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Cross-chain asset trading scheme for notaries based on edge cloud storage

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Abstract

Blockchain has penetrated in various fields, such as finance, healthcare, supply chain, and intelligent transportation, but the value exchange between different blockchains limits their expansion. Cross-chain technology, such as notary mechanism, enables asset exchanges between different blockchain networks. However, existing research still confronts problems such as single inherent value evaluation, collusion risk, credit evaluation and unreasonable resource allocation, making it difficult to ensure the security of cross-chain asset transactions. So this paper proposes a cross-chain asset trading scheme based on edge cloud storage to improve the reliability of notaries and the security of cross-chain value exchange. Firstly, introduce the entropy weight method to determine indicators and adopt multi indicator evaluation to reduce the risk of collusion between notaries and users; Secondly, design a multi-indicator credit evaluation method to improve the accuracy of the evaluation; Finally, design a new and old notary node share allocation method to improve the rationality of resource allocation.The experiment shows that the scheme designed in this paper can reduce the risk of collusion, more accurately screen out high credit nodes to act as notaries, and make resource allocation more reasonable.

Keywords Blockchain, Cross-chain technology, Notary mechanism, Credit evaluation, Entropy weight method

Introduction

Blockchain technology has been widely applied in various fields such as finance, healthcare, supply chain, and intelligent transportation. But with the development of blockchain, information silos have formed between blockchains, and the transfer of value between blockchains has become an urgent problem to be solved. However, blockchain technology is greatly limited by differences in blockchain architecture, data structures, interface protocols, consensus mechanisms, and other aspects, which greatly hinder the development of blockchains [1] and hinder the data flow and value exchange between different blockchains.Therefore, studying the cross-chain technology of blockchain has important research significance.

Many scholars have proposed cross-chain technology to achieve data flow and value exchange between different blockchains. The current cross-chain technologies mainly include notary mechanism [2], sidechain technology [3], hash locking technology [4], and distributed private key control technology [5].

Cross-chain technology was first proposed by Ripple [6] as a cross ledger interoperability solution, aimed at achieving cross ledger transfers through a third-party notary mechanism. Nolan [7] proposed the idea of "Atomic Transfers" at the Bitcointalk forum, which formed the initial technical solution for cross-chain transactions of atomic exchange digital assets. Dilley J. et al. [8] introduced a publicly verifiable Byzantine style strong federal trading network that promotes the flow of assets between different markets. Wood G. [9] proposed the Polkadot project and published a white paper supporting cross-chain asset interaction across different

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consensus systems. Herlihy M. et al. [10] [11] proposed an atomic exchange cross-chain protocol based on hash time locking mechanism, which represents the transfer of cross-chain assets through directed graphs and proposes an atomic exchange cross-chain protocol. Shadab N. et al. [12] proposed a universal unified protocol for cross-chain transactions to address the issue of both parties deviating from the protocol and the absence of a unified protocol. Zhu Y. et al. [13] proposed a new language design for asset driven specific smart contracts to address the issue of insufficient asset representation and operation in smart contracts. Although the above studies have all achieved cross-chain asset transfer, they have overlooked issues such as transaction security, efficiency, and data storage.

Cai J. et al. [14] proposed a cross-chain asset transaction privacy protection scheme based on Pareto homomorphic encryption (PTLC) to address the issue of identity privacy information leakage in the Hashed Timelock Contract (HTLC) algorithm. Han S. et al. [15] proposed a new digital asset security trading scheme based on blockchain technology to address the security issues during data asset trading. Pillai B. et al. [16] proposed a claim based cross blockchain protocol for the security and correctness of transaction processes to complete asset exchange between blockchains. Wang Z. et al. [17] proposed a cross-chain transaction model that includes a quantum multi signature notary mechanism and an asset quantum freezing algorithm to address the issues of insecure and insufficient protection against quantum attacks in classical blockchain authentication. Although the above studies can ensure the security of cross-chain asset transfer, they overlook issues such as transaction efficiency and data storage.

Jiang C. et al. [18] proposed a cross-chain interaction security model based on notary groups to address issues such as centralized node functions and low efficiency in the notary mechanism. Liu W. et al. [19] proposed a secure and efficient interaction protocol for cross blockchain transfer processes, addressing the issues of centralized functionality, difficult collaboration, and low efficiency in existing cross blockchain solutions. Although the above research can ensure the security and efficiency of cross-chain asset transfer, it overlooks issues such as the credibility of notaries and data storage.

Wang G. et al. [20] proposed a decentralized data caching strategy in mobile edge computing environment in order to ensure the security of data caching in mobile edge computing environment. Kang J. et al. [21] proposed a reputation based data sharing scheme to ensure high-quality data sharing between vehicles, aiming at the problem that edge computing servers are not fully trusted. Zeng F. et al. [22] proposed an efficient caching mechanism for on-board edge computing based on edge cloud collaboration for effective data caching and access. Li W. et al. [23] proposed an efficient storage resource collaboration model to address the difficulty of storing massive amounts of data. The above research realizes the secure and limited storage of data through the edge computing environment or edge cloud, providing a new solution for the data storage of cross-chain asset transactions.

Li F. et al. [24] proposed that the notarization mechanism requires trust in specific notaries. Sun Y. et al . [25] designed a secure and fully functional cross-chain service protocol by combining the notary mechanism with hash locking to address the issue of untrustworthiness of notaries. Xiong A. et al. [26] proposed a cross-chain interaction model based on notary groups to achieve interoperability between different blockchains, addressing issues such as improper behavior and poor enthusiasm of notaries. Xue Q. et al. [27] proposed a cross-chain data sharing scheme based on conditional proxy re encryption address issues such as notary trust between consortium chains. Cao L. et al. [28] proposed a cross domain access cross-chain data tracking mechanism to address the trust issue between cross domain users. Dai B. et al. [29] addressed the issue of insufficient node credit supervision in the notary mechanism and constructed a notary node credit evaluation model based on an improved PageRank algorithm. Jiang C. et al. [30] designed an improved notary node credit ranking algorithm based on PageRank to address the issues of witch attacks and insufficient node credit supervision in the notary mechanism.

Although the above research has to some extent addressed the issue of trust in notaries, there are still some issues regarding the credit evaluation of notaries. If the evaluation of intrinsic value indicators is single and the differences between notary nodes are ignored, there may be risks of collusion between notaries and users, inaccurate evaluation of credit evaluation algorithms, and inconsistent allocation of new and old resources. This paper studies the security of blockchain from a more comprehensive perspective. The main contributions of this paper are as follows:

1. A multi-indicator intrinsic value evaluation method. This paper introduces the entropy weight method for determining indicator weights and leverages a variety of indicators to assess the inherent value of both new and existing notary nodes. The goal is to minimize the risk of collusion between users and notaries.
2. A credit rating algorithm. Utilizing the credit ranking algorithm as a foundation, a thorough assessment of notary nodes is undertaken, considering both intrinsic value and indirect trust. This enhancement aims to bolster the precision of the credit evaluation process for notary nodes.

3. We devised a novel method for allocating shares among both new and existing nodes engaged in cross-chain activities. Based on the notary credit evaluation algorithm, a new and old notary node participation share allocation method was designed while ensuring the success rate of cross-chain asset transactions. Intended to strengthen the participation of new nodes and promote more rational allocation of resources.

The rest of this paper is organized as follows. The related work is described in Related knowledge section, and the Cross-chain asset trading scheme for notaries based on edge cloud storage section provides a detailed design of a cloud storage based notary cross-chain asset trading scheme. In Experiment and analysis section, based on our proposed scheme, we conducted scheme analysis and experimental analysis from different perspectives to demonstrate the accuracy of the scheme. Finally, in Conclusion section, we summarized the paper and provided prospects for the next steps of work.

Related knowledge

Notary mechanism

The notary mechanism introduces a trusted third party, known as a notary, between two mutually untrusted users, S and T, to facilitate the transfer of asset value between the target blockchain and the source blockchain. The main advantage of this mechanism is its simplicity and the absence of complex proof-of-work requirements. The specific process of cross-chain transactions based on the notary mechanism is illustrated in Fig. 1.

Although the notary mechanism can achieve asset transfer between different blockchains, it has a high dependence on notaries. If the notary is dishonest or their performance in various indicators is not excellent, it will affect the success rate and efficiency of cross-chain asset transactions.

Entropy weight method

The entropy weighting method objectively determines the weights of indicators and eliminates the influence of subjective factors when data is available. The parameters involved in the calculation are shown in Table 1. The calculation steps are illustrated in Eqs. (1) to (5).

$$X_{ijP} = 0.998\frac{X_{ij} - MinX_{ij}}{MaxX_{ij} - MinX_{ij}} + 0.002 \tag{1}$$

$$P_{ij} = \frac{X_{ij}}{\sum_{1}^{n} X_{ij}} \tag{2}$$

$$e_{ij} = -\frac{1}{ln(n)}\sum_{1}^{n} P_{ij} \cdot ln(p_{ij}) \tag{3}$$

$$g_j = 1 - e_{ij} \tag{4}$$

$$w_i = \frac{g_j}{\sum_{1}^{m} g_j} \tag{5}$$

Although the entropy weight method can objectively calculate the weight of indicators in the presence of data, eliminating the influence of subjective factors, sometimes it may obtain weight values that do not match the actual situation. Therefore, when calculating the weight, it is necessary to conduct an effectiveness analysis of the evaluation indicators.

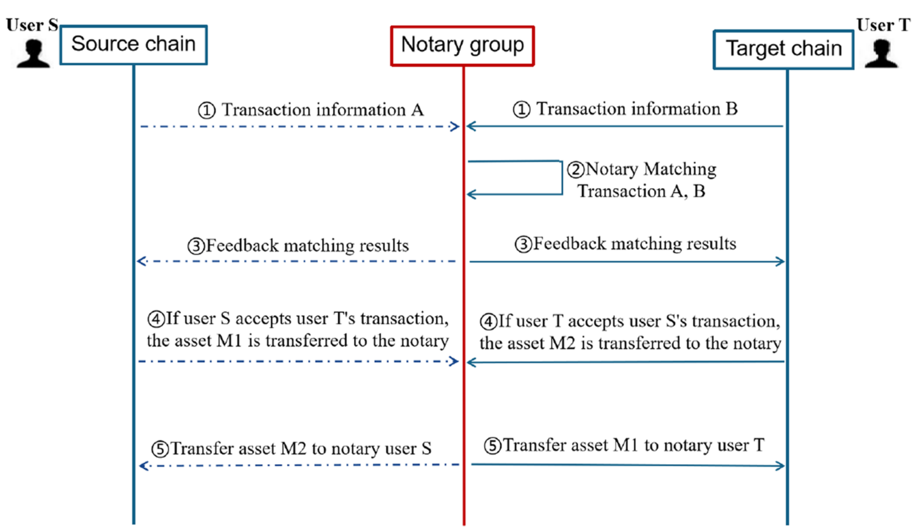

Fig. 1 Cross-chain asset transaction based on notary mechanism

Table 1 Attribute description for index weight solution

Attribute	Description
X_{ij}	The normalized indicator data
X_{ijp}	The normalized forward indicator data
P_{ij}	The proportion of the *i* scheme indicator value under the *j* indicato
e_{ij}	The information entropy
g_j	The information entropy redundancy
w_i	The indicator weight
m	The number of indicators

Credit ranking algorithm

The credit evaluation algorithm was originally used for ranking the importance of web nodes, assuming equal quantity and quality for each node. In this algorithm, the webpage credit value needs to be determined through iterative calculation, so the initial credit value of the webpage needs to be set, denoted as $\frac{1}{n}$ (where n is the total number of web nodes). The PageRank(PR) value of a web node u is determined through iterative calculations using Eq. (6). The parameters involved in this process are shown in Table 2.

$$PR(u)_{i+1} = \sum \frac{PR(v)_{0i}}{L(v)_i}, (i = 0, 1, 2 \ldots n) \tag{6}$$

Table 2 Explanation of credit sorting attribute

Attribute	Description
$PR(u)$	The credit value of web page node *u*
X_{ijp}	The normalized forward indicator data
$PR(v)_0$	The initial credit value of web page node *v*
$L(v)$	The number of outbound links of web page node *v*

When $PR(u)_{n+1} = PR(u)_n$, the iteration ends, the PR values of each node are calculated and sorted.

The credit ranking algorithm can iteratively calculate the credit value of nodes, but when $L(v) = 0$, the trust value PR of nodes cannot be calculated. So, it is necessary for every notary node to have a trusted node pointing to that node, otherwise the node's credit value cannot be calculated.

Cross-chain asset trading scheme for notaries based on edge cloud storage

To address the issues of collusion attacks, inaccurate notary credit evaluation, and unfair resource allocation in the notary mechanism, this paper proposes a cross-chain asset transaction scheme for notaries based on edge cloud storage. The scheme aims to ensure the security of cross-chain asset transactions, the accuracy of credit evaluation, and the fairness of resource allocation. The process of the scheme is illustrated in Fig. 2.

In this scheme, a group of highly creditable nodes is selected to form a notary group, serving as intermediaries for asset transactions between different blockchains. The participants consist of regular notary nodes, notary leader node, and users on the source and target chains. The notary leader node is selected based on the highest credit ranking within the notary group. The parameters involved in the scheme are shown in Table 3 (where new and old notary nodes are referred to as new and old nodes, respectively).

Initialization

The initialization phase of this paper primarily involves the application for node joining, collection of historical information, and computation of indirect trust values.

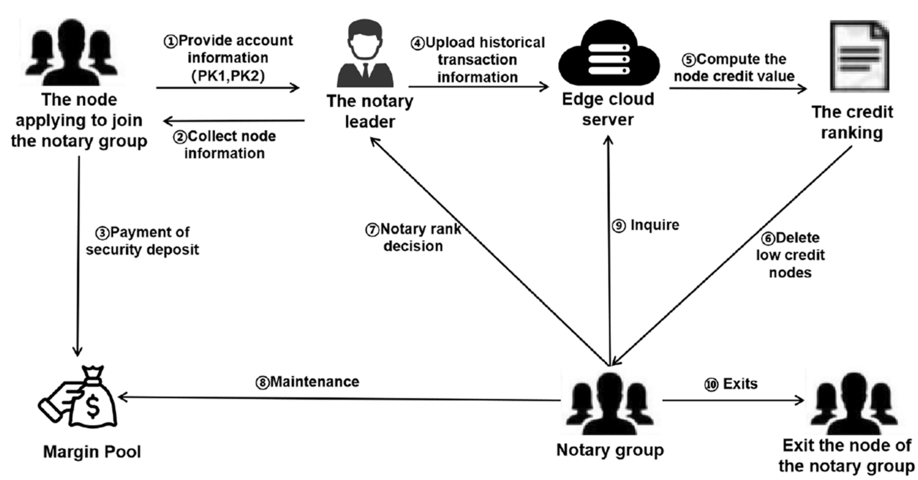

Fig. 2 Flow chart of cross-chain asset transaction scheme for notaries based on cloud storage

Table 3 Scheme parameter description

Attribute	Description
PK_1	The public key on the source chains
PK_2	The public key on the target chains
M_{New_i}	Historical transaction information of new nodes
M_{Old_i}	Historical transaction information of old nodes
S_{iN}	The new node feedback evaluation value
S_{iO}	The old node feedback evaluation value
X_{iN}	Transaction feedback evaluation value of new node
X_{iO}	Transaction feedback evaluation value of old node
T_{jO}	The transaction processing efficiency
R_{iN}	The recommendation evaluation value of new nodes
R_{iO}	The recommendation evaluation value of old nodes
G_{iO}	The negative message evaluation value of old nodes
H_{iO}	The trust relationship table for old nodes
P_{iN}	Proof of new node deposit payment
P_{iO}	Proof of old node deposit payment
$grade_i$	The user feedback evaluation value
Nu_i	The node transaction success volum
Nu_{All}	The total transaction volume of nodes
$number_{agree_i}$	The recommended quantity of nodes
$time_i$	The transaction times
$number_i$	The amount of negative messages
M	Node historical transaction information set
Q_{S_i}	Overall user feedback value
Q_{X_i}	Overall success rate
Q_{T_i}	Overall transaction efficiency
Q_{G_i}	Overall negative user messages
A_i	The index vector
P_{MN}	The similarity between nodes M and N
PR_i	The credit rating value of the new node
PR'_j	Historical transaction evaluation value of old nodes
PR'_{Oj}	Indirect trust values between old nodes
d_0	Damping coefficient of node
t	Participation time in cross-chain transactions
d_j	Cross-chain time t and d_0 function
PR_j	Comprehensive credit rating value of old nodes
$F(X)$	Transaction success rate function
X_x	Transaction success rate of old nodes
X_{xy}	Transaction success rate of introducing new nodes
N_{iN}	The number of new nodes redundancy
N_{iO}	The number of old nodes

Additionally, it includes the calculation of the initial credit value for nodes. In the first round of credit value calculation, $PR(v)_{0i} = \frac{1}{n}$ (where n is the number of notary nodes, and in this paper, n is chosen as 100) is used. For subsequent rounds of credit value calculation, the initial credit value of nodes is determined by their success rate, denoted as $PR(v)_{0i} = X_i$.

(1) Node application for joining. Nodes applying to join the notary group are required to provide their account information, denoted as (PK_1, PK_2). The notary leader node verifies the account information of the applying node. If the account information is correct, the application is approved; if it is incorrect, the application is rejected.
(2) Collection and storage of node historical information. After the application is approved, the applying node is required to submit a deposit and provide either the node's historical transaction information set $M_{New} = \{S_{iN}, X_{iN}, R_{iN}, P_{iN}\}$ or $M_{Old} = \{S_{iO}, X_{iO}, T_{iO}, R_{iO}, G_{iO}, H_{iO}, P_{iO}\}$. Afterwards, the leader node uploads the node's historical transaction information set to the edge server for storage. The collection and calculation process of the trust relationship table between nodes is illustrated in Fig. 3.

Credit evaluation and ranking

(1) Calculation of evaluation indicators. Since new nodes have not participated in cross-chain asset transactions before, their credit evaluation relies entirely on their historical transaction data on the source or target chain and node recommendations as evaluation indicators. The credit evaluation of new nodes takes into account factors such as the historical transaction data performance and trust relationships between nodes. The indicator calculations for new and old nodes are shown in Eqs. (7) and (13), respectively.

$$S_{iN} = \frac{1}{n} \cdot \sum grade_{i_{New}} \tag{7}$$

$$X_{iN} = \frac{1}{n} \cdot \sum \frac{Nu_{i_{New}}}{Nu_{All_{New}}} \tag{8}$$

$$Q_{R_{iN}} = \frac{1}{n} \cdot \sum agree_{i_{New}} \tag{9}$$

$$S_{jO} = \frac{1}{n} \cdot \sum grade_{j_{old}} \tag{10}$$

$$X_{jO} = \frac{1}{n} \cdot \sum \frac{Nu_{j_{old}}}{Nu_{All_{old}}} \tag{11}$$

$$T_{jO} = \frac{1}{n} \cdot \sum \frac{1}{time_{j_{old}}} \tag{12}$$

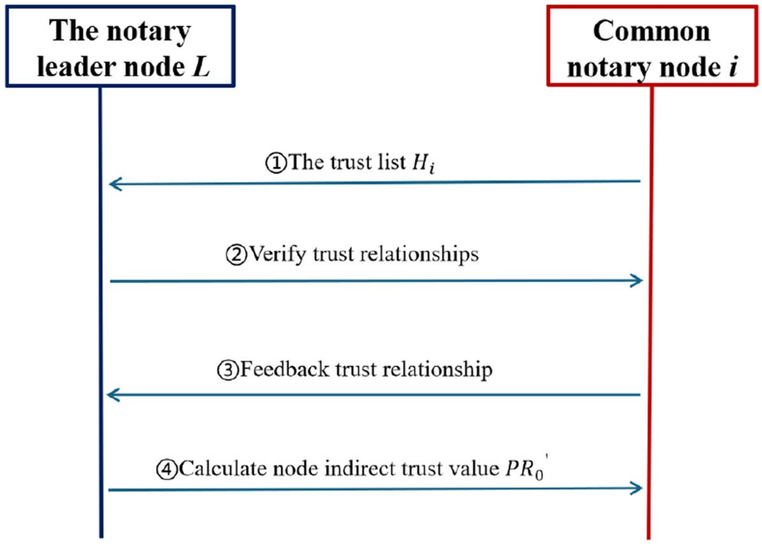

Fig. 3 Indirect credit calculation between nodes

$$G_{jO} = \frac{1}{n} \cdot \sum \frac{1}{number_{j_{old}}} \tag{13}$$

(2) Calculation of similarity between old nodes. Taking into account the transaction situations between nodes, if both nodes exhibit high transaction efficiency, positive user feedback, minimal negative information, and a high success rate, their similarity will be high.When the *PR* value of a node is high, more *PR* values should be passed to the trusted nodes of that node, rather than evenly distributed; Nodes with excellent performance will transmit higher *PR* values to trusted nodes. The steps for calculating the similarity between nodes are:

a. Establish a node's historical transaction information set M as shown in Eq. (14).

$$M = \left\{M_{key_1}, M_{key_2}, \cdots, M_{key_i}, M_{key_n}\right\} \tag{14}$$

b. Calculate the evaluation values of each indicator. The evaluation values of node transaction efficiency, user feedback evaluation, negative information, and transaction success rate are shown in Eqs. (15) to (18).

$$Q_{S_i} = \sum\nolimits_1^n w_S \cdot agree_i \tag{15}$$

$$Q_{X_i} = \sum\nolimits_1^n w_X \cdot X_i \tag{16}$$

$$Q_{T_i} = \sum\nolimits_1^n w_T \cdot \frac{1}{time_i} \tag{17}$$

$$Q_{G_i} = \sum\nolimits_1^n w_G \cdot number_i \tag{18}$$

c. Build indicator vectors. Construct indicator vectors based on the evaluation values of each indicator, as shown in Eq. (19).

$$A_i = \left(Q_{S_i}, Q_{X_i}, Q_{T_i}, Q_{G_i}\right) \tag{19}$$

d. Calculate the similarity between nodes. The similarity calculation between node M and node N is shown in Eq. (20).

$$P_{MN} = \frac{\sum A_M \cdot A_N}{\sqrt{A_M^2} \cdot \sqrt{A_N^2}} \tag{20}$$

(3) Index weight calculation. Firstly, the aforementioned indicators are normalized and transformed into positively-oriented indicators, denoted as X_{ijp}. Then, the indicator weights P_{ij} and information entropy e_{ij} are calculated. Subsequently, the redundancy of information entropy g_j is computed. Finally, the indicator weights w_i are calculated. The specific calculations are shown in Eqs. (1) to (5).

(4) Credit evaluation. Based on the PageRank notary node credit ranking algorithm, historical transaction information of nodes, and trust relationships between nodes, calculate the credit evaluation values of new and old nodes respectively. New Nodes: The credit evaluation algorithm for nodes on a single chain is designed as shown in Eq. (21).

$$PR_i = \omega_1 \cdot \left(\frac{1}{n} \cdot \sum\nolimits_1^n S_i\right) + \omega_2 \cdot X_i + \omega_3 \cdot R_i \tag{21}$$

Old node: The historical transaction value evaluation algorithm (intrinsic value evaluation), indirect trust evaluation, damping coefficient, and comprehensive credit evaluation calculation of the notary's nodes are shown in Eqs. (22) to (25). Among them, considering the influence of time factors, the damping coefficient is calculated in segments using the scheme proposed by Jiang Chuyu et al. [30], as shown in Eq. (24).

$$PR'_j = \frac{1}{n} \cdot \sum_{1}^{n} (\omega_1 \cdot S_i + \omega_2 \cdot T_i + \omega_3 \cdot G_i) + \omega_4 \cdot X_i \tag{22}$$

$$PR'_{Oj} = \sum_{i \epsilon F(u)} \frac{PR(v)_i}{L(v)_i} \cdot (1 + P_{MN}) \tag{23}$$

$$d_j = \begin{cases} d_0, & t \in [0,3) \\ 0.75d_0, & t \in [3,6) \\ 0.5d_0, & t \in [6,9) \\ 0.25d_0, & t \in [9,12) \\ 0.125d_0, & t > 12 \end{cases} \tag{24}$$

$$PR_j = (1 - d_j) \cdot PR'_j + d_j \cdot PR'_{Oj} \tag{25}$$

By substituting Eqs. (21) to (24) into Eq. (25), the comprehensive credit value of notary nodes is iteratively calculated.

(5) Credit ranking and storage. After calculating the credit values *PR* for all new and old nodes, they are respectively sorted in descending order, and store the credit ranking results of each node in the edge cloud server. The notary node with the highest credit value ranking among the old nodes is selected as the leader node for the current evaluation round.

Allocation of shares between new and old nodes

The obtained credit values for both new and old notary nodes are sorted. Starting from the top of the sorted list of new notary nodes, the difference in transaction success rate between introducing the new node and not introducing the new node is calculated as $F(X)$. The calculation determines the number of new notary nodes x and old notary nodes y that satisfy the condition $F(X) = F(X)_{Max}$. The specific calculation is shown in Eq. (26).

$$F(X) = X_{xy} - X_x \tag{26}$$

When $F(X) = F(X)_{Max} \geq 0$, the numbers taken are respectively $x = N_{iN}$ and $y = N_{iO}$.

Determination of notary group and exit of notary nodes

(1) Determination of the notary group.Based on the credit value ranking results and the allocation of shares for new and old nodes, the notary group is formed with the calculated composition of new and old nodes. Subsequently, the list of notary group members is uploaded to the blockchain for the applying nodes to query.
(2) Exit of the notary node. When a notary node voluntarily applies to withdraw from the notary group without any dishonest behavior, the node simply needs to fulfill its role in the notary transactions and withdraw, resulting in the return of the node's deposit. However, if there is a breach of contract, a certain amount from the deposit pool will be deducted as a penalty.

Experiment and analysis

This paper deploys a certain number of old and new nodes. The objective of this approach is to select nodes with high rankings in each evaluation metric to serve as notary nodes and identify nodes with high and low credit. Therefore, this paper selects notary nodes that rank in the top and bottom 20% and the top and bottom 10% of the credit evaluation rankings and compares the ranking error rates for these nodes among different schemes (lower error rates indicating better performance). The error rate is based on the credit value *PR* ranking, and when the ranking of a specific metric differs significantly from the *PR* ranking, it is considered an incorrect selection for that metric. For example, if a node ranks in the top 20% (10%) based on its credit value but ranks in the bottom 20% (10%) based on a specific metric, it is considered an error in the ranking for that metric.

Scheme analysis

(1) Effectiveness analysis of evaluation indicators. In response to the original approach that only utilizes user evaluation indicators to calculate the intrinsic value of nodes, there is a risk of collusion between users and notary nodes to inflate the credit values of the notary nodes. In this proposed approach, historical transaction information of both new and old notary nodes is collected, and the entropy weight method is employed to calculate the weights of the indicators. The weights of the indicators are determined based on their magnitudes, and a multi-

indicator evaluation is employed to mitigate the risk of collusion between users and notary nodes. The weights of each indicator for new and old notary nodes are shown in Table 4.

According to the weight values of the new and old node indicators provided in Table 4, it can be seen that for the new node, the weights of user evaluation, transaction success rate, and node recommendation indicators are 0.197, 0.304, and 0.499, respectively ("-" indicates no indicator data), and the user evaluation indicator with the lowest weight is.For old nodes, the weights for user evaluation, transaction success rate, transaction efficiency, and negative evaluation indicators are 0.267, 0.244, 0.303, and 0.186, respectively, with transaction success rate having the highest weight. The weight of the user evaluation indicator is 0.023 greater than the weight of the transaction efficiency indicator, and the negative evaluation indicator has the smallest weight. From this, it can be concluded that the weight values of each indicator for both new and old nodes are significant and should not be disregarded. Relying solely on user evaluation indicators to calculate the intrinsic value of notary nodes is unreasonable. Instead, it is essential to fully consider the impact of each indicator. Therefore, the evaluation indicators selected in this approach are effective.

(2) Analysis of the effectiveness of credit evaluation for new nodes. This paper collects relevant data for new nodes, calculates indicator weights and credit values (*PR*) for each node, and ranks the credit values (*PR*) and indicators of each node. The top and bottom ten ranked notary nodes are selected for analysis and comparison. For specific information, please refer to Tables 5 and 6.

Based on Tables 5 and 6, it can be observed that among the top ten ranked new notary nodes based on their PR values, the rankings for indicators such as user evaluation, success rate, and node recommendation range from 1 to 14, 2 to 28, and 1 to 18, respectively. Among the bottom ten ranked new nodes, the rankings for indicators such as user evaluation, success rate, and node recommendation range from 32 to 49, 16 to 50, and 29 to 48, respectively. It can be concluded that the credit evaluation of new nodes can select new notary nodes that have the best overall performance in each indicator. This approach accurately identifies nodes with high credit and low credit. Therefore, the credit evaluation for new nodes in this approach is effective.

Table 4 Weighted values of new and old node indicators

Weight	w_1	w_2	w_3	w_4
New Node	0.197	0.304	0.499	-
Old Node	0.186	0.244	0.303	0.267

Table 5 Top 10 PR value rankings of new nodes

Attribute	S Ranking	X Ranking	R Ranking	PR Ranking
24	2	2	1	1
13	4	4	3	2
33	3	9	4	3
25	5	6	7	4
21	6	5	6	5
8	1	28	2	6
4	7	15	5	7
16	9	11	9	8
48	10	10	18	9
3	14	19	8	10

Table 6 Bottom 10 PR value rankings of new nodes

Attribute	S Ranking	X Ranking	R Ranking	PR Ranking
5	39	22	38	41
11	34	46	29	42
1	44	27	37	43
22	47	16	45	44
30	32	48	32	45
34	33	50	33	46
28	41	21	46	47
31	43	40	41	48
20	46	42	40	49
32	49	49	48	50

(3) Analysis of the composition of new and old Notary Nodes. This approach ranks the credit values of both new and old notary nodes and selects the top 100 ranked notary nodes as the notaries for the cross-chain asset transactions in this round. Then, the number of new and old notary nodes in the notary group is calculated separately for the Dai scheme, Jiang scheme, and the proposed scheme (without allocating quotas for new and old nodes). The composition of new and old notary nodes in each scheme's notary group is shown in Table 7.

According to Table 7, it can be observed that the Dai scheme has 0 new nodes, indicating an issue of unfair resource allocation towards old nodes. The Jiang scheme has 36 new nodes, which solves the problem of favoring

Table 7 Number of new notary nodes in each scheme's notary group

Notary node	Dai scheme	Jiang scheme	This scheme
New node	0	36	25
Old node	100	64	75

old nodes in the Dai scheme. However, it introduces a bias towards new nodes, leading to potential issues such as a lower success rate of the notary group due to an excessive number of new notary nodes. In contrast, the proposed scheme (without allocating quotas for new and old nodes) has 25 new nodes, which effectively addresses the bias issue present in both of the aforementioned schemes.

Scheme analysis

In this study, a deployment of notary nodes is conducted, consisting of 100 old nodes numbered 1-100 and 50 new nodes numbered A1-50. The objective is to select notary nodes with both high and low credit ratings, enabling the accurate identification of nodes with varying levels of creditworthiness. To achieve this, the top and bottom 20% of nodes are selected based on their rankings, and the ranking error rates of these selected nodes are compared across different schemes.

(1) Analysis of error rate in credit evaluation of old nodes. This paper analyzes nodes that rank in the top and bottom 20% and presents the corresponding error rates in Figs. 4 and 5.

Based on Figs. 4 and 5, it can be observed that among the bottom 20 ranked nodes, the error rates for each scheme are 2.7%, 8.0%, 9.8%, and 9.8% respectively. The proposed scheme has the lowest error rate, performing 5.3% better than the optimal scheme. Among the top 20 ranked nodes, the error rates for each scheme are 8.6%, 10.5%, 19.3%, and 28.4% respectively. The proposed scheme again has the lowest error rate, performing 1.9% better than the optimal scheme. The analysis focuses on the nodes ranked in the top and bottom 10% and the corresponding error rates are presented in Figs. 6 and 7. Based on the results in Figs. 6 and 7, it is evident that among the bottom 10 ranked nodes, the error rates for each scheme are 0.6%, 4.3%, 4.3%, and 4.3% respectively. The proposed scheme exhibits the lowest error rate, with a 3.7% improvement compared to the optimal scheme. Similarly, among the top 10 ranked nodes, the error rates for each scheme are 3.7%, 6.7%, 10.6%, and 10.8% respectively. Once again, the proposed scheme demonstrates the lowest error rate, achieving a 3.0% improvement over the optimal scheme.

(2) Analysis of the error rate in evaluating the inherent value of old nodes. Calculate the intrinsic value of the old nodes and analyze the error rates by selecting nodes ranked in the top 10% and 20% based on their intrinsic value, as illustrated in Fig. 8.

From Fig. 8, it can be seen that the error rate of the inherent value evaluation of the scheme is lower than that of the schemes proposed by Jiang et al., especially in the

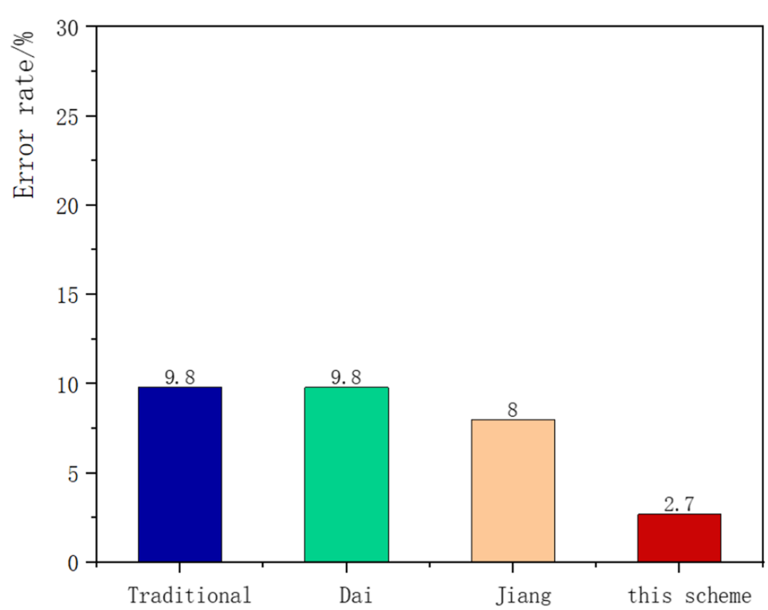

Fig. 4 Error rate of the bottom 20% nodes in the ranking

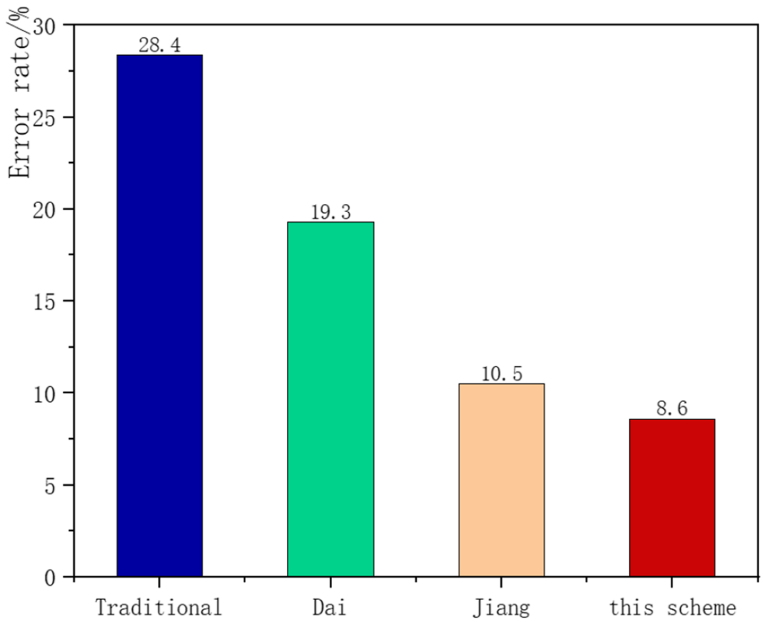

Fig. 5 Error rate of the top 20% nodes in the ranking

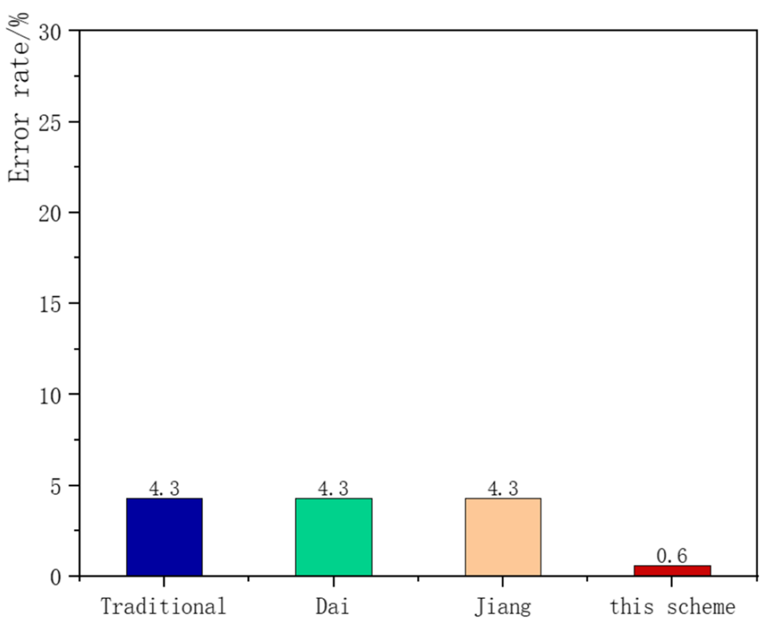

Fig. 6 Error rate of the bottom 10% nodes in the ranking

10% and 20% nodes of the old node's inherent value ranking, with an error rate of 0.0%. Among them, the error rates of Jiang et al.'s plan were 24.2%, 19.4%, 2.6%, and 6.7%, respectively. The error rates of this plan were 1.2%, 4.0%, 0.0%, and 0.0%, respectively. The error rates of this plan were 23.0%, 15.4%, 2.6%, and 6.7% lower than Jiang's plan, respectively. The reason for the low error rate of the bottom 10% in Jiang et al.'s scheme, while the high error rate of the other three ranking schemes is that the inherent value of this scheme only considers the impact of user evaluation S on the inherent value. For the user feedback and indirect trust values of the bottom 10% nodes, which are almost the same and close to 0, this scheme can accurately identify these low credit nodes, so the evaluation

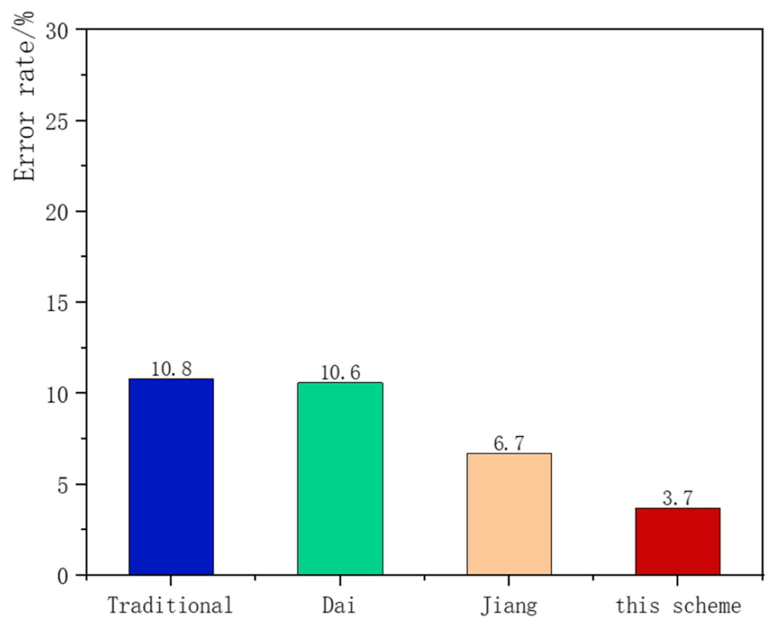

Fig. 7 Error rate of the top 10% nodes in the ranking

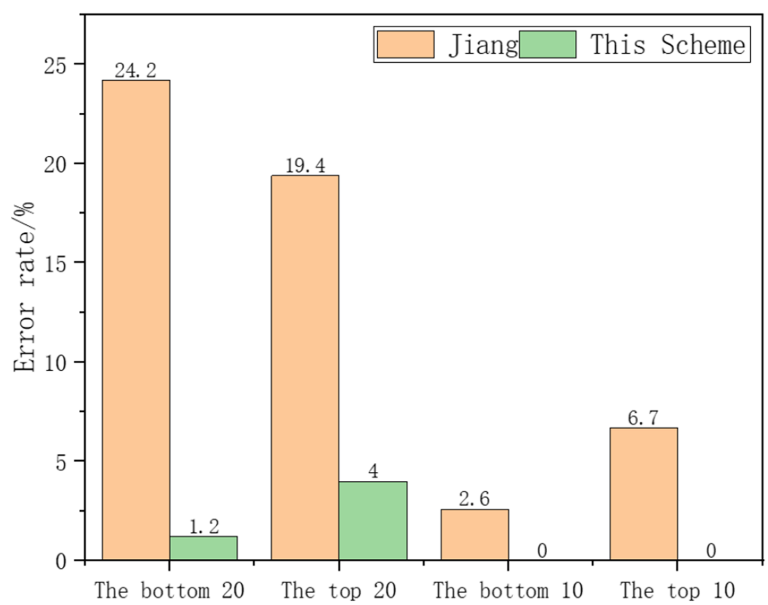

Fig. 8 Error rate of inherent value evaluation of the scheme

error rate of this part of nodes is the lowest. However, the user feedback and indirect trust values of the other three ranking nodes are not the same, and this scheme cannot accurately evaluate the credit value of this part of nodes, resulting in a high error rate.From this, it can be seen that this scheme can more accurately evaluate the inherent value of old nodes. In summary, the proposed scheme exhibits a lower error rate compared to other schemes, enabling accurate identification of both low-credit and high-credit nodes. Furthermore, this scheme takes into account the variations among nodes and the influence of various indicators, allowing for a comprehensive assessment that objectively considers the impact of each indicator.

(3) Allocation of shares between new and old nodes. This study introduces a methodology where different numbers of new nodes are selected to participate in cross-chain transactions, replacing the lower-ranked old nodes. The success rate of transactions after introducing the new nodes is calculated by subtracting the success rate without their introduction (as indicated in Eq. 18). When the condition is met, the allocation of new and old nodes is determined based on the number of nodes at that specific time. The experimental results are presented in Fig. 9.

As depicted in Fig. 9, the success rate initially increases and then decreases. This pattern arises because, while introducing new nodes with higher success rates to replace old nodes with lower success rates, the overall success rate experiences an initial improvement. However, as the number of nodes increases and the disparity in success rates reduces, the final success rate function gradually declines after reaching its peak. When $F(X) = F(X)_{MAX}$, the number of new notary nodes at this time. Once the number of new and old nodes is determined, this approach selects the number of new notary nodes. The success rates of different scenarios are tested at transaction volumes of 30, 60, 90, 120, 240, 480, 720, and 960. The success rates of these different scenarios at the same transaction volume are compared, as illustrated in Fig. 10. According to Fig. 10, it can be observed that after selecting 15 new notary nodes, as the transaction volume increases, the new nodes gradually adapt to cross-chain transactions, resulting in an increase in their success rate. On the other hand, the success rate of the old nodes remains relatively stable. As a result, both Jiang et al.'s scheme and the proposed scheme experience an initial increase in success rate followed by stability, as they involve the participation of new nodes. In contrast, Dai et al.'s scheme, which does not involve new nodes, exhibits a relatively stable success rate.With the increase in transaction volume, the proposed scheme demonstrates a higher success rate compared to Jiang et al.'s scheme and Dai et al.'s scheme. This approach not only ensures a successful cross-chain transaction rate but also addresses the issue of resource allocation imbalance caused by the bias towards old nodes in the original scheme.

(4) The impact of malicious nodes. This paper created 100 notary nodes and set up different proportions of malicious notaries to test their impact on the number of successful transactions. The total number of transactions is 100. The experimental results are shown in Fig. 11.

From Fig. 11, it can be seen that as the proportion of malicious nodes increases, the transaction success rate of Dai et al.'s scheme (without guarantee fund pool) decreases; However, regardless of the proportion of malicious nodes, the success rate of cross-chain transactions

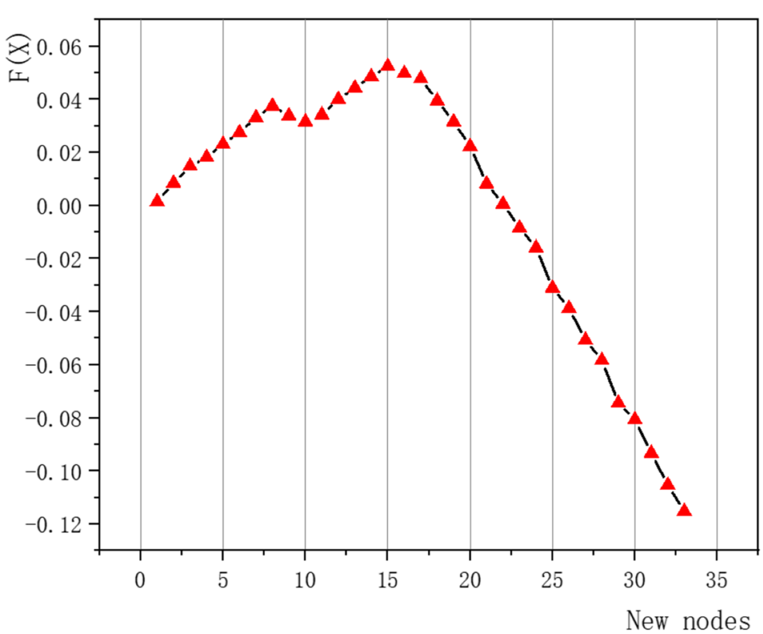

Fig. 9 Relationship between success rate function and new node count

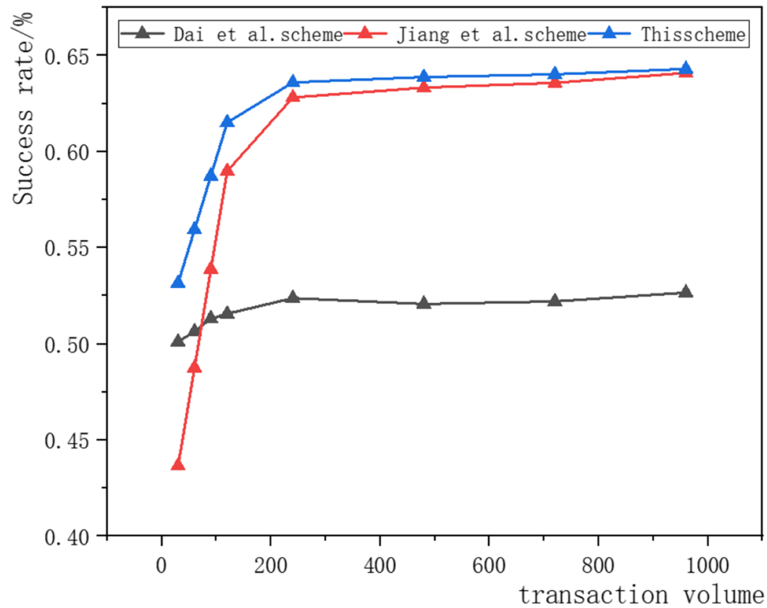

Fig. 10 Success rate of transactions with the same transaction volume after introducing a new node

remains stable for Jiang et al.'s scheme and this scheme, and the success rate of this scheme is higher than Jiang et al.'s scheme. This is due to the introduction of a deposit pool, which regulates the behavior of notaries. When the notary is a malicious node, the security deposit of the notary node can be deducted to compensate for transaction losses, thereby improving the reliability of the notary node and the security of cross-chain asset transactions.

Conclusion

This paper proposes a cross-chain asset trading scheme for notaries based on credit ranking algorithm to address issues such as collusion attacks by notaries, inaccurate credit evaluations, and unreasonable resource allocation, in order to improve the reliability of notaries and the security of cross-chain value exchange. The entropy weight method was introduced to calculate indicator

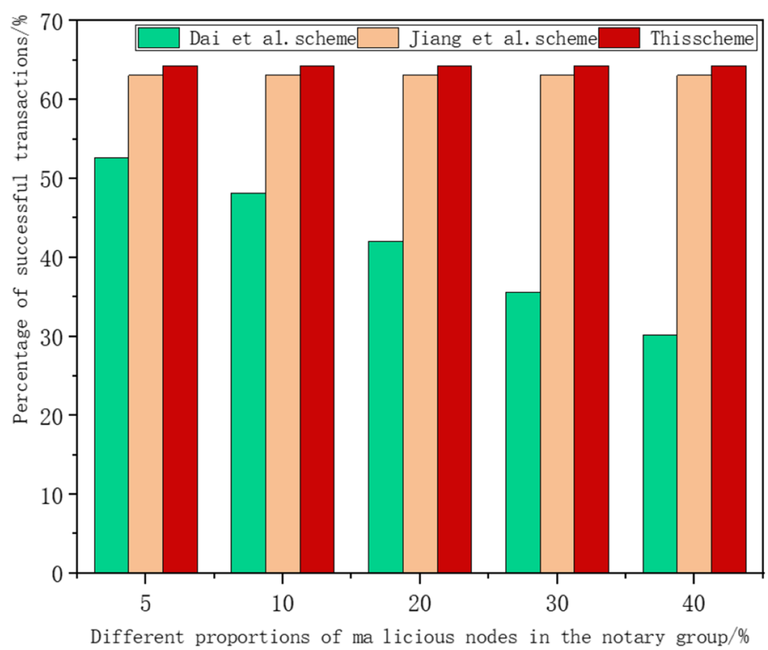

Fig. 11 Transaction success rate corresponding to different proportions of malicious nodes

weights, and a multi indicator intrinsic value evaluation method was designed to improve the security of asset transactions.Based on multi indicator intrinsic value evaluation, a comprehensive credit evaluation method for notary nodes is designed from both intrinsic value and indirect trust aspects to improve the accuracy of notary node credit evaluation.In addition, a new and old notary node participation method for share allocation was designed, which improved the participation of the new node and promoted the rationality of resource allocation.Although this solution has indeed solved some problems in cross-chain asset transactions, further solutions are needed on how to motivate notary nodes to enhance their enthusiasm and protect the privacy and security of cross-chain data.

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Authors' contributions
Lang Chen wrote the main manuscript text, Yuxiang Yang, Hui Dou and Yun Luo prepared tables and figures, Yuling Chen and Chaoyue Tan provided helpful suggestions and revised the manuscript. All authors reviewed the manuscript.

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Availability of data and materials
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
The results/data/figures in this manuscript have not been published elsewhere, nor are they under consideration by another publisher.

Competing interests
The authors declare no competing interests.

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