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Creativity in Trusted Data: Research on Application of Blockchain in Supply Chain

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Abstract

Creative computing is very popular in recent years and has great potential. The introduction of systematic creative mechanisms and principles can provide solutions to practical problems, such as potential forgery and tampering of trade data in traditional supply chains. Guided by being creative, this paper proposes a new trusted data management scheme based on blockchain. First, a smart contract suitable for supply chain is designed to code trade rules in order to prevent performance risks and improve the credibility of trade data processing. Then, a ZSS04 scheme and sampling techniques are used to complete transaction data integrity check. Furthermore, an optimized PBFT consensus mechanism is proposed to achieve efficient, low cost, and scalable transaction data management. Finally, the trusted data management in untrusted environment is implemented by using the native characteristics of blockchain. Results show that the scheme can provide new ideas and technical support for transaction data management in supply chain.

Keywords: creative computing; blockchain; supply chain; smart contract; PBFT

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1. Introduction

The earliest definition of creativity refers to the ability to produce new and useful products. Creativity is used in a wide range of applications [1]. Creative computing is a new research field. The intuitive explanation of creative computation is that computing is done through an innovative method. However, in the field of software engineering, the computation in creative computation refers to software development. Therefore, creative computing in software engineering develops software with a creative method [2]. The specific meaning of creativity is to use the ideas of other disciplines to develop software, such as mathematics, physics, chemistry, and so on [3]. Therefore, the most important feature of creative computing is interdisciplinary, and because of this feature, creative computing can inject new vitality into software development.

Since the European Renaissance in the 14th century, when capitalism sprouted, global trade has been the most powerful “wealth creator” in human history. However, in the practice of promoting the rapid development of the supply chain, the key problem to be solved is to ensure the trustworthiness of the transaction data [4]. In the process of organizational cooperation, the transaction information provided by trade subjects is true and reliable without monitoring or controlling. Over the years, in order to establish trust mechanism in trade, trust institutions and trust instruments came into being. The traditional centralization of third-party data management not only lacks technical credibility, but also has many uncontrollable factors such as inefficiency, high cost, and easy attack [5-6]. All these problems severely restrict the healthy development of the supply chain. Therefore, it is particularly important to solve the problem of trustworthiness of transaction data in the supply chain.

From the point of view of data management, a trusted database management system ensures the credibility of the

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system from three levels [7], that is, the credibility of storage, the credibility of processing, and the credibility of external access. This article focuses on the credibility of data storage and the credibility of processing. Once the transaction is completed, there will be no malicious tampering or loss of transaction information by the attacker.

At present, supply chain management and information technology is a common research hotspot in academia and industry. In academic circles, reference [8] provides the proof of trading information by means of big data technology. Reference [9] puts forward that part of the B2B+B2C supply chain is placed in ERP. However, ERP is a very complex information management system in enterprise management, and it cannot effectively ensure the full credibility of transaction data. Reference [10] discusses the key factors, common strategies and design directions of supply chain management and control. The characteristics and advantages and disadvantages of various modeling methods in supply chain management and control are analyzed in reference [11]. Reference [12] proposes several key indicators and a measurement framework for evaluating supply chain performance. Reference [13] presents an information supply chain management and control scheme based on the SCOR model, which enables computers to assist and monitor the flow of the supply chain. Reference [14] designs a supply chain information interaction model based on RFID and Internet of things technology, which improves the efficiency of the supply chain in information acquisition, data circulation, and overall monitoring. In industry, WAL-MART has built a low-cost and efficient loan system using UPC technology and RFDC technology, which has greatly improved the gross interest rate [15].

The solutions proposed above are all control work of supply chain trade data on the basis of trusted third parties, which cannot guarantee the absolute safety and reliability of trade data. This paper proposes a research method to guide the research of trusted data management methods in creative supply chains. The result of this research is a method of trusted data management in the supply chain that incorporates ideas, theories, or laws in the discipline of cryptography [16].

Section 2 of this paper briefly introduces bilinear pairing, smart contract, blockchain, and creative computing. Section 3 presents a supply chain trusted data management solution. Section 4 provides the feasibility analysis and consensus algorithm verification for the supply chain trusted data management scheme. Finally, the paper is summarized and the next step is forecasted.

2. Preparatory Knowledge

2.1. Bilinear Pairing

Definition 1 Suppose G_1 is a multiplicative cyclic group of order q, G_2 is a multiplicative cyclic group of order q, and a generator of G_1 is p. Assuming that the discrete logarithm problem on G_1 and G_2 is difficult, if the following three properties are satisfied, the mapping $e: G_1 \times G_1 \to G_2$ is called bilinear mapping.

1) Bilinearity: for $\forall Q \in G_1$, $\{a,b\} \subseteq Z_q^*$, there is $e(ap,bQ) = e(p,Q)^{ab}$.

2) Non-degenerate: $\exists\{p,Q\} \subseteq G_1$, Satisfy $e(p,Q) \neq 1$.

3) Computability: for $\forall\{Q,R\} \subseteq G_1$, the existence of polynomial time algorithms can calculate $e(Q,R)$.

2.2. Smart Contract

The smart contract [17] was first proposed by cryptographer Nick Szabo: a smart contract is a computer protocol. It facilitates, verifies, or enforces contract negotiation and fulfillment, and it supports Turing-complete calculations. In fact, it works like a conditional statement if-then in a computer programming language. The smart contract will be triggered automatically, and then the corresponding terms will be executed. Otherwise, it will not be executed.

2.3. Blockchain

Blockchain is a brand new distributed accounting system [18]. Multiple independent nodes participate in maintenance. It has original features such as being unchangeable, centerless, and traceable. Blockchains divide the data into different blocks, each of which consists of a block head and a block body. The block head stores the hash value of the precursor block, and the block body stores the data. The blocks are connected in turn to form a complete data chain, as shown in Figure 1.

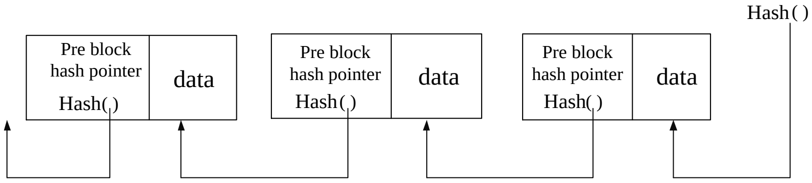

Figure 1. Schematic diagram of blockchain

2.4. Creative Computing

Creative computing comes from a hypothesis by Professor Yang of De Montfort University in England [19]. Usually, people study how to use computer science to assist in the development of other disciplines, such as computer assisted instruction and computer aided art. Conversely, other disciplines should also assist in the development of computer science. In the field of software engineering, there are always problems that cannot be solved so far. Then, with the theories, ideas, laws, or methods of other disciplines, the development of computer software can inject new vitality into the field of software engineering. It is the meaning of "interdisciplinary" to solve the unsolvable problems in the field of software engineering with the ideas of other disciplines. Therefore, the emerging research field of creative computing has emerged.

3. Design of Trusted Data Management in Supply Chain

3.1. Creative Direction of Supply Chain

The specific research ideas in this paper are divided into three steps, as shown in Figure 2.

Figure 2. Research contents

a. Research on the creative direction of supply chain data management, that is, research on the problems existing in traditional supply chains.

b. Under the guidance of creative direction (i.e., problem), the model structure of creative supply chain data management is designed.

c. The research method is proven by experiments.

In view of the problems existing in traditional supply chain data management methods, creative computing needs to solve efficiency problems, trustworthiness problems, cost problems, and safety problems, as shown in Figure 3.

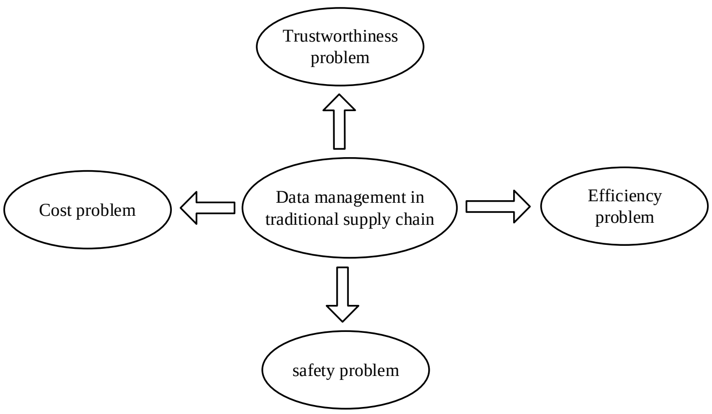

Figure 3. Problems in data management of traditional supply chain

The most important characteristic of creative computing is interdisciplinary [20]. Applying theories, rules, or methods of other disciplines to software design brings new vitality to software development. Therefore, creative computing can apply theories, rules, or methods in the field of supply chain to software design and guide the development of trusted software.

3.2. Model Structure Design

This paper first studies the creative direction of the traditional supply chain management methods, after getting the creative direction. Through the collation and research of general research methods, the definition and standard of research methods have been obtained. Based on this definition and standard, the paper designs the implementation scheme of the model. The scheme consists of four main units: the trade agent ***P***, the trade center ***S***, the audit center ***B***, and the Ethereum Blockchain business network ***C***. The model structure is shown in Figure 4.

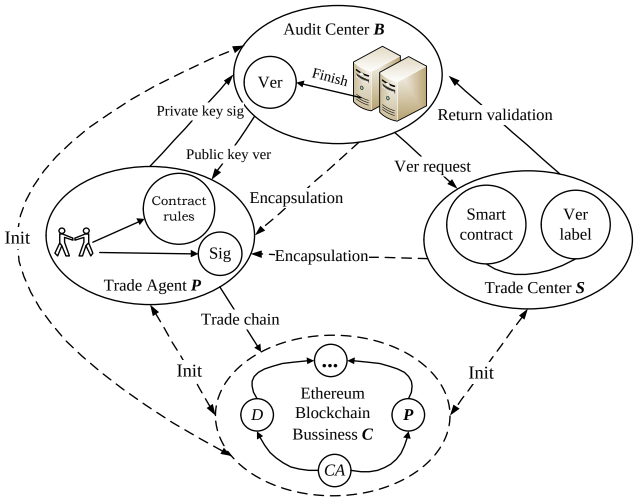

Figure 4. Schematic diagram of system model

The process of this scheme is specifically stated as follows:

Step 1 Each principal unit in the scheme first completes the certification work with a Certificate Authority (CA) and applies for a public key digital certificate.

Step 2 The trading rules are freely formulated between the trading agents ***P***. The trade center ***S*** uses smart contract to computerize the trading rules. When the trading behavior is legal, the intelligent contract will be triggered and the transaction will be generated. Information related to transactions is distributed to the audit center ***B***.

Step 3 The audit center ***B*** verifies the authenticity of the signature by using the public key of the trading agent ***P***. If true, it issues an evidence challenge request to trade center ***S***.

Step 4 The trade center ***S*** sends the evidence to the audit center ***B***. The audit center ***B*** verifies whether the bilinear equation is established or not. If the equation is established, the audit center ***B*** and the trade center ***S*** will challenge the evidence, the smart contract code, and the related transaction information. It is encapsulated in JSON format and sent to the trading agent ***P*** for signature.

Step 5 Send the transaction signed by the trading agent ***P*** to the Ethereum blockchain business network ***C***. Write the transaction information into the Ethereum blockchain network through the distributed multi-node consensus mechanism algorithm.

3.3. Scheme Construction

3.3.1. Parameter

The parameters in the scheme and their meanings are as follows:

1) The trade agent ***P***: Primary, secondary, tertiary and other suppliers/dealers, financial institutions, and major participants in trading activities in the supply chain.

2) The trade center ***S***: Responsible for the generation of transactions (smart contracts) and a series of key generation tasks to provide short-term storage of transaction data.

3) The audit center ***B***: The domain expertise organization responsible for key verification and transaction data integrity audit enforcement.

4) The Ethereum blockchain business network ***C***: The data created by the audit center ***B*** together with the trade center ***S*** is registered. This network contains all the consensus subject units D, the trade agent ***P***, the registration center CA, and other consensus subjects. The identity verification of each principal unit is completed by the CA, and the CA distributes the public key certificate to the subject unit past the audit.

5) Let G_1 and G_2 be multiplicative loop groups of order prime number q, and there is a bilinear map $e: G_1 \times G_1 \to G_2$ between them. p is a generator of G_1, a cryptographic hash function $H_1: \{0,1\}^* \to G_1$, and a cryptographic hash function $H_2: \{0,1\}^* \to Z_q^*$.

3.3.2. Scheme Construction Process

This scheme is constructed by four phases: the initial stage of the transaction, the stage of transaction confirmation, the stage of transaction verification, and the stage of registration.

1) The initial stage of the transaction

i. First, the trade agent ***P***, the trade center ***S***, the audit center ***B***, and other consensus entities need to verify the identity information at the registry CA. If it passes, it issues a certificate for identifying and authenticating the network entity. At the same time, initialize the Ethereum blockchain business network ***C***.

ii. The trade agent ***P*** can freely develop a trading smart contract that suits its interests. Take the smart contract model for the first-purchasing pledge purchase in the supply chain as an example, as shown in Figure 5. The procurement rules of supply chain companies and suppliers and the sales rules of supply chain companies and distributors use the Solidity language to write smart contracts. A contract consists of a set of code (contract function) and data (contract state) and is written into the blockchain distributed network system. The registry CA initializes a contract with the trade entity P when it registers an account. When the trade agent ***P*** invokes a contract, the contract first verifies the identity of the initiator of the transaction and then performs contract operations if the authentication passes. When a condition in the contract is triggered, the corresponding contract terms are automatically executed.

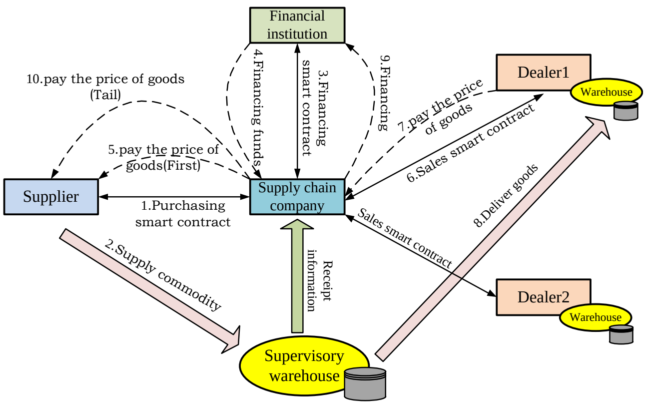

Figure 5. An intelligent contract model for procurement of goods in advance in the supply chain

2) The stage of transaction confirmation

i. The trade center ***S*** divides the transaction data T into i blocks by attribute, that is, $\{t_1, t_2, \cdots, t_i\} \subseteq Z_q^*$. q is a prime number, and the transaction data set is $T = \{ j | t_j, 1 \le j \le i \}$. The trade agent ***P*** selects a random signature key pair (rpk, rsk), $x \in Z_q^*$, $y \leftarrow G_1$ and calculates the public key $p_{pub} \leftarrow xp$. The trade agent ***P*** public *Param*: rpk, p_{pub}, p, i, j, y, $e(y, p_{Pub})$, but confidential *Param*: x and rsk.

ii. In trade center ***S***, the verification label $\gamma_j \leftarrow p\left(x + H_2(\omega j) y^{t_j}\right)^{-1} \in G_1$ is taken for the data t_j in the transaction. Among them, $1 \le j \le i$, where ωj is a random number RN ($RN \in Z_q^*$, and it be used to identify the transaction data T) connected to j. The data verification label is denoted as the set $\xi = \left\{ j \middle| \gamma_j, 1 \le j \le i \right\}$.

iii. To prevent malicious changes for transaction data T identifier RN, calculate the label of transaction data T $tag = RN \parallel Sign_{rsk}(RN)$. Among them, $Sign_{rsk}(RN)$ uses the private key rsk to sign RN.

3) The stage of transaction verification

i. The trade center ***S*** will verify that the required data (ξ, rpk, i, p_{pub}) is sent to the audit center ***B***. After the verification data is received by audit center ***B***, illegal tampering with transaction data T will be detected during the evidence challenge stage, thus ensuring the security and integrity of transaction data.

ii. The audit center ***B*** uses the public key rpk to verify $Sign_{rsk}(RN)$ and outputs information if it verifies success. Otherwise, the verification is aborted.

iii. The audit center ***B*** passes the one-way hash function: g. Randomly extract i block indexes in m data blocks in transaction data T.

$$x_k = \left(\left(g^k(tag)\right) \bmod m\right) + 1, \left\{ k \middle| 1 \le k \le i \right\} \tag{1}$$

Where

$$g^k(tag) = \begin{cases} g(tag), & k \in \{1\} \\ g\left(g^{k-1}(tag)\right), & k \in [2, m] \end{cases} \tag{2}$$

Challenge request:

$$Challenge = \left\{ (j, \Gamma_j) \middle| x_1 \le j \le x_m, \Gamma_j \in Z_q^* \right\} \tag{3}$$

Equation (3) is sent to the trade center ***S***, and its calculation is:

$$\Phi = I + \zeta \cdot \sum_{j=x_1}^{x_m} t_j \Gamma_j \bmod q \tag{4}$$

$$\gamma = \prod_{j=x_1}^{x_m} \gamma_j^{\Gamma_j} \tag{5}$$

In Equation (4), $I \in Z_q^*$, $E = e\left(y, p_{pub}\right)^I \in G_2$, $\zeta = H_2(E) \in Z_q^*$.

Finally, the trade center ***S*** returns γ, Φ, and E as a verification certificate to the audit center ***B***. The audit center ***B*** verifies that equation $\zeta = H_2(E) \in Z_q^*$ is established and verifies the correctness of the received data by Equation (6).

$$\prod_{j=x_1}^{x_m} e\left(H_2(\omega j) y^{t_j} p + p_{pubj}, \gamma_j\right) = e(p, p) \tag{6}$$

4) The stage of registration

After verification by the audit center ***B***, the transaction data, trade subject information, verification data, and parameters are signed by ZSS04 short signature scheme and sent to blockchain business network ***C***. The audit center ***B*** and the trade center ***S*** encapsulate the validated transaction Tra_i, send the transaction to the trade agent ***P*** for verification, and then sign the transaction with its private key. Then, the transaction Tra_i is broadcast in blockchain business network ***C***, and all nodes receive and verify the transaction. After the optimized PBFT consensus mechanism, the transaction is written into the blockchain network. At this point, in the supply chain, a transaction data on chain storage is completed.

3.4. Optimization under the Guidance of Creative Direction

The biggest advantage of blockchain is that it can actively participate in verifying the authenticity of the block data through the incentive mechanism in the highly decentralized system [21]. However, this mechanism has apparent shortcomings in the application of trusted data management in supply chain trade: the main focus is on the consensus algorithm represented by the workload proof (PoW), which has high performance and inefficiency. In the Bitcoin trading system, the TPS is only 6.67, the generation of a block takes 10 minutes, and it takes up to 1 hour to determine the first transaction in the whole network. These performance issues are difficult to meet the actual needs of supply chain trade data management applications. Under the guidance of creative direction, this paper selects the ideas of management to select the primary node in the PBFT consensus algorithm. The specific optimizations are as follows:

1) All nodes in PBFT have equal opportunities to be primary nodes, but the non-honest nodes as primary nodes will significantly damage the consensus of the whole network node of blockchain system. Therefore, this paper takes trading volume as a necessary and sufficient condition to select primary nodes. Firstly, the nodes are initially ranked according to the transaction volume, and the top one takes the priority of the primary node, which can reduce the communication overhead caused by the cutter.

2) PBFT delivers messages through message broadcasting. In addition to the necessary three-stage protocol, it also proposes a checkpoint protocol, which significantly increases the network overhead. Therefore, this paper proposes the concept of time threshold, that is, each node clears the request log of the block every certain time, so as to reduce the network overhead of traditional PBFT garbage collection mechanism.

4. Feasibility Analysis of Scheme

4.1. Correctness Analysis

Lemma 1 The correctness of the proof (6).

Proof: Due to $\gamma_j \leftarrow p\left(x+H_2(\omega j)y^{t_j}\right)^{-1} \in G_1$, $\gamma = \prod_{j=x_1}^{x_m} \gamma_j^{\Gamma_j}$, $I \in Z_q^*$. Therefore, there is the following Equation (7): First, order $A = H_2(\omega j)y^{t_j}p + p_{pubj}$; $B = H_2(\omega j)y^{t_j}p + p_{pubk}$; $C = \sum_{j\neq k} I_j\left(H_2(\omega j)y^{t_j}p + p_{pubj}\right)$. If and only when $j \neq k$, then there are:

$$\begin{aligned}\prod_{j=x_1}^{x_m} e\left(H_2(\omega j)y^{t_j}p + p_{pubj}, \gamma_j\right) &= \prod_{j\neq k} e\left(A, I_j p\right).e\left(B, \left(H_2(\omega j)y^{t_j}p + \gamma_k\right)^{-1}(p-C)\right) \\ &= e(C,p).e(p,-C).e(p,p) = e(p,p)\end{aligned} \tag{7}$$

4.2. Performance Analysis

This section will simulate the optimized PBFT from the throughput and fault tolerance and compare with other blockchain platform algorithms to verify the effectiveness of the optimized PBFT consensus mechanism. The hardware environment of the experiment is CPU: Intel Core i5-6500 3.2GHz, memory: 16GB RAM. The algorithm is implemented by Java language and uses Multithreading technology to simulate multiple verification nodes.

Six different time intervals (10s, 25s, 5s, 20s, 65s, 100s) were selected in the experiment. Each time interval was tested ten times, and the average value was taken as the TPS (Transaction Per Second, the number of transactions per second). As shown in Figure 6, the total number of transactions represented by six intervals is represented by Matlab.

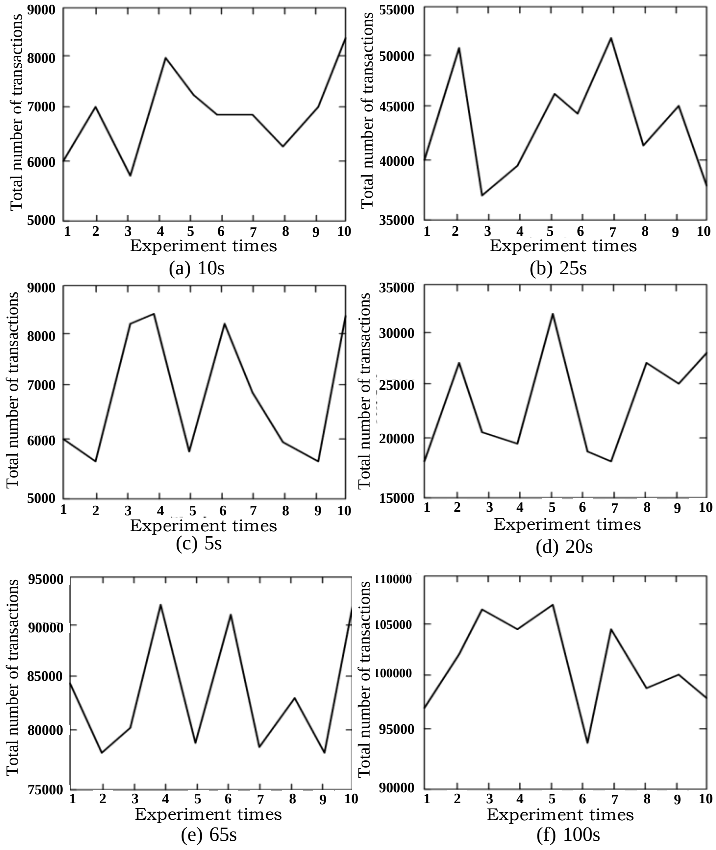

Figure 6. Change of total number of transactions when time interval changes

The average value of these 60 experiments is selected to represent the TPS of PBFT optimized in this paper. Among them, the relationship between the time interval of block generation and the change of TPS is shown in Figure 7. The optimized PBFT is compared with other blockchain algorithms, as shown in Figure 8.

In this paper, 20 nodes are selected to test the fault-tolerance of the optimized PBFT, and the values of the dishonest nodes f are set to 0, 1, 2, 3, 4, 5, 6, 7, and 8 in turn. The TPS index is used to judge whether the block is normal consensus of nodes, and the relationship between TPS and different number of non-honest nodes is obtained through experiments, as shown in Figure 9.

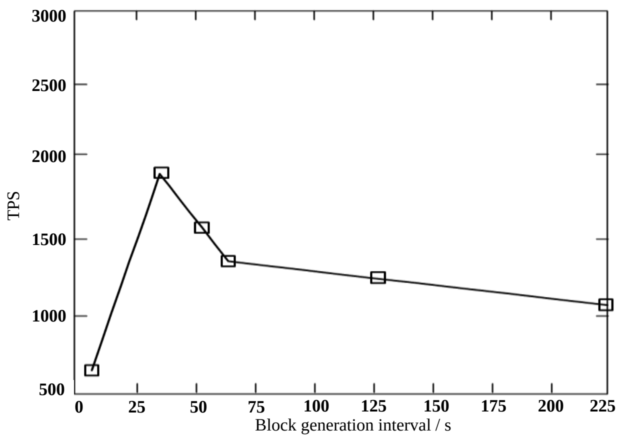

Figure 7. Change time of block time and TPS

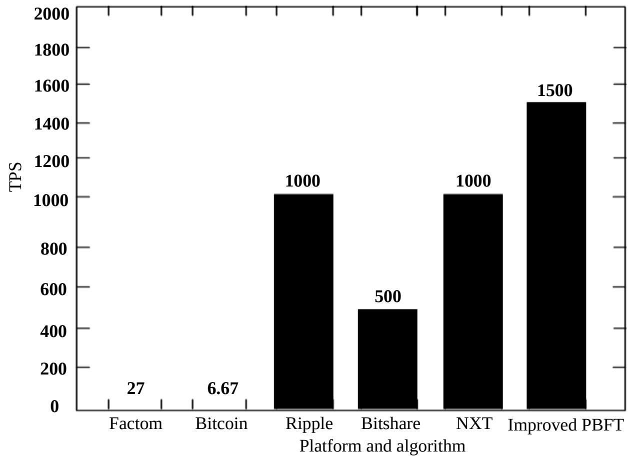

Figure 8. TPS comparison of optimized PBFT and other platform algorithms

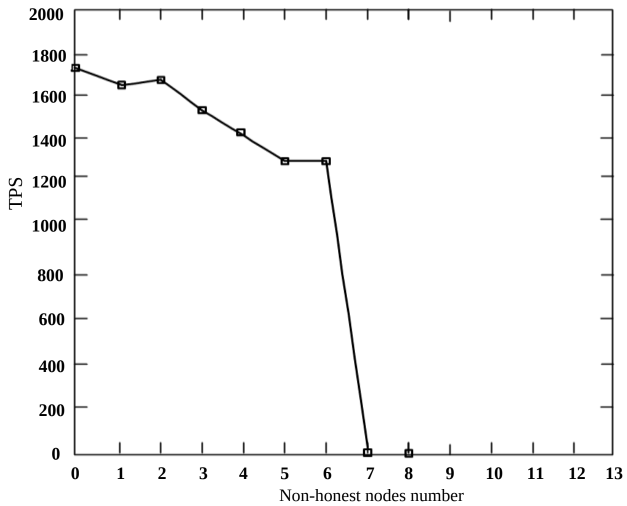

Figure 9. Relationship between number of non-honest nodes and TPS

From the graph, when the number of dishonest nodes reaches more than seven, the consensus between nodes will not be able to be completed normally, so new blocks cannot be generated.

4.3. Comparative Analysis of Research Methods

4.3.1. Comparison of Research Steps

Compared with the steps of existing general research methods, the research steps of new research methods truly embody the characteristics of interdisciplinary. The research steps of the new research methods include not only some research techniques of the general research methods, but also the related knowledge of cryptography, distributed accounting technology, and software engineering. The research steps of the new research methods include integrating the ideas, theories, rules, or methods of selected disciplines into the traditional supply chain software design methods, which are not included in the general research methods.

4.3.2. Comparison of Research Technology and Activity

The research techniques used in the new research methods are more abundant than those used in the existing general research methods. Moreover, the new research method uses the optimized PBFT consensus algorithm to improve efficiency while ensuring distributed consistency. These technologies are able to maintain the vitality of the research methodology of the trusted data management in the creative supply chain.

4.3.3. Comparison of Research Results

The new research method runs through the whole research process of trusted data management in the creative supply chain. The final research result is a complete supply chain management system integrated with decentralized and trusted blockchain. However, the existing general research methods that are widely used can only solve one aspect of the research on the trusted data management method of creative supply chain, which is not comprehensive enough.

5. Conclusions

Every new research method should have a creative direction. Through the addition of smart contracts, this article enables two or more parties in a transaction to fulfill their obligations as expected and realize the transition from external contracts to built-in contracts, effectively controlling the compliance risk. In view of the fact that it is difficult to verify the authenticity of the transaction itself and the prominent trust problem in the traditional supply chain, a trust mechanism with low delay, low cost and low power consumption is constructed by putting forward a consensus mechanism suitable for the supply chain. It realizes the trusted storage of trade data, improves the trustworthiness of data, and reduces the cost of wind control in the trade. Based on this work, the next step will be to build a "debt-to-platform platform" and use the credit certificate as a carrier to reduce the financing cost to solve the external payment of suppliers and the financing needs of upstream customers. The evaluation of creative computation of blockchain needs further study. The purpose of creative computing is to solve the problems that cannot be solved in the field of software engineering. However, to what extent can it be called a solution and how to evaluate the quality of creative computing need to be studied in depth.

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