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Research on Higher Vocational Education Resource Sharing System Incorporating Edge Computing in the Perspective of "Blockchain+Education"

Yifang Hu[1,✉]

[1] *Dean's Office, Zhejiang Technical Institute of Economics, Hangzhou, Zhejiang, 310000, China*

ABSTRACT

This study focuses on the "blockchain + education" perspective, focusing on the integration of edge computing in the higher education resource sharing system. Through the benign interaction between blockchain and edge computing in the system data management system, the security and efficiency of data storage and transmission of shared resources in the system can be improved. In order to improve the performance of the system's educational resource sharing, this paper utilizes the node identification model on the basis of the traditional PBFT consensus algorithm for the selection of master nodes and the monitoring of malicious nodes. Meanwhile, in order to ensure the balanced allocation of educational resources within the sharing system as much as possible, this paper utilizes the differential evolution (DE) algorithm for the balanced allocation of system resources and the educational resources within the system. The results of experiments and system tests show that the improved PBFT consensus algorithm (NR-PBFT) in this paper shows obvious superiority in tests such as throughput and latency. Although the educational resource allocation model performs poorly in the allocation of resources with larger technology such as digital books, the results for the allocation of teacher resources can effectively prove the effectiveness of the resource allocation model in this paper. In addition, the system test results also show that the system in this paper has good performance, and the introduction of edge computing can significantly reduce the packet loss rate of resource sharing, which has considerable application value.

Keywords: edge computing, consensus algorithm, DE algorithm, blockchain, educational resource sharing

✉ Corresponding author.
E-mail address: zjhzhyf2022@163.com (Y. Hu).
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1. Introduction

With the rapid development of modern information technology centered on network technology and multimedia technology, education informatization has entered a new stage of development and become an important symbol of modern education. Higher vocational education, as an important part of higher education, has become the focus of attention in today's society. Focusing on the construction of higher vocational education resources from the three dimensions of school-enterprise industrial development needs, school-enterprise deep integration, and social recognition, it promotes higher vocational colleges and universities to innovate the system and mechanism, accelerate the talent cultivation and the teaching reform of higher vocational education, and practically take the service as the purpose and employment as the orientation [1-4]. Adhere to the school education and vocational training and the implementation of the combination of work and study, school-enterprise cooperation, top internship mode of professional training, explore and seek “industry-university-research integration” development of new ideas, so that the higher vocational education should be oriented to the school, facing the enterprise, facing the public, and focusing on cultivating the students' professional skills and entrepreneurial ability, for the construction of the country's modern industrial system to send a large number of high-end skilled and specialized personnel, and to provide a large number of students to the national modern industrial system. The construction of national modern industrial system conveys a large number of high-end skilled specialists [5-8]. In order to achieve this goal, higher vocational education has made use of the achievements of high and new technology, completed its overall leapfrog change in teaching and initially formed an open, interactive network learning environment, informationization and digital teaching environment, which have laid a solid foundation for the digital network sharing of educational resources in higher vocational colleges and universities [9-12]. Nowadays, the form of network education has become a global trend of education and training, the development of lifelong education and the economic restructuring of the new requirements for higher vocational education. The development of resource sharing platforms and so on all provide conditions for the overall promotion of the common construction, sharing and application of the educational resource sharing system in higher vocational colleges and universities to a certain extent, which promotes the development of the construction of the educational resource base in higher vocational colleges and universities in the present time [13-14]. However, there are still some common problems in the current educational resource sharing system, such as slow data transmission, transmission interruption, data loss, resource sharing property rights.

With the continuous development of science and technology, blockchain technology has been widely used in various fields, and the education field is no exception. Blockchain technology, with its distributed, decentralized, transparent, and tamper-proof features, brings many new opportunities for the education industry, such as academic credential certification [15], copyright protection [16], learning records and lifelong learning [17], educational evaluation [18], and educational resource sharing [19]. Edge computing, on the other hand, is an emerging computing paradigm that shifts computation and data processing tasks from traditional cloud computing centers to be processed and analyzed on edge devices closer to the source of data generation [20]. It places computational resources and services as close as possible to the data source to minimize the latency of data transmission and the pressure on network bandwidth. The emergence of this model allows computing tasks to be accomplished more quickly and efficiently, while also reducing the cost of data transmission and storage [21]. Blockchain technology can guarantee the security and reliability of resource sharing, and edge computing guarantees the efficiency, accuracy, and matching of resource sharing [22-24]. The security, reliability, and accuracy of the higher education resource sharing system constructed in this context are guaranteed.

In this paper, we study the characteristics and structure of blockchain and its application scenarios in the field of education from “blockchain+education”, which gives this paper certain theoretical support for the construction of higher vocational education resource sharing system using blockchain technology. In order to further improve the performance of resource storage and transmission in the process of educational resource sharing, this paper focuses on exploring the application of edge computing technology in this system. Through the analysis of the concept and architecture of edge computing, this paper puts it together with blockchain technology in the overall design of the system at the data management level, stores digital educational resources such as video, audio, etc. through the edge computing model, and maps the unique hash value of the resources to the blockchain, so as to ensure the security of educational resource data. Aiming at the problems of traditional PBFT consensus algorithm in practical application, this paper utilizes NR-PBFT consensus algorithm to improve it. The 3-stage protocol of PBFT is extended to a 4-stage protocol by introducing BLS aggregation signature and increasing with the submission stage. At the same time, the node identification model is utilized to select the master node in the system, and the malicious nodes in the system are monitored to maximize the security of transactions within the consensus system. The differential evolution algorithm is used to allocate system resources and educational resources to improve the original unbalanced distribution of educational resources in higher vocational colleges and universities. The rationality and effectiveness of the methods proposed in this paper are demonstrated through experimental testing and verification, and the application value of this paper's system in the sharing of higher vocational education resources is highlighted based on the results of the sharing system test.

2. Overview

Educational resource sharing system related to higher vocational colleges and universities has begun to be studied.Han and Wang [25] proposed a sparse clustering algorithm to obtain the influence factor of resource sharing space and the optimal sharing code of remote online resources, and then created online resource sharing for higher vocational to realize remote management and collaboration, and its sharing performance in has been confirmed.Liu et al [26] for the dilemma of higher vocational education resource sharing and a variety of emerging technologies, they gave the mechanism and path for artificial intelligence to realize vocational education resource sharing.Zhang [27] constructed a higher vocational education resource sharing system through wireless network technology, which not only has advantages in resource integration, but also shows better performance in data transmission efficiency and teacher-student interaction.Zhang and Zhu [28] proposed a vocational education resource sharing platform architecture, and used coupled collaborative filtering model, attention mechanism, and image analysis technology to solve the problem of resource parity in the platform, while increasing the sharing pathways. Chen [29] constructed a resource sharing framework and a sports online teaching resource base supported by a service-oriented architecture, which divides the different teaching resource attributes into modules and creates an entity-contact diagram in order to convert these resources into database Wang and Niu [30] considered the security of resource sharing, set the composite chaotic password via wavelet composite chaotic password matrix, and introduced the blockchain technology to develop a data security sharing system for teaching resources in higher vocational mobile education.He and Cao [31] also introduced the blockchain technology for the information sharing hierarchy of the higher vocational physical education teaching resource sharing platform. Resource sharing platform for modeling and encrypting the information sharing hierarchy, using cloud computing to allocate resources for sharing tasks as well as transferring the data of the information sharing model to the data center, and this method reduces the packet loss rate of the sharing process. However, the higher vocational education resource sharing system still faces challenges such as information asymmetry, complex sharing procedures, inconsistent resource standards, and low data sharing efficiency, which are yet to be solved.

3. Theoretical foundations

3.1. Blockchain + Education

3.1.1. Blockchain. Blockchain technology [32] has four core features: one is decentralization. The nodes in the chain are all independent individuals, all enjoy equal rights and obligations. The trust between nodes is built by means of mathematical operations, and each node independently realizes relevant operations during data transmission and processing, which improves the security coefficient of the whole system. The second is transparency. The data in the blockchain is shared on the chain. The storage and update of independent nodes have to be recognized by multiple nodes on the chain. Therefore, the nodes on the chain are similar and independent of each other. Thirdly, it has high stability. Transactions in the blockchain will be stored permanently after authentication by each node unless more than half of the data nodes are deleted at the same time. In this way, after the transaction data of any node is illegally deleted, the data of the root node can be analyzed to determine whether the transaction is legal. The fourth is intelligence. In the automatic fulfillment of the terms and conditions of the program, each node on the chain can be implemented independently.

Figure 1 shows the general architecture of blockchain. Blockchain technology is a distributed database maintained by multiple nodes. Data is stored in the database in the form of blocks. Each block packages and stores the transactions that have occurred in the blockchain network over a certain period of time. The basic storage unit of the blockchain is the block. Blocks have a special data structure, including block header and block body. Blockchain technology utilizes cryptographic principles to construct blocks. Each block has its own key. These keys are mainly composed of public and private keys, which can guarantee that the information will not be tampered with during the data transmission process. In addition, the consensus mechanism solves the trust problem between network nodes after decentralization and can effectively prevent malicious attacks.

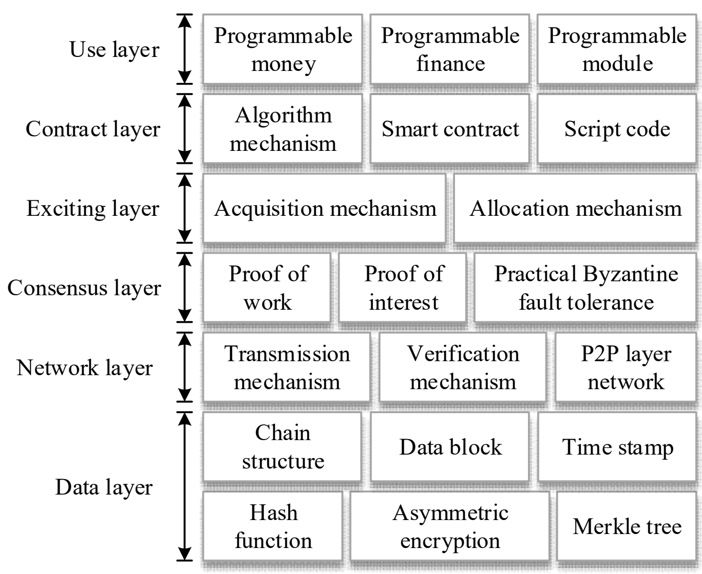

Fig. 1. Block chain architecture

3.1.2. Blockchain in Education. The application of blockchain technology in the field of education has a broad prospect and potential to provide learners with a more secure, transparent and efficient way of learning. By recording learning outcomes in the form of credits on the blockchain, learners can query and use these credits at any time. The decentralized feature of blockchain makes learners' credits traceable and tamper-proof, which can effectively prevent credit forgery and false academic qualifications. Figure 2 shows several application scenarios of blockchain technology to boost the modernization and development of education in the future.

Digital school register/educational account: with the support of the Blockchain Identity Project, the education sector is able to provide each learner with a unique blockchain identity and construct a personal learning archive, thus facilitating the learning process as well as the querying of learning outcomes.

Distributed Learning Ledger: Utilizing blockchain technology, a unique and globally accessible distributed learning ledger can be constructed, which is not only highly secure and reliable, but also capable of comprehensively and meticulously recording every learning activity of learners.

Digital Education Certificate Authentication: Due to the unique ledger mechanism supported by blockchain technology, blockchain education certificates not only realize the function of storing certificates, but also carry out real-time verification and traceability to guarantee the authenticity and credibility of the certificates.

Digital Education Asset Management: The application of blockchain technology has led to great changes in the collaborative production of educational content, access to educational resources and resource sharing, and with the increasing maturity of blockchain payment technology, the operation of educational assets will become faster, smoother and fairer, which provides a strong support for the sustainable development of the education industry.

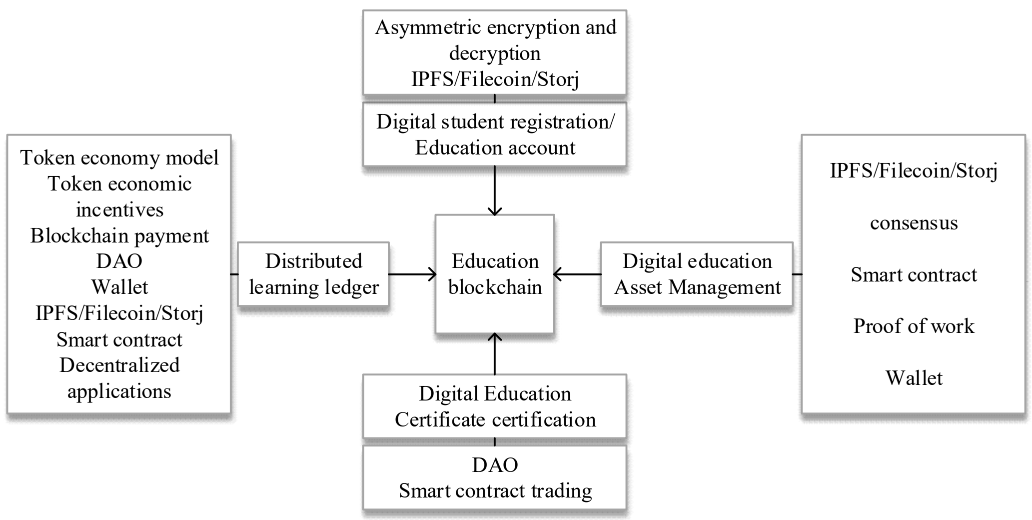

Fig. 2. Application of block chain in teaching field

3.2. *Edge computing*

3.2.1. Overview of Edge Computing. Edge computing, as an emerging computing model [33], looks at solving the problems of high latency and bandwidth bottlenecks that exist in the traditional cloud computing model. Its core concept lies in placing computing resources at the edge of the network, making data processing and storage closer to end users, thus reducing the latency of data transmission. Application scenarios for edge computing include, but are not limited to, IoT, smart cities, industrial automation and other fields. Compared with traditional cloud computing, edge computing realizes a more immediate and efficient computing experience by performing data processing on edge devices.

3.2.2. Edge Computing Architecture. The architecture of edge computing is key to its ability to operate efficiently. It typically contains three main layers: the end-device layer, the edge layer, and the cloud data center layer.

At the end-device layer, IoT devices generate large amounts of data through sensors and other means. To perform preliminary data processing locally, lightweight algorithms such as moving average filtering algorithms are often used:

$$Y_n = \frac{1}{N}\sum_{i=0}^{N-1} X_{n-i} \tag{1}$$

where, Y_n is the filtered data, X_n is the original data and N is the filter window size. Such an algorithm allows the data to be smoothed quickly at the end devices and reduces the amount of data transmitted to the edge layer. At the edge layer, the edge server is responsible for receiving data from multiple end devices for further processing and analysis. In order to improve the efficiency of data processing, deep learning algorithms such as convolutional neural networks (CNN) can be used. Taking image recognition as an example, the forward propagation process of CNN can be represented as:

$$H(i,j) = g(b + \sum_m \sum_n \omega(m,n) \cdot x(i-m, j-n)) \tag{2}$$

where, $H(i,j)$ is the pixel value of the output image, g is the activation function, b is the bias term, $\omega(m,n)$ is the weight of the convolution kernel and $x(i-m, j-n)$ is the pixel value of the input image. By using deep learning algorithms at the edge layer, efficient processing of complex data can be achieved.

In the cloud data center layer, the data that has been initially processed will be transferred to the cloud for deeper analysis and mining. At this point, large-scale machine learning algorithms such as Random Forest can be used:

$$F(x) = \frac{1}{N}\sum_{i=1}^{N} f_i(x) \tag{3}$$

where, $F(x)$ is the final prediction result, $f_i(x)$ is the prediction result of each decision tree and N is the number of decision trees.

By using machine learning algorithms in the cloud layer, it is possible to realize global analysis of the whole system data and mine deeper associations and patterns. Such a layered architecture makes the edge computing system more flexible and scalable, able to adapt to the needs of different scenarios.

4. Educational resource-sharing systems incorporating edge computing

4.1. Overall architecture

The overall architecture of the higher education resource sharing system incorporating edge computing proposed in this paper is shown in Fig. 3, which is divided into three layers from top to bottom: the data management layer, the smart contract layer, and the Web application layer.

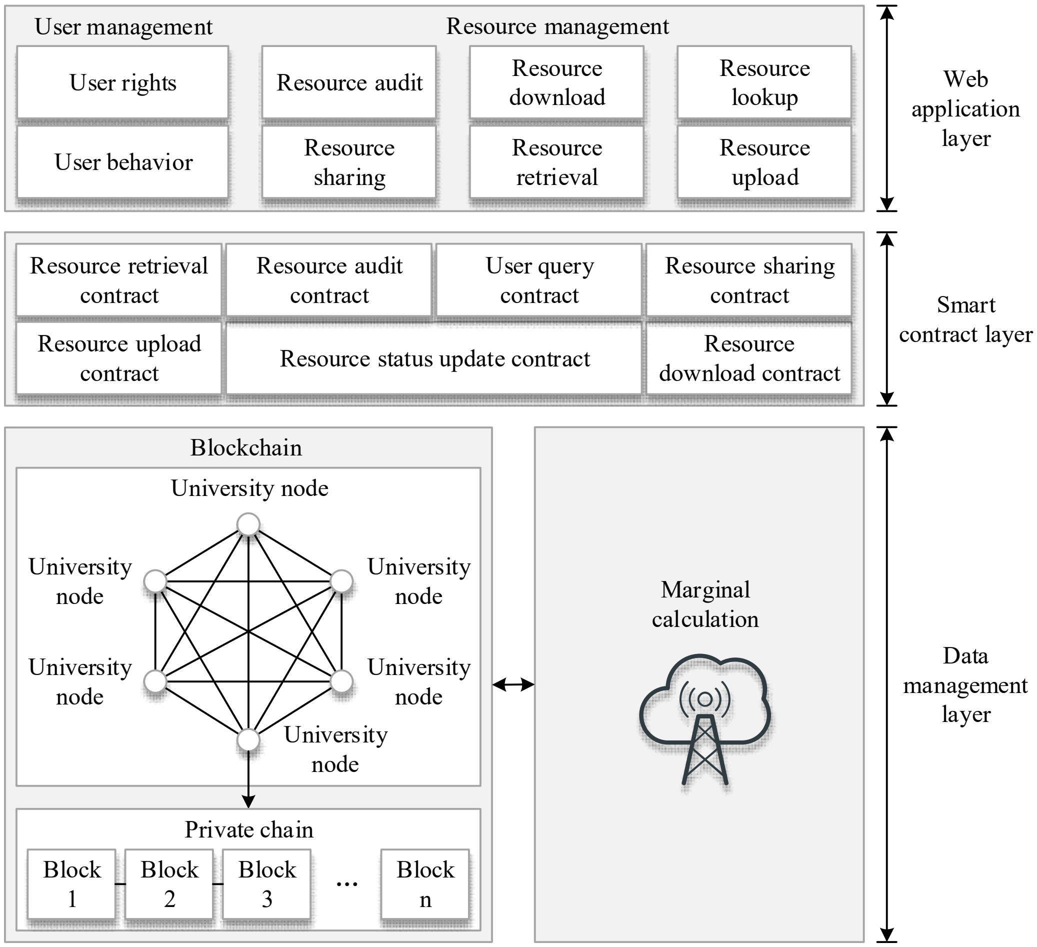

Fig. 3. Overall architecture of education resource open system

4.1.1. Data management layer. The data management layer is the basis of the system, and the storage operation of educational resources is realized by blockchain and edge computing together. The blockchain is divided into a coalition chain and a private chain: the coalition chain consists of nodes from various higher education institutions, which use an improved consensus algorithm to reach agreement. The private chain is used to process the digitized resource data. The edge computing model is responsible for storing digitized educational resources in various formats, such as video, audio, documents, images, etc., and storing the unique hash values of the resources on the blockchain to ensure the data's tamperability and security. In addition, the data management layer is responsible for recording the metadata and transaction information of the educational resources to provide the necessary data support for the upper layer applications.

4.1.2. Smart Contract Layer. The smart contract layer defines the specific rules and conditions of educational resource sharing, which includes multiple contracts for resource uploading, sharing, downloading, and status updating. Once deployed on the blockchain, smart contracts can automatically execute corresponding operations when specific conditions are met, thus realizing the traceability of resource transactions and significantly improving the efficiency and transparency of resource sharing.

4.1.3. Web application layer. The Web application layer is the interface for the system to interact with users and consists of two parts: user management and resource management. This layer assigns appropriate permissions according to user roles and provides an intuitive interface for users to retrieve, access and purchase educational resources through Web pages. Meanwhile, the Web application layer is also responsible for recording and managing the transaction information of the resources and recording the user's purchase request in the form of a transaction on the underlying blockchain through a smart contract.

4.2. Workflow design

Utilizing blockchain technology and integrating the edge computing model can facilitate the sharing and circulation of educational resources among higher vocational colleges and universities, and the workflow of the system is shown in Figure 4. First, the administrator of the higher vocational institution is responsible for authenticating teachers and students and assigning corresponding operation privileges according to their roles. Teacher users are given the rights to upload, query and share resources, while student users have the rights to retrieve, access and download resources. After authentication, teachers upload self-created teaching resources to the edge computing model and upload the returned resource hash values and other attribute information to the blockchain for storage. Teachers can choose to publish the resources for sharing and set the corresponding resource coins after they have been uploaded and stored to the blockchain. Students can then retrieve and download the desired resource through the blockchain platform and use the resource coins to complete the payment. Once the transaction is completed, the transaction information will be packaged into blocks and stored on the blockchain. The blockchain network is responsible for recording all transaction data and user behavior to ensure the authenticity and integrity of the information. Through the consensus mechanism, the blockchain network ensures that all university nodes are able to synchronize the digital resources and achieve decentralized data management. In addition, user behavior is recorded by means of timestamps to ensure the non-tamperability and traceability of resource transactions, thus providing security for both parties in the transaction.

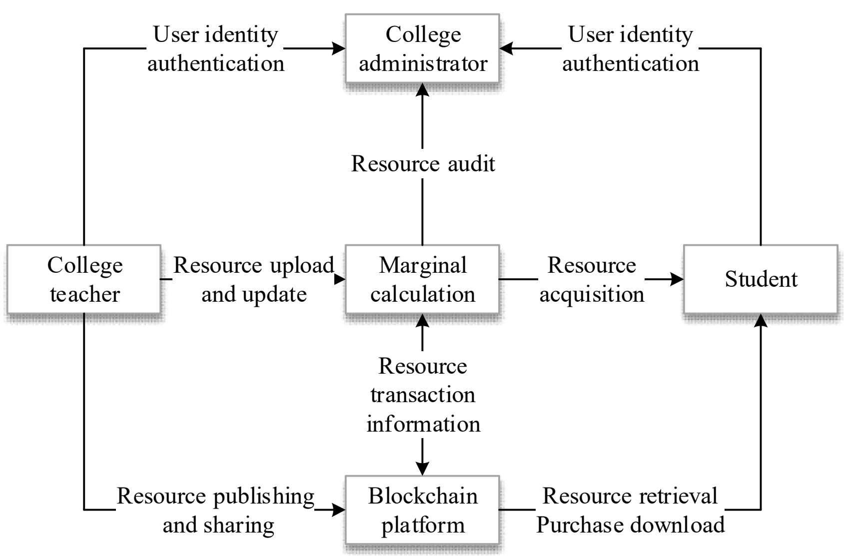

Fig. 4. Workflow of educational resources sharing system

4.3. System Key Algorithm Implementation

4.3.1. Improved PBFT consensus algorithm:

1) Traditional PBFT algorithm. The PBFT algorithm is designed to solve the Byzantine general problem [34], that is, to ensure that when there is a malicious attack by Byzantine nodes, the nodes in the whole network can still reach a consistent consensus and keep the transaction stable. However, the fault tolerance rate of PBFT is only 1/3, that is, the number of Byzantine nodes in the whole network can

not exceed 1/3 of the total nodes, if the number of Byzantine nodes exceeds 1/3 of the total nodes, then it is difficult to make normal nodes reach consensus. Moreover, PBFT adopts the three-stage communication of pre-preparation, preparation and submission, when the number of nodes in the whole network is large, the communication pressure will be very large, resulting in an increase in the consensus delay and affecting the consensus efficiency. The selection of PBFT master node is too random, and it is unavoidable that the Byzantine node will become the master node, and it is necessary to switch the view many times, which not only seriously wastes the communication cost, but also causes the consensus efficiency to decline and the system availability to deteriorate. PBFT consensus algorithm communication flow is shown in Figure 5.

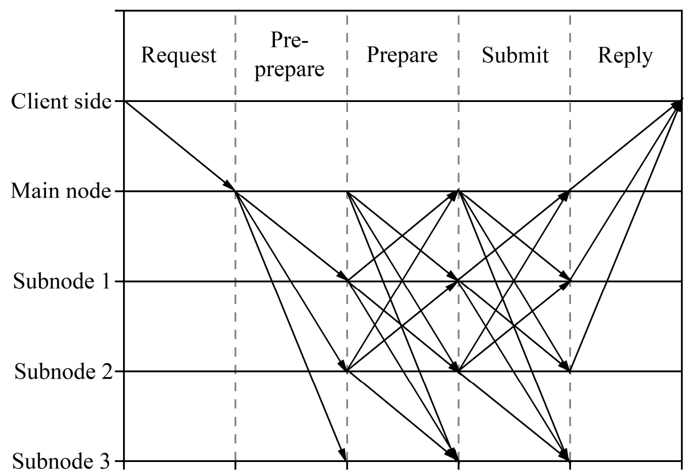

Fig. 5. PBFT consensus algorithm communication process

2) NR-PBFT algorithm. The NR-PBFT algorithm predefines the nodes before the consensus starts and trains the node recognition model after collecting data. After the consensus starts, it follows the consistency protocol process to ensure the integrity and consistency of blockchain data.

(1) Consistency agreement. The NR-PBFT algorithm extends the PBFT 3-phase protocol to a 4-phase protocol by introducing the BLS aggregation signature [35] and adding a pre-submission phase. The communication flow of the improved PBFT consensus algorithm is shown in Fig. 6.

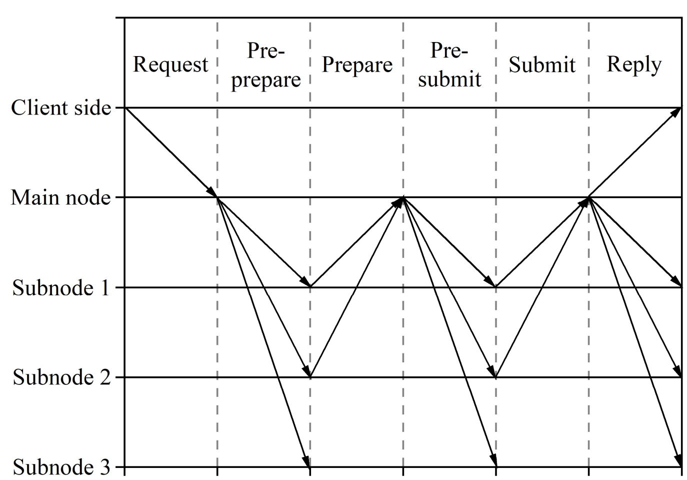

Fig. 6. NR-PEFT algorithm phase

(2) Node Recognition Modeling. In order to comprehensively capture the node characteristics, three types of nodes are preset: high-reputation nodes, medium-reputation nodes, and low-reputation

nodes. During the consensus process, high-reputation nodes submit valid transactions in a timely manner, broadcast messages, and quickly verify and confirm the transactions of other nodes. Medium-credit nodes are similar to high-credit nodes, but have some occasional abnormal behaviors that remain within acceptable limits. Low-reputation nodes, on the other hand, exhibit malicious behavior, such as delayed response to messages and downtime.

The following are the definitions of the 4 characteristic attributes:

Definition 1: Consensus availability, which refers to the ability of a node to successfully reach consensus. The expression is:

$$N(i)=\frac{s_i}{t_i} \tag{4}$$

s_i is the number of times node i has successfully reached consensus, and t_i is the total number of times node i has participated in consensus.

Definition 2: Node contribution, refers to the degree of activity of a node in the consensus process. The expression is:

$$M(i)=\frac{2\arctan(t_i-a)}{\pi} \tag{5}$$

t_i is the total number of times a node i participates in consensus, and a is the moderating factor.

Definition 3: Delay index, which reflects the delay of nodes in the communication process. The expression is:

$$Y(i)=e^{-\frac{(d_\alpha+d_\beta)}{d_{\max}}} \tag{6}$$

d_a is the time interval between broadcasting a pre-prepared message from the master node and receiving a prepared message from node i, d_β is the time interval between sending a pre-submission message from the master node and receiving a submission message from node i, and $d_{\max}$ is the maximum latency allowed for 1 round of consensus, if the maximum latency is exceeded, it means that this consensus fails.

Definition 4: Network utilization, which reflects the use of network resources, is expressed as:

$$U(i)=\frac{net_{sant(t)}+net_{sant(t)}}{net_{band(t)}} \tag{7}$$

Denotes the ratio of the sum of bytes received and sent in time interval t to the network bandwidth.

(3) Master node selection. In order to ensure the security of the system and the balance of master nodes, this paper improves the traditional rotation selection method. By selecting the master node from the group of high-reputation nodes, the malicious nodes or faulty nodes are avoided to be elected as the master nodes. Meanwhile, a uniform randomized algorithm is introduced to give each high-reputation node the same probability of being randomly selected. Assuming that there are M nodes in the high-reputation node cluster, the uniform randomized algorithm process is as follows.

In the first step, obtain the hash value $Blockhash$ of the previous block with timestamp $Timestamp$ to get R_0, as shown in equation (8):

$$R_0=Blockhash\oplus Timestamp \tag{8}$$

where $\oplus$ means mixing the 2 parameters.

In the second step, the hash operation is performed on R_0 and mapped to between 0 and 1 as shown in equation (9) to obtain R, $0<R<1$, where $hash()$ is the hash function and $float()$ denotes taking a floating point number:

$$R = float(hash(R_0)\%10^4)/10^4 \tag{9}$$

In the third step, the master node index value Index is calculated as shown in equation (10):

$$Index = \left[(M-1)\cdot R\right] \tag{10}$$

(4) Malicious node monitoring mechanism. When there is a malicious node in the system, it may lead to the decrease of consensus efficiency and system security. When the node status is recognized as malicious node, the master node under this view puts forward the proposal of deleting the malicious node and broadcasts the proposal to other nodes, and the nodes receiving the proposal vote on the proposal and broadcast the voting result to all nodes. If more than 2 / 3 nodes agree, the system executes the decision of deleting the malicious node, and updates the data state after deletion, while the system updates the view and nodes.

4.3.2. Algorithms for the allocation of educational resources. In the higher education resource sharing system constructed in this paper, an educational resource allocation algorithm based on differential evolutionary algorithm is designed in order to realize the reasonable allocation of resources. The algorithm allocates educational resources to the most suitable edge nodes according to the existing educational resource data in the system and the capacity indicators of each edge node, such as storage capacity, computing capacity and network bandwidth.

1) Resource allocation steps of differential evolutionary algorithm. Differential evolutionary algorithm, as a population evolution optimization method, has the characteristics of stability and practicability [36], covering three basic steps: mutation operation, crossover operation and selection operation, and has been widely used in many fields. In this paper, the differential evolutionary algorithm is introduced into the task of educational resource allocation, and its powerful search ability is used to find out the educational resource allocation strategy that best meets the current environment, and complete the reasonable scheduling of resources.

The differential evolutionary algorithm uses the roulette principle to select individuals within the parent individual e_i^t and the experimental individual s_i^t for computation, without considering the rest of the external elements, and using only the fitness as an indicator, the optimal fitness value is fitted as a new generation of individuals, and the detailed computational procedure of the selection operation is as follows:

$$e_i^{t+1} = \begin{cases} e_i^t & \text{if } fitness(e_i^t) < fitness(s_i^t) \\ s_i^t & \text{otherwise} \end{cases} \tag{11}$$

where $fitness(e_i^t), fitness(s_i^t)$ represents the fitness function of the parent individual and the experimental individual, respectively.

The selection operation is used to determine the individual optimal solution, and the mutation probability is used to adjust autonomously to improve the performance of the differential evolution algorithm, and the operation steps are:

First, chromosome coding. Integrate the characteristics of resource allocation in higher vocational education, use the indirect coding mode of resource-task, the total value of user resource request is the length of chromosome, the gene represents the resource allocation task, and the bit value of the gene position indicates that the task is assigned to the corresponding resource code. Assuming that p_i is the request code and u_j is the resource code, the corresponding chromosome is decoded as $p_1:\{u_1\}, p_2:\{u_2\}, \cdots, p_n:\{u_n\}$. It can be seen that each chromosome corresponds to a resource allocation scheme.

Second, initialize the parameters such as the maximum number of iterations, the termination condition of the selected generation, and the population size, and set the edge node fitness function. If

v resources are allocated on the t th node, the iteration period for the l th edge node to get resource allocation is:

$$F(l) = \sum_{i=1}^{n} M_i^i \tag{12}$$

where M_i^l represents the number of iteration cycles for the l nd edge node to get resource allocation.

Third, the population evaluation, which projects the fitness of all individuals, analyzes the level of superiority and inferiority of each individual, and preserves the optimal individuals of the contemporary population. The load mean LB and the load balancing standard deviation LCT of the set of educational resources are denoted sequentially as:

$$LB = \sum_{l=0}^{o-1} F(l) / o \tag{13}$$

$$LCT = \sqrt{\sum_{l=0}^{n-1} (F(l))^2 \ / o} \tag{14}$$

where o represents the number of edge nodes.

The individual fitness function is further expressed as:

$$Fitness = \frac{1}{1 + Q_\delta + LCT} \tag{15}$$

where Q_b represents the iteration period for the allocation of all educational resources.

Fourth, evaluate whether the iteration termination condition is satisfied, and if not, use a roulette selection strategy to select superior individuals and pass the high-quality genes to the next generation, and take elite preservation measures to prevent the superior individuals from being lost in the evolutionary process.

Fifthly, multi-point cross-operation of individuals in the current population will change the gene arrangement pattern and generate brand new individuals to ensure the diversity of the population. The calculation process of cross-operation is:

$$s_i^t = \begin{cases} w_{ij}^t \text{ if } rand\left[0,1\right] \le CR \text{ or } j = j_r and \\ e_{ij}^t \text{ if } rand\left[0,1\right] > CR \text{ or } j \ne j_r and \end{cases} \tag{16}$$

In the formula, $rand\left[0,1\right]$ represents the random value selected in the interval of [0, 1], CR represents the constant in the interval of [0, 1], named as crossover factor, the higher the value of CR, the higher the crossover probability, and j_rand represents the integer randomly selected in the interval of [0, 1].

Sixth, a number of individuals are randomly selected to carry out the mutation operation according to the mutation probability adjusted autonomously. The mutation probability can be independently adjusted to a critical value, and the individual genes are arbitrarily selected to implement a small range of mutations.

The randomized iterative process autonomously adjusts the mutation probability R. As:

$$R_o = 0.35 - \frac{0.25}{g^{0.0011}} \tag{17}$$

where g represents the self-adaptation time.

Seventh, evaluate the population state, project the fitness values of all individuals, find the optimal individual, and replace the old individual with the new one if the fitness of the new individual is higher than that of the original optimal individual.

Eighth, confirm whether the loop termination condition is satisfied, if so, output the final result, otherwise jump to the fourth step to continue the calculation, until the search for the optimal allocation of educational resources.

2) Educational resource allocation model based on differential evolutionary algorithm. According to the resource allocation step of differential evolutionary algorithm to design the allocation program. The assessment standard of the fitness function is the size of the mean square deviation of the ratio of each higher education institution. The initial total value of the degree of adaptation is set to 0, the number of resources in each higher vocational institution before allocation is expressed as M_i, the number of allocated resources in each institution is expressed as m_i, and the total number of students in each institution is n_i, then the degree of adaptation can be expressed as equation (18):

$$Fitness = Fitness + \left(\frac{M_i + m_i}{n_i} - \frac{\sum M_i + \sum m_i}{\sum n_i} \right)^2 \tag{18}$$

where: $Fitness, M_i, \frac{\sum M_i + \sum m_i}{\sum n_i}$ are known and determined, so equation (18) has and only one variable, the number of allocated resources m_i. Compare the total value of fitness for each program, and the program corresponding to the one with the smaller total value of fitness is the best allocation program.

5. Experimental analysis and system validation

5.1. Performance Analysis of Improved PBFT Consensus Algorithm

In order to verify the effectiveness of the improved PBFT consensus algorithm (NR-PBFT) in this paper without reducing the fault tolerance and security of the system, the experiment uses the AlgoRand consensus algorithm and the PBFT algorithm as the comparison algorithm, comparing the performance of the three algorithms in terms of throughput, latency, stability and security. In this experiment, Windows system is chosen as the experimental environment, simlock blockchain simulator is chosen to simulate the blockchain network, Gradle-6.3 tool is used to build, and the experimental data is drawn by MATLAB. In the experiments of this paper, certain parameters need to be set, and some assumptions are needed at the same time:

1) In order to reduce the impact of block size on the experimental data, the transactions contained in a block are fixed at 150 in the experiments of this paper.

2) In the security test, the attack rule is defined as a denial-of-service attack when the gap between the evil node number and the master node number is less than or equal to 2. It is also necessary to ensure that the nodes dropped due to the attack can be recovered and joined into the system.

5.1.1. Throughput testing. In order to verify the throughput of the NR-PBFT algorithm at different scales, set up under a blockchain network with different numbers of nodes, count the average time for the three algorithms to complete 10,000 transactions respectively and calculate the average throughput (TPS) according to the formula, and the results are shown in Figure 7. It can be seen that with the increase of the total number of nodes in the system, the TPS of the three algorithms have different degrees of decline, but the TPS of the NR-PBFT consensus algorithm is significantly higher, and with the increase in the number of nodes this gap will become bigger and bigger. The overall performance of the algorithm is higher than that of the other two algorithms, which achieves the purpose of improving the throughput of the system.

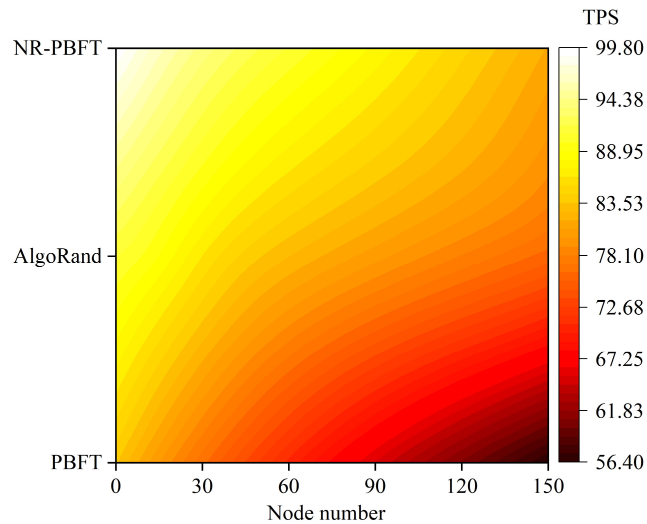

Fig. 7. Node number and TPS

5.1.2. Time delay testing. In order to verify the latency of the NR-PBFT algorithm at different scales, set up under the blockchain network with different numbers of nodes, statistics on the average latency of the three algorithms to complete 10,000 transactions respectively, and the statistical results are shown in Figure 8. With the increase of consensus nodes in the system, the latency of the three algorithms have different degrees of growth, compared to the AlgoRand algorithm in the longest latency is due to the AlgoRand algorithm in the consensus to add a leader and verifier random selection, affecting the performance of the system. nr-PBFT consensus algorithm, although in the view switching protocol to add a random number generation and random selection of the master node process, it avoids the continuous view switching problem and improves the three-phase communication protocol of the PBFT algorithm, which makes the NR-PBFT algorithm reduce the transaction delay of the PBFT algorithm on the basis of guaranteeing the security and reliability, shorten the confirmation time, and improve the availability of the system.

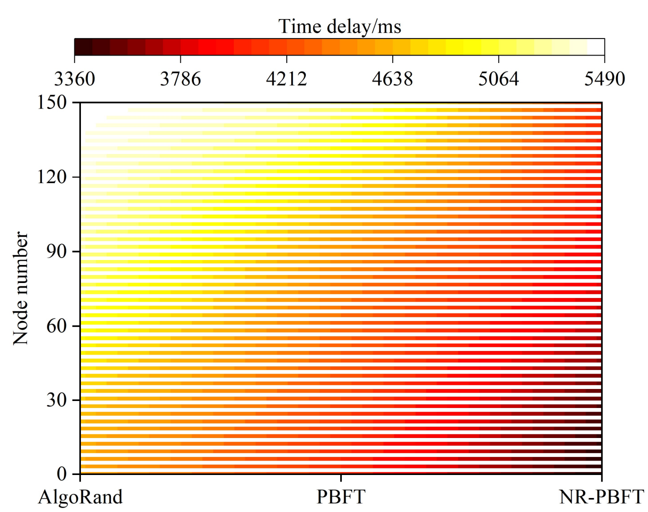

Fig. 8. Comparison of time delay

5.1.3. Stability testing. The stability test is mainly to verify that the NR-PBFT algorithm can run more stably in a large-scale blockchain network. Set in a blockchain network with 150 nodes, the statistics of view switching times under different Byzantine node ratios are shown in Fig. 9, where the size of the scatter point indicates the number of view switching times, and the larger the scatter point indicates the more view switching times. It can be seen that the view switching times of both algorithms are very small in the case of a low percentage of Byzantine nodes, and with the increase of Byzantine nodes, the number of view switching times grows to varying degrees, but at the same time, the number of view switching times of the NR-PBFT algorithm has always been smaller than that of the PBFT algorithm. This is due to the fact that the NR-PBFT consensus algorithm can avoid the attacks launched by the evil nodes according to the selection order of the master node, which reduces some of the view switches due to malicious attacks, enhances the security and stability of the system, and makes the system stable and safe to operate in large-scale networks.

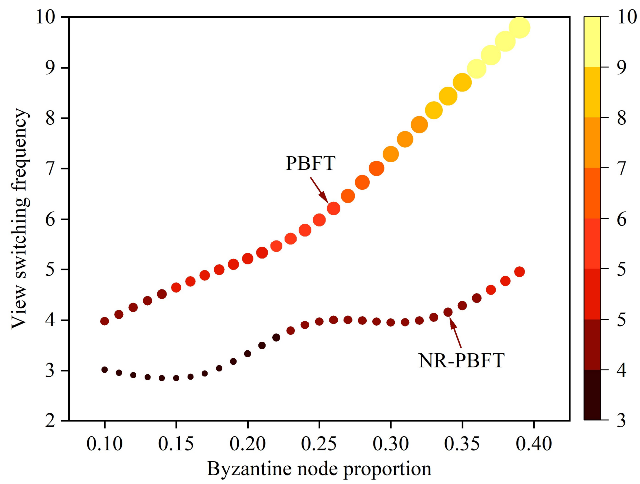

Fig. 9. View switching frequency

5.1.4. Security analysis. The PBFT consensus algorithm has no punishment for the Byzantine nodes and the Byzantine nodes will always exist in the system, which leads to a decrease in the security of the system.The NR-PBFT algorithm sets up the reputation nodes in the system, and the nodes participating in the consensus will be directly deducted from the reputation score once they become Byzantine nodes. Once the node status is recognized as suspicious node, the consensus node will be restricted to participate in consensus for a period of time. When the node status is recognized as a malicious node, the consensus node is directly excluded from the blockchain, which greatly reduces the probability of Byzantine nodes to do evil again, thus improving the security of the system. In order to quantify the security of the system, set up Byzantine nodes in the system and check the change of the number of Byzantine nodes with the increase of consensus times. In the experiment, the number of consensus is set to increase from 0 to 20 times with a step size of 2. In order not to lose the generality, 50 rounds of consensus are repeated, and the final value of the number of Byzantine nodes under different consensus times is the mean value of the 50 consensus times.The results of comparison of the number of Byzantine nodes in the consensus algorithms of PBFT and NR-PBFT are shown in Fig. 10. From the experimental results, it can be seen that the number of Byzantine nodes in the PBFT consensus algorithm remains unchanged with the increase in the number of consensus rounds, and the number of Byzantine nodes in the NR-PBFT consensus algorithm shows a decreasing trend until the number of Byzantine nodes is 0. Therefore, the NR-PBFT consensus algorithm improves the security of the system.

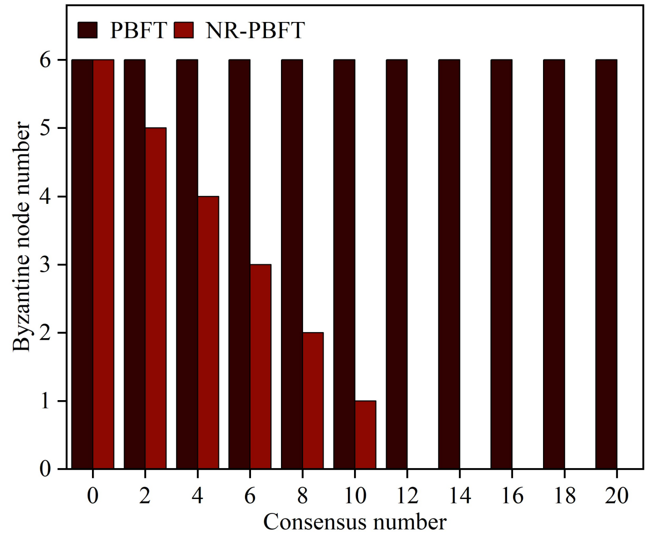

Fig. 10. Comparison of number of Byzantine nodes

5.2. Performance Analysis of Educational Resource Allocation

Before allocating educational resources, it is first necessary to verify whether the differential evolution algorithm can allocate system resources to each edge node in a balanced way, so as to lay the foundation for the balanced allocation of educational resources within each edge node. Taking the load balancing standard deviation as a measure, the smaller the standard deviation is, the better the algorithm's performance is for the allocation of system resources, and the more balanced the system resources allocated to each edge node. Table 1 shows the load balancing standard deviation of system resources for 15 randomly selected edge nodes before and after using differential evolution. From the table, it can be seen that the load balancing standard deviation of each edge node is significantly reduced after using differential evolution algorithm to allocate resources within the system, and the mean value decreases from 12.275 to 2.792, with a decrease of 77.25%. It shows that the differential evolutionary algorithm can effectively realize the balanced allocation of system resources in the edge nodes and provide technical support for the balanced allocation of educational resources in each edge node.

Table 1. Load balancing standard deviation

Marginal node	Before	After
1	10.079	1.830
2	9.486	4.459
3	13.322	1.037
4	19.724	4.630
5	7.899	0.085
6	8.086	1.575
7	5.862	3.296
8	14.833	4.651
9	13.184	1.222
10	5.258	4.145
11	15.025	1.754
12	14.770	1.007
13	10.240	4.182

14	17.022	3.878
15	19.342	4.123

After using the differential evolutionary algorithm to realize the balanced allocation of system resources in each edge node, the next step is to allocate educational resources through the educational resource allocation model constructed based on the differential evolutionary algorithm. The data used in the educational resource allocation experiment are shown in Table 2, where Numbering indicates the number of higher vocational colleges and universities, and a total of 15 higher vocational colleges and universities have been counted in the experiment.Teacher indicates the online course resources uploaded by teachers, and for the convenience of analysis, the teacher resources in the following section indicate the online course resources uploaded by teachers.Proportion indicates the student-teacher ratio of different higher vocational colleges and universities, and the smaller the ratio is, the more effective each teacher can tutor the students. The smaller the student-teacher ratio, the more effective each teacher is in counseling students. Taking digital book resources as a proxy, PCB denotes the number of books per student, and its larger value indicates that more resources are allocated to students. The statistics in the table show that there is a big gap between the student-teacher ratio and the average number of books per student in some higher vocational colleges and universities, indicating that the original unbalanced distribution of educational resources is more serious.

Table 2. Statistics of educational resources

Numbering	Student	Teacher	Proportion	Book	PCB
1	20028	1540	13.005	462774	23.106
2	6509	2702	2.409	934491	143.569
3	11185	1812	6.173	330792	29.575
4	18086	2842	6.364	1626844	89.950
5	14741	1790	8.235	903002	61.258
6	18021	3206	5.621	761857	42.276
7	7885	3556	2.217	741138	93.993
8	8204	2186	3.753	660254	80.480
9	9328	1126	8.284	714276	76.573
10	12222	2776	4.403	1246224	101.966
11	9438	1515	6.230	1577841	167.180
12	9627	729	13.206	1027246	106.705
13	6397	2097	3.051	1293815	202.253
14	12240	1824	6.711	1320906	107.917
15	18168	2538	7.158	1678024	92.362

In order to improve the original uneven distribution of educational resources among higher vocational colleges and universities, the educational resource allocation model constructed by using the difference plan algorithm in the educational resource sharing system in this paper focuses on appropriately lowering the student-teacher ratio and increasing the average number of books per student in the process of resource allocation, so that the student-teacher ratio and the average number of books per student among higher vocational colleges and universities converge to a balanced state as much as possible.

5.2.1. Allocation of student-teacher ratios. According to the algorithmic objective, the educational resource allocation model based on differential evolutionary algorithm will prioritize the allocation of teacher resources to higher vocational colleges with higher student-teacher ratios, so as to reduce the total value of the adaptation degree. The model will compare the fitness value of each allocation scheme and take the allocation result corresponding to the time when the fitness takes the minimum value as the optimal scheme, thus reducing the gap of teacher resources among higher vocational institutions. Table 3 shows the results of the educational resource allocation model based on Differential Evolutionary Algorithm (DE) and Particle Swarm Optimization Algorithm (PSO) for 1500 teachers. As can be seen from the table, the allocation results of both models reduce the student-teacher ratio of higher vocational institutions, and five institutions with higher student-teacher ratios, i.e., institutions 12, 1, 9, 5, and 15, are allocated new teacher resources.The DE algorithm outperforms the PSO algorithm for the allocation of teacher resources, and all of them have student-teacher ratios of less than 10 percent after allocation. In contrast, the PSO algorithm reduces the student-teacher ratio less, and the student-teacher ratio of institution 1 is still above 10%. It shows the effectiveness of the educational resource allocation model constructed based on DE algorithm in this paper.

Table 3. Changes in student-teacher proportion

Numbering	Student	Teacher	Proportion	Teacher (PSO)	Proportion (PSO)	Teacher (DE)	Proportion (DE)
1	20028	1540	13.005	282	10.992	489	9.871
2	6509	2702	2.409	0	2.409	0	2.409
3	11185	1812	6.173	0	6.173	0	6.173
4	18086	2842	6.364	0	6.364	0	6.364
5	14741	1790	8.235	259	7.194	289	7.090
6	18021	3206	5.621	0	5.621	0	5.621
7	7885	3556	2.217	0	2.217	0	2.217
8	8204	2186	3.753	0	3.753	0	3.753
9	9328	1126	8.284	271	6.677	293	6.574
10	12222	2776	4.403	0	4.403	0	4.403
11	9438	1515	6.230	0	6.230	0	6.230
12	9627	729	13.206	297	9.383	396	8.557
13	6397	2097	3.051	0	3.051	0	3.051
14	12240	1824	6.711	0	6.711	0	6.711
15	18168	2538	7.158	391	6.203	33	7.067

Figure 11 shows the trend of student-teacher ratio before and after the allocation of teacher resources by the educational resource allocation model based on the DE algorithm. From the figure, it can be arbitrarily seen that before the allocation of the student-teacher ratio of each institution, the student-teacher ratio of Institution 12 is as high as 13.206, while the student-teacher ratio of Institution 7 is only 2.217, and the original gap in the allocation of teacher resources is large. After the allocation, the gap in the student-teacher ratio of each institution was significantly reduced. Thus, it is verified that the model can effectively improve the problem of unbalanced distribution of faculty resources among institutions in the allocation of faculty resources.

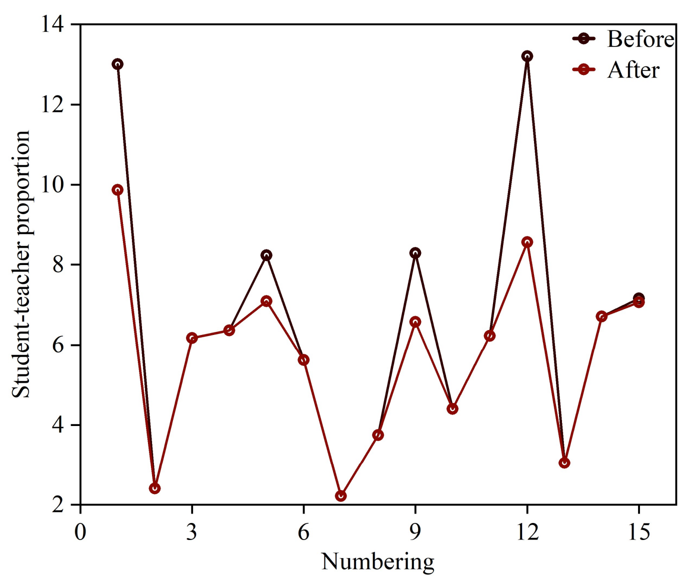

Fig. 11. The student-teacher proportion of before and after allocation each school

5.2.2. Allocation of books per pupil. Table 4 shows the results of the allocation of 150,000 digital book resources by the educational resource allocation model based on DE algorithm and PSO algorithm. From the table, it can be seen that the two algorithms have allocated new book resources for the five institutions 1, 3, 6, 5, and 9 which have less number of books per student. The number of books per student after allocation has a certain magnitude of improvement compared to the pre-allocation, and the DE algorithm has a slightly larger magnitude of improvement than PSO. However, on the whole, the improvement of the two algorithms is almost negligible. Thus, relying only on the resource allocation model constructed in this paper does not achieve complete allocation equilibrium, and the algorithm in this paper can only ensure that the digital education resources of each higher education institution in the system are allocated in a reasonable and balanced way as much as possible. If we want to improve the problem of unbalanced distribution of educational resources due to the large base number, we need to fully consider whether the distribution of book resources is reasonable in the initial book allocation stage, rather than relying only on the educational resource allocation model to allocate new books to solve the problem of unbalanced resources in the number of books among higher vocational colleges and universities.

Table 4. Changes in books per student

Numbering	Student	Book	PCB	Book (PSO)	PCB (PSO)	Book (DE)	PCB (DE)
1	20028	462774	23.106	35732	24.890	47200	25.463
2	6509	934491	143.569	0	143.569	0	143.569
3	11185	330792	29.575	33468	32.567	39836	33.136
4	18086	1626844	89.950	0	89.950	0	89.950
5	14741	903002	61.258	23584	62.858	25836	63.011
6	18021	761857	42.276	30260	43.955	27469	43.800
7	7885	741138	93.993	0	93.993	0	93.993
8	8204	660254	80.480	0	80.480	0	80.480
9	9328	714276	76.573	26956	79.463	9659	77.609
10	12222	1246224	101.966	0	101.966	0	101.966
11	9438	1577841	167.180	0	167.180	0	167.18
12	9627	1027246	106.705	0	106.705	0	106.705
13	6397	1293815	202.253	0	202.253	0	202.253
14	12240	1320906	107.917	0	107.917	0	107.917
15	18168	1678024	92.362	0	92.362	0	92.362

5.3. Shared System Performance Testing

5.3.1. Test preparation. In the process of analyzing and testing the application effect of higher vocational educational resource sharing system incorporating edge computing, a comparative test environment is constructed, in which the control groups involved in the test are the educational resource data sharing method based on GT-DEMATEL (Method 1) and the educational resource data sharing method based on Asmuth-Bloom algorithm (Method 2), respectively.

The digital educational resources of higher vocational colleges and universities M, H, G, J, S, and K are used as the specific test data, including video tutorials, online courses, digital book resources, and teachers' teaching resources, which are represented by R1-R4, respectively, and the specific data scale is shown in Table 5. In the specific testing process, the scale size and coverage of digital resources are mainly analyzed, in which the coverage mainly refers to the system's coverage of all test data, and the scale size mainly reflects the redundancy of the system, i.e., the higher the coverage, the smaller the scale of redundancy within the system, indicating that the application of the sharing method in this paper is more effective.

Table 5. Test data size

School	R1/GB	R2/Hour	R3	R4/GB

M	122.74	88	457836	17.83
H	118.43	79	503948	16.49
G	93.82	63	433261	15.21
J	91.63	61	475692	11.49
S	104.58	65	451843	13.28
K	103.97	67	519237	14.37

5.3.2. Test results and analysis. The test results of different sharing systems are shown in Table 6. From the results shown in the table, it can be seen that the GT-DEMATEL-based educational resource data sharing method (Method 1) has the largest redundancy scale among different resources, and accordingly, it has the lowest sharing coverage for the resources in the system. The educational resource data sharing method (Method 2) based on Asmuth-Bloom algorithm has lower resource redundancy scale and higher sharing coverage compared to Method 1. And the educational resource sharing system incorporating edge computing in this paper has lower resource redundancy scale and higher resource coverage compared to Method 1 and Method 2. For four different kinds of higher education resources, the sharing coverage of this paper's method is above 95%, and its application effect is the best among all methods.

Table 6. Test results of different methods

Resources	Index	Method 1	Method 2	Ours
R1	Scale/GB	155.79	126.75	1.69
	Coverage/%	75.47	80.04	99.73
	Ratio	2.06	1.58	0.02
R2	Scale/Hour	137	96	14
	Coverage/%	67.61	77.30	96.69
	Ratio	2.03	1.24	0.14
R3	Scale	910071	457560	43423
	Coverage/%	67.98	83.90	98.47
	Ratio	13387.33	5453.64	440.98
R4	Scale/GB	24.75	14.30	2.08
	Coverage/%	72.09	83.87	97.65
	Ratio	0.34	0.17	0.02

In order to test the sharing efficiency of the educational resource sharing system constructed by different methods, the number of front-end concurrently requested resource data that can be processed per second by the three methods is the most critical index to test the sharing efficiency, and the results are shown in Figure 12. From the experimental results, it can be seen that among the three methods, the method of this paper has the highest number of resource data per second when sharing educational resource data, and the number of concurrent front-end requests per second of Method 1 is also relatively high, but the change is unstable, and it is easy to have problems such as interruption and loss of data in the sharing transmission, etc. The process of resource data sharing and transmission of Method 2 is more stable, but compared with the method of this paper, it is more stable. The resource data sharing and transmission process of Method 2 is more stable, but compared with the method of this paper, the number of concurrently requested resource data that can be processed by this method per second is lower. Comprehensively analyzing the above analysis, it is concluded that this paper's method has a relatively high efficiency of data sharing of higher vocational education resources.

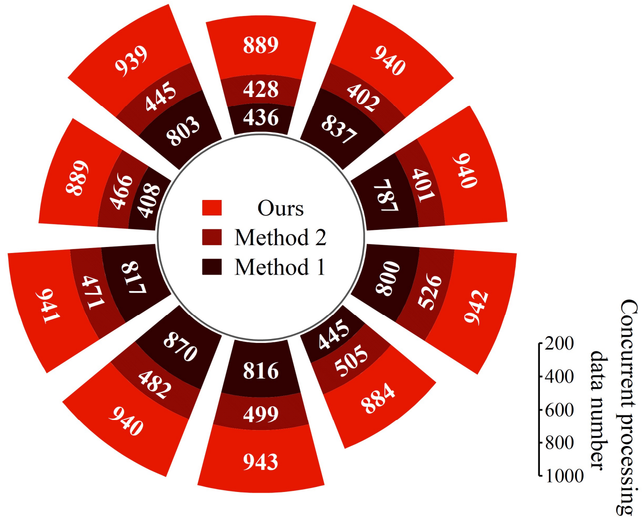

Fig. 12. The number of data that can be processed per second in shared medium

On the basis of the above experiments, in order to test the reasonableness of the integration of edge computing in this paper, the experimental process is set up with different sharing and transmission interruptions, and during the process of sharing and transmission of educational resource data, a number of edge nodes are randomly set up in the communication nodes of the system to monitor the number of lost and abnormal data entries in the different resource packages, and the statistical results are shown in Table 7. From the experimental results in the table, it can be seen that the method of this paper due to the integration of edge computing technology, so the number of lost and abnormal data in the process of resource data sharing and transmission is 0, while using the other two methods of educational resource data sharing, the resources in the transmission of the user side, by the external environment and other factors, there are different degrees of packet loss phenomenon. Summarizing the above results, this paper incorporates edge computing in the construction of higher education resource sharing system with obvious rationality, which has important application value for the security and integrity of the data transmission process of shared resources.

Table 7. Statistical results of different methods

Test frequency	Ours	Method 1	Method 2
1	0	26	5
2	0	28	13
3	0	41	10
4	0	27	12
5	0	15	5
6	0	15	11
7	0	10	9
8	0	19	9
9	0	36	6
10	0	23	5

6. Concluding remarks

In this paper, a higher vocational education resource sharing system integrated with edge computing is proposed in the perspective of “blockchain+education”, which solves many problems in the traditional higher vocational education resource sharing model by combining the security and trust mechanism of blockchain technology with the efficiency and real-time performance of edge computing. The improved PBFT consensus algorithm and educational resource allocation algorithm are proposed, and the significant advantages of these algorithms in improving system performance, resource sharing efficiency and security are experimentally verified.

Future research can further explore the deep integration applications of blockchain and edge computing in higher vocational education, such as blockchain-based credit authentication and academic authentication, and the use of edge computing to realize intelligent teaching and tutoring. Meanwhile, with the popularization of 5G technology and the wide application of IoT devices in the field of education. How to better integrate these emerging technologies to provide stronger technical support for the sharing of resources in higher education is also a direction worthy of in-depth research.

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