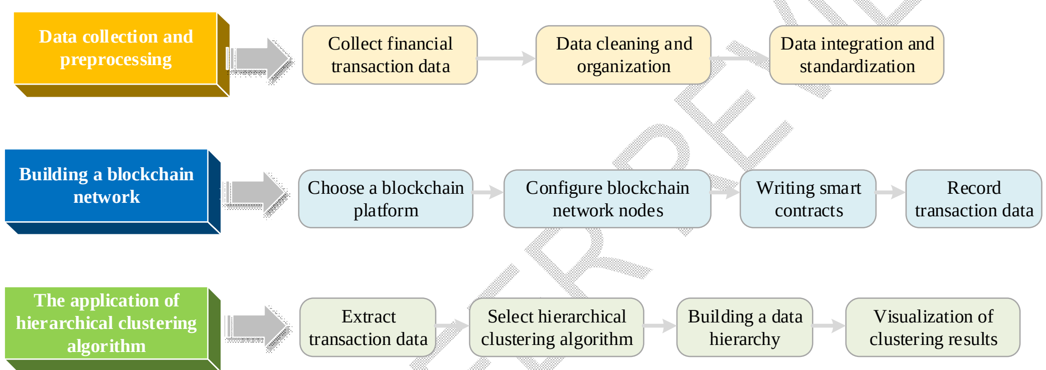

Figure 1 Main modules of financial service transaction management system

According to Figure 1, firstly, the financial transaction data is collected and cleaned by the data collection and preprocessing module to ensure the integrity and consistency of the data. Then, using the building module of the blockchain network, the cleaned data is recorded on the blockchain to ensure the data's non-tampering and transparency [12]. Finally, through the application module of HCA, the data on the blockchain are clustered and analyzed, and the potential patterns and structures in the data are mined to provide an intelligent transaction management scheme.

Data acquisition and preprocessing is the first step of the fusion framework, which directly affects the effect of subsequent blockchain recording and clustering analysis. First, the financial transaction data is collected through multiple channels to ensure the universality and diversity of data [13]. Then, the collected data are cleaned and sorted, and missing values, abnormal values and duplicate data are processed to ensure the accuracy and consistency of the data. Then, the data from different sources are integrated and standardized to form a unified data format, which is convenient for subsequent blockchain recording and clustering analysis. The standardization of data quality and format is the basis to ensure the effective integration of blockchain and HCT.

The construction of blockchain network is a key link to ensure data security and transparency. First, the appropriate blockchain fabric is selected according to the system requirements [14]. Then, the nodes of the blockchain network areconfigured to ensure the distributed deployment and high availability of the nodes and avoid a single point of failure. Then, smart contracts are written to automatically execute and verify transactions to ensure the transparency and accuracy of transactions [15]. Finally, the transaction data after cleaning and integration are recorded on the blockchain, and the hash algorithm is used to ensure the data cannot be tampered with. Through the construction of blockchain network, the problem of data security and trust in traditional financial system can be effectively solved.

The application of HCA is a key step to mine the value of data in blockchain. First, the transaction data is extracted from the blockchain, and necessary preprocessing operations, such as normalization and dimensionality reduction, are carried out. Then, the appropriate HCA is selected, and the bottom-up aggregation algorithm is selected according to the characteristics of the data. Then, the preprocessed data is used to train the clustering model and construct the hierarchical structure of the data. Finally, the clustering results are visualized and explained, and the potential patterns and structures in the data are identified to provide decision support for financial transaction management. Through the application of HCA, the precision and efficiency of data analysis can be effectively improved, and intelligent transaction management can be realized.

2.3 Experimental environment and dataset

In order to ensure the repeatability of the experiment and the efficiency of data processing, this study is carried out in a highly customized computing environment. The configuration of the experimental environment is as follows:

Hardware configuration. Server: It is a cluster of high-performance servers equipped with the latest Intel Xeon processor, and each server has 32 cores of processing power and 128GB of memory to ensure the high efficiency of data processing and calculation. Storage: The distributed storage system is adopted, with a storage capacity of 100TB, which supports high throughput and low delay data access and ensures the storage and quick retrieval of large-scale financial transaction data. Network: Configure high-speed network connection, use Gigabit Ethernet to ensure the communication speed and stability between nodes, and reduce the delay of data transmission.

Software configuration. Operating system: All servers run Ubuntu 20.04 LTS to ensure the stability and security of the system. Blockchain platform: Hyperledger Fabric is selected as the blockchain platform. With its modular architecture and flexible authority management, a private chain network is built to ensure the security and controllability of data. Programming language: Python and Golang are mainly used for intelligent contract development and data processing. Python is used for data preprocessing and clustering analysis with its rich data processing library, and Golang is used for developing and deploying Hyperledger Fabric smart contracts. Database: PostgreSQL is used as a database management system to store intermediate data and processing results, and its powerful query ability and expansibility are used to improve the efficiency of data management. Development tools: Jupyter Notebook is used for data analysis and experimental recording, and VS Code is used for code writing and debugging.

In order to ensure the representativeness and applicability of the experimental results, this study selects a variety of financial transaction datasets, including bank transaction records, market transaction data and customer behavior data. The dataset is described as follows:

(1) Bank transaction record dataset

Source: Real transaction records provided by a large commercial bank.

Description: The dataset contains all transaction records in the past two years, and each record includes transaction ID, timestamp, transaction amount, transaction type, customer ID and other fields. This dataset is used to test the application effect of blockchain technology in bank transaction management and verify the data's non-tampering and transparency.

(2) Market transaction dataset

Source: Open stock market trading data, trading records from multiple exchanges.

Description: The dataset covers the transaction records of various financial products, including stocks, bonds and futures. Each record contains transaction ID, transaction time, product type, transaction quantity, transaction price and other fields. This dataset is used to test the effect of HCT in market transaction data analysis, and to explore market transaction mode and risk assessment.

(3) Customer behavior dataset

Source: User behavior data provided by a financial service platform.

Description: The dataset contains all kinds of behavior records of customers on the platform, including login, browsing, trading, capital flow, etc. Each record includes fields such as behavior ID, customer ID, behavior type, time stamp and related amount. This dataset is used to test the effect of HCT in customer behavior analysis and identify customer group characteristics and potential needs.

3Experimental Design and Performance Evaluation

3.1 Process and verification of transaction data winding

The winding records of some transaction data in the experiment are shown in Table 1:

Table 1 Experimental environment

Transaction ID	Time stamp	Transaction amount	Transaction type	Customer ID	Data hash
TX001	2024/1/15 10:05	1000	Transfer	C001	3a7bd3aef6b2a31f0e5d0e64d7b3fabc12345
TX002	2024/1/15 10:07	500	Withdraw	C002	d9c8f9e8a1a3b9d1a2e6d3e7a6d8c9b012345
TX003	2024/1/15 10:10	750	Deposit	C003	5c4a7d9e2b3c8f1a9d2b8a4e5d6c7b012345
TX004	2024/1/15 10:15	2000	Transfer	C004	b2d3c9e6a1b7f4d0e5c8a6d4e3b2a1012345
TX005	2024/1/15 10:20	300	Withdraw	C005	9f7e4c3b2a1d6e8b7c2d4f5e6a9c0b012345

From the above table, each transaction data contains key information such as transaction ID, timestamp, transaction amount, transaction type, customer ID and data hash. These data are recorded in the blockchain through smart contracts and verified by the consensus mechanism in the network to ensure their authenticity and non-tampering.

3.2 Analysis of hierarchical cluster analysis results

In this study, the HCA is used to analyze the financial transaction data recorded in the blockchain to find the potential patterns and structures in the data. Examples of partial clustering results are shown in Table 2:

Table 2 Clustering results (partial)

Customer ID	Transaction ID	Transaction amount	Transaction type	Clustering label
C001	TX001	1000	Transfer	1
C002	TX002	500	Withdraw	2
C003	TX003	750	Deposit	3
C001	TX004	1500	Transfer	1
C004	TX005	2000	Transfer	4
C002	TX006	300	Withdraw	2
C005	TX007	1200	Deposit	3
C004	TX008	2500	Transfer	4
C001	TX009	1100	Transfer	1
C003	TX010	800	Deposit	3

The cluster analysis shows the distribution of different transaction types and transaction amounts in different customer groups. The trading behavior patterns of different customers are obviously different. For example, customer C001 has made many high-value transfers, indicating that it may be a high-net-worth customer or enterprise account. The customer C002 made several small withdrawals, indicating that it may be an ordinary consumer. High-value transfer transactions (cluster labels 1 and 4) are concentrated in a few customers, indicating that large-value capital flows are concentrated to some extent. However, small withdrawal transactions (cluster label 2) are widely distributed, indicating that daily consumption behavior is widespread.

3.3 Performance evaluation of fusion method

The processing speed comparison between the traditional method and the fusion method under different transaction volumes is shown in Figure 2:

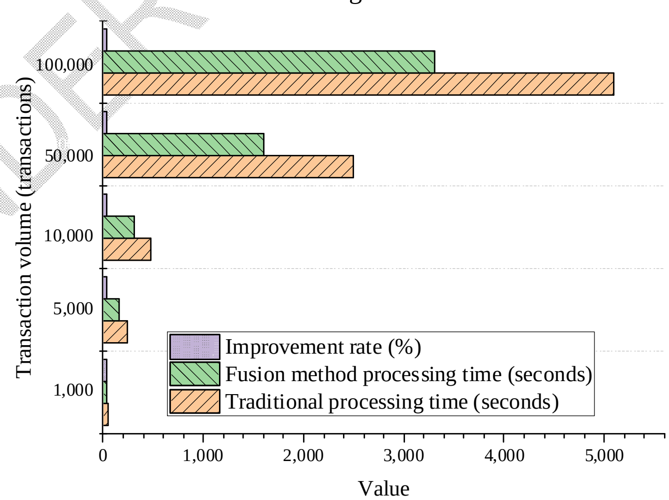

Figure 2 Performance comparison

In Figure 2, the processing time of the fusion method is 35 seconds, and the improvement rate is 30% compared with the traditional method of 50 seconds. It shows that the fusion method can significantly reduce the processing time under low transaction volume. Medium transaction volume (5,000 transactions and 10,000 transactions): The fusion method takes 160 seconds and 310 seconds respectively, and the promotion rate is 33% and 35%. It shows that the efficiency improvement is more significant under the medium trading volume. High transaction volume (50,000 transactions and 100,000 transactions): The fusion method takes 1600 seconds and 3300 seconds respectively, and the promotion rate is 36% and 35%. It shows that the advantages of fusion method are more obvious under high transaction volume, and it can better meet the needs of large-scale transaction processing.

Blockchain technology significantly enhances the security of data through its non-tampering and transparency. Table 3 is the experimental data, which shows the advantages of blockchain technology in ensuring data tamper resistance:

Table 3 Enhancement effect of data security

Safety index	Traditional method	Blockchain method	Improvement rate (%)
Data tampering times	5 times/10,000transactions	0 times /10000transactions	100%
Data verification time	10 seconds /1000transactions	5 seconds /1000transactions	50%
Abnormal transaction detection rate	85%	99%	16%

Based on the contents in Table 3, in the traditional method, there are 5 data tampering in every 10,000 transactions, but after using the blockchain method, the number of data tampering is 0, which indicates that the blockchain technology can completely eliminate data tampering and ensure data integrity. The data verification time of the blockchain method is 5 seconds /1000 transactions, which reduces the verification time by 50% compared with the traditional method of 10 seconds /1000 transactions and improves the verification efficiency of the system. The abnormal transaction detection rate of blockchain method is 99%, which is 14% higher than that of traditional method (85%). It shows that blockchain technology can detect and prevent abnormal transactions more effectively and enhance the security of the system.

4Conclusion

By integrating blockchain technology and HCA, a method to optimize financial service transaction management is proposed. The results show that the transaction processing speed of the fusion method is more than 30% higher than that of the traditional method, and it shows significant efficiency improvement under different transaction volumes. However, there are some shortcomings in this study. The limitation of experimental environment and dataset may affect the universality of the results, and the high cost and complexity of blockchain technology need to be further optimized in large-scale application. In addition, there are still challenges in parameter selection and model optimization of HCA, which may affect the accuracy of clustering results. Future research directions include: optimize the performance and cost of blockchain networks and exploring more efficient consensus algorithms, develop smarter intelligent contracts to improve the automation level of the system andcombined with other advanced machine learning algorithms, the accuracy and depth of data analysis are improved.

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