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Research on Convergence Media Consensus Mechanism Based on Blockchain

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Abstract: In recent years, the media industry has achieved rapid development and experienced three development stages from traditional media to new media and then to the current convergence media. Convergence media has brought about great changes in content production, communication mechanism, operation and maintenance management, but also brought about problems such as declining credibility of the industry, difficulty in confirming content rights, difficulty in protecting user privacy, etc. Research on convergence media based on blockchain can make use of the characteristics of blockchain to design or optimize the media industry. In this paper, we introduced the development of convergence media, blockchain and consensus mechanism, then we described a sustainable convergence media ecology based on blockchain. Furthermore, we designed and implemented a consensus mechanism named proof of efficiency (PoE). After analysis, PoE can provide high security and resist 51% resource attack, sybil attack, etc. The experimental results show that PoE has the characteristics of decentralization, strong consistency, low energy consumption, short average block generation time, high throughput and short block confirmation time; the consensus results of PoE can reflect the node's ecological characteristics in convergence media which can stimulate the activity of nodes and better solve the generation of the Matthew effect.

Keywords: blockchain; consensus mechanism; convergence media; media ecology; half-life; PageRank

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Citation: Hu, H.; Wang, Y. Research on Convergence Media Consensus Mechanism Based on Blockchain. *Sustainability* **2022**, *14*, 11026. https://doi.org/10.3390/su141711026

Academic Editor: Hoon Ko

Received: 29 July 2022
Accepted: 29 August 2022
Published: 3 September 2022

1. Introduction

In recent years, with the development of science and technology, the media industry has achieved rapid development and experienced three development stages from traditional media to new media and then to convergence media [1]. Traditional media are mainly represented by radio, television, newspapers and periodicals [2]. New media are mainly represented by mobile phone media and Internet media [3]. Convergence media focuses on the integrated development of media forms.

Convergence media is a new media form that makes full use of media carriers and integrates different media, which has both common ground and complements each other, in terms of manpower, content, communication and governance [4]. The convergence media stage is based on the mature development of new media. Due to the continuous development of new media, the media landscape and transmission may have a profound change. In this context, the recombination of various media forms and resources become the main form of media formation. At the same time, with artificial intelligence, big data, blockchain and other technologies gradually applied in the media industry, it finally realized the adjustment of the media industry, forming a diversified and sustainable business model and profit model, and it also realized the intelligent matching information with the user requirements, which greatly improved the operational efficiency of the convergence media [5,6].

Blockchain is generally defined as a distributed ledger technology, which is a shared database with the characteristics of decentralization, openness and transparency, traceability and tamper resistance [7]. The core technology of blockchain is consensus mechanism and smart contract. The consensus mechanism is a kind of protocol and governance system in blockchain system, which enables the system to reach a unified recognition of certain results without centralized control and trust foundation [8]. Some consensus mechanisms are prone to the Matthew effect, which will destroy the original intention of blockchain decentralization to some extent. The Matthew effect is a phenomenon in which the strong become stronger and the weak become weaker [9]. Smart contract is a special type of embedded programming that runs in a reproducible shared computer program block on chain data [10]. In recent years, blockchain has made great progress in finance, government affairs and other fields, and the application of blockchain technology has been extended to digital finance, Internet of Things, intelligent manufacturing, supply chain management, digital asset trading and other fields [11]. At present, many countries are speeding up the layout of blockchain technology development.

With the rapid development of the media industry, it is an urgent task for us to promote the integrated development of media. We should make use of the achievements of the information revolution to deepen media integration. Convergence media has brought about great changes in content production mode, presentation form, communication mechanism, operation and maintenance management and other aspects, but also brought about problems such as declining credibility of the industry, difficulty in confirming content rights, difficulty in protecting audience privacy and slow iteration of management mode [12]. We should promote the integration of traditional media and new media, and establish a media communication system based on content construction, supported by advanced technology and guaranteed by innovative management. We should use advanced technologies to lead and drive integrated development, make good use of the achievements of the information technology revolution, such as 5G, big data, cloud computing, the Internet of Things, blockchain and artificial intelligence, strengthening forward-looking research and application of new technologies in the field of news and communication [13].

This paper introduces the development history of convergence media, the current development status of blockchain and its consensus mechanism, analyzes the challenges encountered in the development of convergence media, and in response to these challenges, it describes a sustainable convergence media ecology based on blockchain; at the same time, it designs and implements a consensus mechanism named proof of efficiency (PoE) running in the blockchain-based convergence media ecosystem. Extensive experiments and analysis results demonstrate that PoE has the characteristics of decentralization, energy saving, short average block generation time, high throughput and short block confirmation time. Moreover, the consensus result can reflect the ecological characteristics of convergence media and solve the Matthew effect in consensus. At the same time, after a lot of analysis, PoE can resist 51% resource attack, sybil attack, selfish mining attack, long-range attack, etc.

The remainder of this paper is organized as follows. The second part briefly introduces the related work of convergence media and blockchain technology. The third part describes the blockchain-based convergence media and its consensus mechanism. In the fourth part, we design and implement a consensus mechanism named proof of efficiency (PoE) running in the blockchain-based convergence media ecosystem, and analyze the algorithm's characteristics and security. The fifth part describes experiment and results analysis. The sixth part concludes this paper.

2. Related Work

At present, how to promote the convergence development of media has become an urgent issue facing the media industry, and how to effectively promote the application of blockchain technology has also become a key topic discussed by technology researchers. Therefore, this paper is devoted to researching how to combine them to promote the development of the media industry and blockchain technology together.

2.1. Key Aspects of Convergence Media Development

Media convergence is not simply the addition of media, but the chemical integration of existing system mechanisms, content, channels, platforms, talent and market [14]. We believe that the current media industry has a clear consideration of the development of media convergence in recent years, but due to the fact that the reform and development time of media convergence is still short, many applications have not been actually implemented, and the application depth needs to be further strengthened. The development of convergence media should be promoted mainly from the following aspects.

(1) Thinking concept

There is no denying the fact that technologies such as artificial intelligence, big data, and blockchain will bring new changes to media integration development; these technologies will change the operation of the media to a certain extent, which requires that the media industry on the business philosophy to keep pace with the times, or it will be the elimination of change [15]. The concept of media work guides us towards a new understanding about the media industry and media professions under digital transition [15].

(2) Media content production

The content production mode of convergence media will undergo profound changes, including the production and editing of content will be more efficient, intelligent, and diversified, which can save some labor and time costs. The original content production based on the accurate positioning of the target as a niche player is positively linked to performance and profitability [16].

(3) Integrate media information dissemination

The information communication of convergence media may change from the five elements of information communication, including communication subject, communication object, communication content, communication channel, and communication effect [17]. The vertical mass communication model is replaced with the horizontal social networks, and the influence of traditional media is decreasing [18].

(4) Convergence media ecological governance

With the gradual development of convergence media, its overall scale and business scope will increase greatly, thus forming an industrial ecology. In order to maintain and further promote the ecological development of convergence media, we must do a good job in convergence media ecological governance from various aspects, including establishing and improving the ecological dynamic management system and mechanism, and improving the efficiency of convergence media ecological operation and maintenance.

To sum up, along the main development direction of convergence media, we can make full use of the existing media carriers which have both commonalities and complementarities, and comprehensively integrate them in terms of manpower, content, publicity and technology, which can greatly improve the overall operation and maintenance efficiency of the media industry.

2.2. The Challenges Facing Convergence Media Development

At present, convergence media still faces some challenges in the process of development, mainly in the following aspects.

(1) The deep integration of technology and media

Many new media technologies have emerged in modern society. The application of new media technologies has impacted the traditional media industry, which not only faces great challenges, but also brings some lessons for the development of traditional media [19]. Artificial intelligence, blockchain, data mining and other technologies have been developed for a long time, but the actual application time in the media industry is not too long. It is necessary to find the right entry point to improve the operation and maintenance efficiency of media, and it must not be completely mechanically copied.

(2) Data quality

The development of convergence media largely depends on the quality of media data [20]. Evaluation of data quality is important for data management, which influences data analysis and decision making [21]. In fact, from traditional media even to the era of new media, the quality of data is not very high [22], and the utilization rate about these data of convergence media is low. It is necessary to clean the original data to ensure its effectiveness and utilization rate.

(3) Accurate information push and information island

In the era of convergence media, media platforms may use intelligent recommendation algorithms for media content in order to increase operation efficiency.

On the one hand, intelligent recommendations of media content can accurately deliver content according to users' preferences, which can improve the propaganda efficiency of media to a certain extent [23]. On the other hand, in the long run, users' reading range may gradually narrow, thus reducing the probability of obtaining comprehensive information, which will reduce readers' discrimination of news value, gradually solidifying their thinking and gradually losing their complete judgment. Therefore, convergence media platform should not only take into account the commercial value of media operation and maintenance, but also take into account the responsibility of disseminators of social values in the design of rules, so as to avoid the "information island" mentioned above, which loses the social value of the media platform while gaining commercial value [24].

(4) Fake news

In the era of convergence media, the production, communication and feedback of media content are relatively dependent on artificial intelligence and other technical means. In fact, the current scientific and technological means are not perfect in the recognition of media content, which easily leads to deviations in the authenticity of media content and the orientation of public opinion [25]. Fake news is not a new phenomenon but when powered by modern information dissemination and AI technologies, they are manifesting themselves at scales and in ways previously not possible [26].

(5) Data security and user privacy

The intelligent operation and maintenance of convergence media largely depends on the acquisition of user data, such as user portrait generation, intelligent recommendation of content, blockchain news, etc., which all involve user information [27]. Thus, the data security and user privacy protection should be strengthened. When obtaining user information in the operation and maintenance process of convergence media, users should be prompted and consent. The data security management level and prevention awareness of the convergence media platform should be improved.

From what has been discussed above, the development of convergence media requires our media industry to carry out transformation and reform in many aspects. For example, the operation and maintenance mode needs to adopt a more macro management mode, the production of media content needs to be more intelligent, and the flow of data needs to be more clear [28]. We can change the media operation and maintenance with the help of existing science and technology, so that it can adapt to the development of society in some aspects.

2.3. The Current State of Blockchain

Generally speaking, blockchain is defined as a distributed ledger technology, and the core technologies of blockchain are consensus mechanisms and smart contracts. According to the scope of users or the decentralization degree of the blockchain, we generally divide the blockchain into three categories: public chain, private chain, and alliance chain [29]. Public chain refers to each node on the network can freely join and exit the network, the familiar Bitcoin and Ethereum are both public chains [30]; private chain means that the write permissions of each node are controlled by the internal node, it mainly provides data sharing, credit guarantee mechanism, and technical services for enterprises and teams at the microlevel, and it is generally believed that the digital currencies issued by the central banks belong to the category of private chain [31]; alliance chain refers to the alliance of relevant institutions with common interests, and the alliance will jointly maintain the operation and maintenance of the blockchain [32]. The essential difference between the three types of blockchain lies in the different degree of decentralization. Generally speaking, the higher the degree of blockchain decentralization, the higher the degree of trust and security, the lower the operation efficiency and the degree of supervision.

Blockchain technology has its distinct characteristics, such as tamper-resistant, traceable, decentralization, etc., which means its application scenarios will be more clear, in copyright protection, digital assets, and information sharing which has unique advantages; however, blockchain technology is not omnipotent, and the blockchain technology low efficiency, low interactive performance (between different chains) and security issues (such as 51% attack) also need to improve in succession [33,34]. Using blockchain technology does not equate to complete decentralization, it only provides a decentralized technology alternative, and decentralization is not exactly equivalent to deregulation.

2.4. Research on Consensus Mechanism of Blockchain

Consensus mechanism is a kind of protocol and governance system in the blockchain system, which enables the system to reach a unified recognition of certain results without centralized control and trust foundation. Consensus mechanism combines game theory, distributed technology, cryptography, economics and other disciplines to form a system, which can ensure that all nodes in the blockchain can actively and effectively maintain the blockchain system. At present, the mainstream consensus mechanism algorithms include PoW (Proof of Work), PoS (Proof of Stake), DPoS (Delegated Proof of Stake), PBFT (Practical Byzantine Fault Tolerance) and so on [35].

In [36], the authors introduced the computing power competition of PoW into DPoS to design an improved consensus mechanism. Through the further modification, the impact of both computing resources and stakes on generating blocks is reduced to achieve higher efficiency, fairness, and decentralization in the consensus process. In [37], the authors proposed a credit-based proof-of-work (PoW) mechanism for IoT devices, which can guarantee system security and transaction efficiency simultaneously. In [38], the authors proposed a novel consensus protocol that is suitable for the crowdsourcing as well as the general online service industry, whereby it selects transaction validators based on the service participants' trust values while leveraging RAFT leader election and Shamir's secret sharing algorithms.

2.5. The Application of Blockchain in Media

The wide application of blockchain technology is changing the traditional media format and triggering a new round of changes in business processes, organizations, governance systems and business models.

In [39], the authors reviewed the relevant research and projects on blockchain applications in the media industry, and discussed the possibility of developing "Blockchain + Media". In [40], the authors proposed a preventative approach using a novel blockchain-based solution suited for Fake Media incorporated with a gamification component, and the proposed approach uses concepts of a customized Proof-of-Authority consensus mechanism, along with a weighted-ranking algorithm, serving as an incentive mechanism in the gamification component to determine the integrity of fake news.

Through the above analysis of the current situation of convergence media and blockchain, we find that the development of convergence media can bring many changes to the media industry and improve the operation and maintenance efficiency [41]. However, the development of convergence media is also facing many challenges. In order to adapt to the changes brought by the development of convergence media, we need to carry out further research and reform from multiple dimensions [42]. Since the beginning of the blockchain technology, it mainly serviced the financial industry, but the applications of its important features such as decentralization, traceability, and tamper-resistant are indeed an opportunity for the development of the media industry. With the characteristics of blockchain, we can solve the problems of declining industry credibility, improvement of intelligence which the media industry is facing and urgently needs to solve, and we can design or optimize the fields of copyright identification and transaction, content dissemination and traceability, precise advertising and intelligent transaction, public opinion environment analysis and so on [43,44].

The existing research results are mostly focused on the macro description of the application of blockchain in the media industry, and there are still some gaps in the research on the specific application methods of blockchain in convergence media. This paper will try to describe a kind of convergence media ecology based on blockchain, and focus on the consensus mechanism applicable to convergence media ecology.

3. Convergence Media Based on Blockchain and Its Consensus Mechanism

3.1. The Significance of Studying Convergence Media Based on Blockchain

The rapid development of the media industry, which will produce great changes in content production mode, presentation form, communication mechanism, operation management, but also brings problems such as industry credibility decline, content confirmation difficulty, audience privacy protection difficulty and slow management mode iteration. Currently, blockchain technology is becoming mature and is gradually developing towards the industry beyond finance.

In the media industry, we can make use of the tamper-resistant, traceable and decentralized characteristics of blockchain to design or optimize the fields of media content copyright recognition and transaction, content dissemination and audit traceability, accurate advertising and intelligent trading, public opinion traceability and public opinion environment analysis.

3.2. Consensus Mechanism for Convergence Media Based on Blockchain

Consensus mechanism is an important part of blockchain technology. Although the existing mainstream consensus mechanism is relatively mature, the analysis of its consensus reaching process reveals the following disadvantages for the convergence media ecology:

(1) The formation of consensus is universal and cannot fully reflect the ecological characteristics of convergence media;
(2) The formation of whole consensus has great randomness, which tends to reduce the media activity of nodes in the convergence media ecology;
(3) Partial consensus mechanism tends to produce the Matthew effect, which is not conducive to the balanced development of convergence media ecology;
(4) Some consensus mechanisms rely too much on calculation, which is easy to cause unnecessary waste of resources.

In conclusion, the existing mature consensus mechanism will reduce the enthusiasm of convergence media nodes in terms of media characteristics to some extent, fail to meet the needs of the operation and development of convergence media ecology, and is not conducive to the balanced development of convergence media ecology. Consensus mechanism based on blockchain convergence media ecology should combine the characteristics of blockchain and convergence media. We believe that consensus mechanism in convergence media ecology should be considered from the following aspects:

(1) The social attributes of convergence media should be considered. Convergence media should adhere to the core values of news media and guide and publicize positive social energy. Therefore, the blockchain based convergence media can be decentralized, but it does not mean that it can be totally deregulated;
(2) Operation and maintenance characteristics of convergence media ecology, such as participation, credit, and fairness of nodes in the ecology, should be considered;
(3) The generation of relevant functional nodes in the system should have unpredictability;

(4) The efficiency of system consensus should be considered;
(5) The overall security of the system should be considered.

4. Consensus Mechanism Based on Node Efficiency

Blockchain-based convergence media can solve problems in convergence media, such as media traceability, combating fake news, personal privacy protection, accurate advertising delivery and so on [27]. However, the establishment of blockchain-based convergence media ecology should focus on the establishment of consensus mechanism in the ecology.

Some aspects should be considered in establishing consensus mechanism of blockchain-based convergence media ecology:

(1) Try to establish a balance between the efficiency of reaching consensus and the acceptance of consensus;
(2) Combine some characteristics of convergence media ecology to make consensus mechanism promote the balanced development of convergence media ecology;
(3) Conditions should be considered to ensure the safety and effectiveness of the consensus mechanism;
(4) Make sure it is compatible with the existing media convergence ecology, while considering any possible drawbacks.

Through the analysis of the existing consensus mechanism and the consideration of the above problems, we try to propose a consensus mechanism named "Proof of Efficiency" (PoE). The function of consensus mechanism in the convergence media based on blockchain is shown in Figure 1.

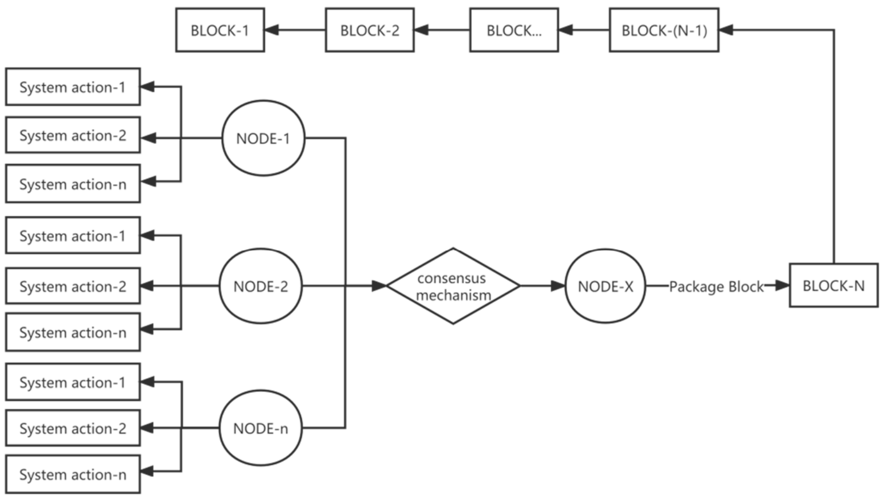

Figure 1. Function of consensus mechanism in convergence media based on blockchain.

4.1. Overview of Proof of Efficiency

In the blockchain-based convergence media ecology, we define the efficiency value of nodes as a comprehensive reflection of the interaction between nodes, node participation, credit, accounting times, etc. A consensus mechanism based on node efficiency is just an operation and maintenance mechanism based on this. Participation is reflected in the node's participation in the system operation and the maintenance-related behavior. The interactive relationship is embodied in the relationship that nodes actively or passively produce system behavior. Credit is reflected in the behaviors related to trust generated in the process of node operation and maintenance.

The purpose of designing a consensus mechanism in a convergence media ecosystem is to reach consensus on some behaviors in the process of system operation and maintenance based on the cognition of most nodes and to promote the coordinated development of a system ecosystem. Node participation can reflect the willingness of nodes to participate in system operation and maintenance; interaction between nodes can reflect the importance of nodes in ecology; node credit can reflect the ability and trust of nodes in ecology.

4.2. Algorithm Design and Implementation

4.2.1. Establish Node Participation System

Node participation is a digital representation of the comprehensive state of node participation in system affairs, including the frequency, scope and popularity of interaction, etc. The establishment of the participation system is mainly divided into the following steps:

(1) Set up initial participation for nodes joining the convergence media ecosystem;
(2) Nodes publish content in the media ecosystem, including news, articles, audio, video, patent and other content, and get bonus points for participation;
(3) Nodes participating in media ecological management get participation bonus points;
(4) In order to improve the participation mechanism in the system, nodes set to participate in the interaction of works forwarding, comments, likes and so on in the media ecosystem will be rewarded with corresponding tokens;
(5) If a node is defined to initiate a transaction, an out degree is added, and the node corresponding to the transaction is added with an in degree;
(6) The output degree and input degree corresponding to the same two nodes can be accumulated;
(7) The participation P of the Node is defined as the comprehensive embodiment of the output degree Op, input degree Ip and the number of interactive nodes $Node$.

$$P = a \times Op + b \times Ip + c \times Node \tag{1}$$

We can adjust the weights of the out degree, in degree and total number of nodes by adjusting the coefficients a, b and c. If necessary, we can also set different weights for different types of transactions, which will not be expanded in this paper. In general, $c > b > a$, that is in the system the scope of interaction can better represent the significance of nodes' participation in system construction, whereas the weight of input is second. Passive initiated interaction can better reflect the popularity of nodes and can also prevent nodes from active attacks to obtain high participation.

4.2.2. Establish a Node Credit Rating System

Node credit is the digital embodiment of node credit in the system, and the establishment of node credit system in the convergence media ecology can be regarded as the credibility reference of the system node to participate in the system affairs. Each node has its own credit rating, and its behavior in the system will produce corresponding credit rating changes. The establishment of the participation system is mainly divided into the following steps:

(1) Establish the initial credit for the nodes joining the integration media ecology;
(2) Get credit points for publishing popular media content;
(3) The accounting node completes the block packaging and obtains the system consensus to get credit points;
(4) If the node is punished, there will be a credit deduction;
(5) Credit points will be reduced if the node publishes illegal content;
(6) There will be credit deduction for the evil behavior of nodes;
(7) If the candidate consensus node and accounting node are not online for many times, there will be credit deduction;
(8) If the candidate consensus node does not participate in the voting for many times, it will have a credit deduction.

4.2.3. Influence of Credit Rating

In an accounting cycle, the system generates accounting nodes based on their credit, so in principle, nodes with high credibility will have more probability to get right to account. At the same time, for the consideration of the incentive of the accounting node, the accounting node will get credit rewards and token rewards after completing the block packaging, so that the next accounting cycle, the probability of this node getting the next accounting right is still very high, and such repetition will form the Matthew effect in the system. In some fields, the Matthew effect can play a positive role in promoting the development of media ecology. However, the Matthew effect will hinder the coordinated development of ecology to some extent. In order to solve this problem, the credit influence of nodes is defined in the system, and the half-life algorithm is used to modify the credit influence of nodes in the accounting cycle. In the accounting cycle, the credit influence of nodes decreases with the increase in the number of accounting.

Half-life is used in many fields, such as physics, medicine, chemistry and so on. In statistical terms, a half-life is defined as a 50% probability that an unstable isotope of an element will decay within a time period T [45]. When we set the node to obtain the right to account for N times, its credit influence is halved. Then, after the node obtains the right to account for n times, its credit influence can be calculated according to the following formula:

$$E_i = C_i \times (\frac{1}{2})^{\frac{n}{N}} \tag{2}$$

where C_i is the credit of node i in the current accounting cycle. We assume that the credit of a node has no data change caused by internal factors in the consensus cycle, then with the change of its accounting times, its actual influence in the consensus cycle tends to decline, which can solve the Matthew effect problem in the system.

Nodes will be rewarded with a credit rating after accounting. Assume that the credit reward of the node after accounting is e, then the reputation rewards should not let the node's credit influence grow in the next cycle of accounting, namely the accounting node's credit influence should be less than the last after being rewarded with a credit rating, otherwise the system will lead to the Matthew effect because of the credit growth.

$$C_i \times (\frac{1}{2})^{\frac{n}{N}} > (C_i + e) \times (\frac{1}{2})^{\frac{n+1}{N}} \tag{3}$$

where C_i is the current credit of node i, N is the half-life accounting times set by the system, and n is the current accounting times of node i. According to Formula (3), we can get the relationship between e and C_i.

$$e < C_i \tag{4}$$

The Matthew effect is not easy to occur in the system when the credit reward of an accounting is smaller than the current credit of the node.

4.2.4. Select the Candidate Consensus Nodes

The PageRank algorithm is an algorithm to evaluate the valuation of nodes based on the relationship and characteristics between nodes in a complex network [46]. The importance of a node depends on the number and quality of other nodes pointing to it.

System initializes the node's participation state when the candidate consensus cycle starts. In the establishment of the participation system, the degree of Op and Ip between nodes can be accumulated; so the state graph generated according to the interaction between nodes is a weighted directed graph. In combination with the idea of the PageRank algorithm, the participation state of nodes is iterated until convergence, and the first m nodes with the largest participation convergence value are candidate consensus nodes of this round. To some extent, the convergence value of participation can reflect the importance of nodes in this round of the candidate consensus cycle. Choosing highly important nodes to participate in consensus can improve the recognition of consensus and avoid consensus mechanisms that have too much randomness.

Let the total number of nodes be N, the column vector of initial participation is P_0, the column vector of participation in the nth iteration is P_n, and the probability of node i

initiating interaction on the specified node is α, then the probability of random interaction on a node is $1 - \alpha$. Then we can get the Formula (5) as follows:

$$p_{n+1}(i) = \alpha \times \sum_{j \in B(i)} p_n(j) \times \frac{out_{ji}}{\sum_{k \in N(j)} out_{jk}} + \frac{1-\alpha}{N} \tag{5}$$

where $B(i)$ is the node set with node i as the interactive object node; $N(j)$ is the set of interactive object nodes of node j; $p_n(i)$ is the participation of node i after the nth iteration; out_{ji} is the output of node j pointing to node i.

$$out_{ji} = \sum_{e \in B(e)} w_e \times n_{ji} \tag{6}$$

where $B(e)$ is the set of interaction types, w_e is the weight corresponding to the interaction type e, and n_{ji} is the number of such interactions.

Define the system node interaction relationship matrix R, where the values of the matrix elements R_{ij} can be calculated by Formula (7):

$$R_{ij} = \frac{out_{ji}}{\sum_{k \in N(j)} out_{jk}} \tag{7}$$

We define e as a column vector with all components equal to one, and define the matrix A by Formula (8):

$$A = \alpha \times R + \frac{1-\alpha}{N} \times e \times e^T \tag{8}$$

According to Formula (5), the iterative process can be identified as a Markov process.

$$P_{n+1} = AP_n \tag{9}$$

Different from the PageRank algorithm, the non-zero elements in the column vector of the state transition matrix A can be unequal, reflecting the relative relationship of the interaction among the nodes. Set the threshold ε and the upper limit t of the iteration times, and the participation of node i converges to the corresponding element in the column vector $p_{n+1}(i)$ when the following Formula (10) is satisfied.

$$|P_{n+1} - P_n| < \epsilon \tag{10}$$

When the times of iterations reaches t, the participation convergence value of node i is $p_t(i)$.

According to the process of calculating the convergence value of participation, its time complexity is $O\big(t(\epsilon)n^2\big)$, where n is the number of network nodes, and $t(\epsilon)$ is the number of iterations, which is related to the threshold of convergence ε. For large networks, the relationship between the number of iterations and edges is nearly linear $O(\log n)$ [46]. Of course, there may be "Dead Ends" and "Spider Traps" problems in systems based on the PageRank algorithms, but there are currently mature solutions for such situations, and we will not expand here.

4.2.5. Select the Accounting Node

Verifiable Random Function (VRF) is an encryption scheme that maps the input into a verifiable pseudo-random output. It has three major characteristics: verifiability, randomness, and uniqueness [47]. The VRF has a non-interactive zero-knowledge proof compared to the pseudo-random function. It can generate a proof using the private key and the input, and other nodes can use the proof, the public key and the input to verify the correctness of the random number output.

In order to prevent the attacker from predicting the block accounting node and launching the attack on the accounting node in advance, and also reflect the accounting advantages of the node efficiency value, this paper adopts an algorithm based on the combination of verifiable random function and stake lottery, and produces accounting nodes according to the results of the stake lottery. The specific process is as follows:

(1) Each node produces an asymmetric encryption public key PK and a private key SK pair;
(2) The system stores the credit influence (C_i, T) at the beginning of each accounting cycle of each candidate consensus node, which C_i is the credit influence of node i, and T is the timestamp;
(3) Set the initial number of seeds in the system $Seed_0 = 1$, and after the block is determined, the accounting node randomly generates and broadcasts the next block seed number $Seed_n$;
(4) Each node in turn generates a random number result according to function VRF_Hash(SK_i, $Seed_n$) and a zero-knowledge proof according to function VRF_Proof(SK, *info*) at the same time according to Formulas (11) and (12) [48];

$$result = \text{VRF\_Hash}(SK, Seed_n) \tag{11}$$

$$proof = \text{VRF\_Proof}(SK, Seed_n) \tag{12}$$

In the formula, SK is the private key used in VRF, result is the VRF output random number, and proof is the zero-knowledge proof of VRF, and $Seed_n$ is the seed of current accounting cycle.

If no random number meets the requirements after a round of calculation, add the seed number by one, and start a new round of calculation again, until a node i meets the Formula (13) as follows when the seed number is increased by k.

$$\text{VRF\_Hash}(SK_i,\ Seed_n + k) < R \times E_i \tag{13}$$

where R is the threshold value set in the system, E_i is the credit influence of node i, and calculation see Formula (2). If the situation satisfies Formula (13), then node i is selected as the accounting node of this round.

(5) The accounting node i packs and broadcasts blocks while broadcasting its random numbers result, zero-knowledge proof as well as seed number increment k;
(6) Block and random numbers are checked by the candidate consensus nodes. The verification of block is mainly the verification of block legality, including the size of block, the integrity of block content, etc. Random number verification is mainly to check whether the following two Formulas (14) and (15) are valid [48];

$$\text{VRF\_P2H}(proof) == result \tag{14}$$

$$\text{VRF\_Verify}(PK,\ Seed_n + k,\ proof) == \text{True} \tag{15}$$

VRF_P2H function and VRF_Verify function are used to determine whether the random number is generated by the node providing information by verifying the relationship between *result*, *proof* and $Seed_n$. If both formulas are true, it means that the random number is verified.

(7) After the verification passes, the block will be updated on the chain, and the accounting node's credit, accounting number, block height and other information will be updated. This round of accounting cycle will be ended.

4.2.6. Algorithm Implementation

In order to clearly describe the implementation process of the algorithm, some relevant definitions of the PoE algorithm are described below:

1. Nodes efficiency: the comprehensive embodiment of the interaction between nodes, node participation, node credit and accounting times;
2. Nodes participation: it is a value representing the node initiated or participated system behavior, and it is the comprehensive embodiment of the node out degree, in

degree and the number of interactive nodes, which is updated in real time according to the behavior of the node system;

3. Nodes credit: it reflects the value of node comprehensive credit, and it is updated in real time according to the behavior of node system;
4. Ordinary node: a basic unit involved in the blockchain system in the convergence media ecosystem, generally refers to computer, mobile phone, etc.;
5. Candidate consensus node: The candidate consensus node is the node generated by the ordinary node election in the candidate consensus cycle. It can participate in the accounting right competition, and can initiate proposals and votes, etc.;
6. Accounting node: the accounting node is the node selected by the candidate consensus node in the accounting cycle and is allowed to complete the accounting task.
7. Candidate consensus cycle: the period of competing candidate consensus nodes;
8. Accounting cycle: the period of competing accounting node and packaging block;
9. Consensus cycle: it is generally composed of a candidate consensus cycle and multiple accounting cycle;
10. Influence of node credit: the comprehensive embodiment of node credit and accounting times in the consensus cycle;
11. Effective interaction: the system behaviors related to the convergence media generated by the nodes in the system, such as publishing the media content, forwarding, praising, commenting, initiating proposals or voting, etc.

The variables in the algorithm are defined in Table 1.

Table 1. Notations.

Symbol	Name	Description
P_i	Participation of node i	It is the comprehensive embodiment of node interaction behavior, Number of candidate consensus nodes
$NodeIpt_i$	Importance of node i	Participation convergence value calculated with PageRank algorithm
C_i	Credit rating of node i	It is the credit of node i in the credit system, updated in real time
E_i	Credit influence of node i	It is calculated with the half-life algorithm
n_i	Accounting times of node i	Number of accounting times of node i in the consensus cycle
N	Value of half-life	It evaluates influence of node credit combined with accounting times
S_i	The state of node i	It can be set to the participation of the node
PK, SK	Public key PK and private key SK pair	Generated based on the asymmetric encryption algorithm
Nodes	Number of total nodes	Number of total nodes
ConNodes	Number of candidate consensus nodes	Number of candidate consensus nodes which enter accounting cycle

The basic process of the PoE consensus mechanism in convergence media ecology is described as follows:

(1) Start the consensus cycle;
(2) Start the candidate consensus cycle;
(3) Update the node interaction relationship and set the participation as the initial state in the consensus cycle ($S_i = P_i$);
(4) The PR_S value of each node is calculated according to the node importance algorithm until it reaches convergence or the upper limit of calculation times. The calculation method can be found in Formulas (5) and (10);
(5) According to the set proportion, the first t nodes of the ordinary node importance value are the candidate consensus nodes of this round of consensus cycle;
(6) Candidate consensus cycle ends;
(7) Start this round of accounting cycle;

(8) In each accounting cycle, the system calculates the credit influence of the candidate consensus nodes by combining the credit state and half-life algorithm of the candidate consensus node. The calculation method can be found in Formula (2);
(9) Calculate random number and zero-knowledge proof based on the Verifiable Random Function. The calculation method can be found in Formulas (11) and (12);
(10) The nodes calculating random number judge whether it meets the threshold and credit influence requirements, and if satisfied, it will be selected as the accounting node of this round, and if not satisfied, the next node will start random number calculation until find the accounting node. The calculation method can be found in Formula (13);
(11) The accounting node that meets the requirements completes the block packaging, and broadcasts block, the random number, the seed number, and the corresponding zero-knowledge proof;
(12) Each candidate consensus node verifies the random number and block content, and the block will be updated to the blockchain synchronously after passing the verification. The Judgement method can be found in Formulas (14) and (15);
(13) Adjust the number of accounting times of accounting node as $n_i + 1$, and update the credit rating and tokens of the accounting node;
(14) This round of accounting cycle ends;
(15) Loop step 7 to step 14 to start the next accounting cycle during the consensus cycle;
(16) After the setting time, this round of consensus cycle ends (such as in one natural day). The next round of consensus cycle will start, and at the same time the candidate consensus nodes will be updated synchronously.

Flowchart of PoE consensus mechanism is shown in Figure 2.

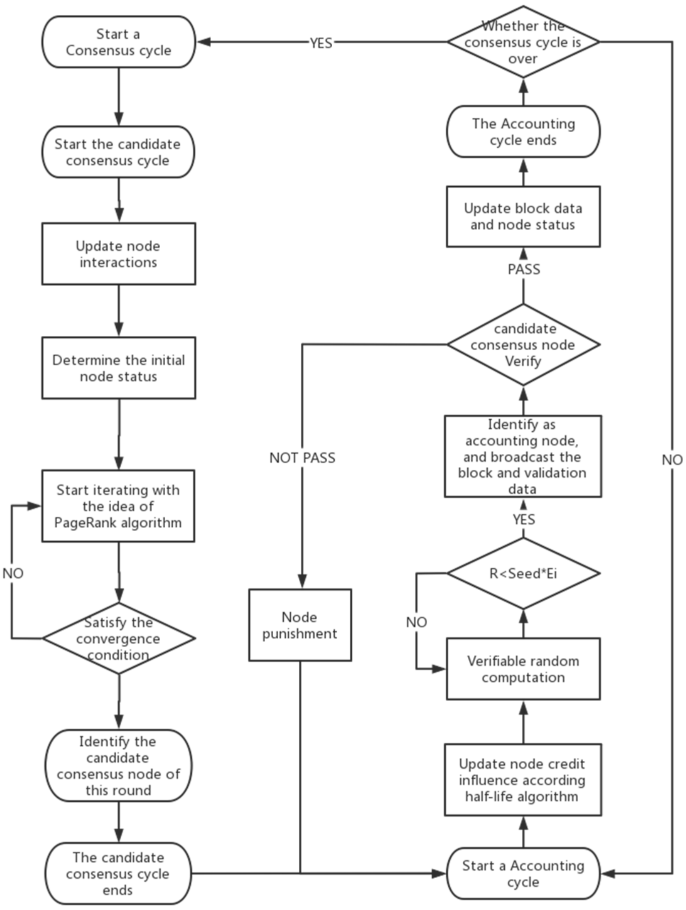

Figure 2. Flowchart of Proof of Efficiency.

Algorithm 1 below briefly describes the PoE consensus algorithm.

Algorithm 1. Proof of Efficiency Consensus Mechanism

Input: P_i: participation of nodes, C_i: credit of nodes, $A[][]$: interaction of nodes.
N: value of half-life, $NodeNum$: total number of nodes.
$CnNum$: number of candidate consensus nodes.

Output: $CN[]$: candidate consensus nodes, $AN[]$: accounting node.

```
Initialize nodes' characteristic properties of Nodes[]
Nodes[i] ← nodes' characteristic properties;
Nodes[i].rsa = RSA.generate(1024); /* rsa is the key pair of node */
/* start candidate consensus cycle */
Old_node_important[i] ← [0];
New_node_important[i] ← P_i;
Gm[] = getGm(A); /* getGm():get the state transition matrix Gm for A */
/* p:accuracy of iterative convergence */
while abs(New_node_important[i] − Old_node_important[i]) > p do
    Old_node_important[i] = New_node_important[i];
    New_node_important[] = Gm[] × Old_node_important[];
end while
/* getElement(a[], b):return the first b node in a[] in order of node importance */
CN[]=getElement(new_node_important[], CnNum);
/* start accounting cycle */
Seed, K=Random(); /* K:increment of seed in cyclic calculation of random number */
for nodes[i] in CN[] do
    Random = VRF_Hash(SK_i, Seed_n + K);
    Proof = VRF_Proof(SK_i, Seed_n + K);
    E_i = Nodes[i].Credit*(1/2)^(n_i/N); /* E_i:the credit influence of node i */
    if Random ≥ R* E_i then /* R:the threshold value set in the system */
        if calculation one round then
            K += 1;
        end if
        i += 1;
    else if Random < R* E_i then
        AN[] = Nodes[i];
        Seed = Random();
        Nodes[i].Package(Block);
        Nodes[i].Broadcast(Block, Random, Proof, Seed);
        Update(Nodes[i]);
    end if
end for
```

4.3. Characteristic Analysis of PoE Consensus Mechanism

4.3.1. Consistency Analysis

The consistency of the consensus mechanism in the blockchain refers to the certainty of the block generation [49]. The blockchain with strong consistency is generally not easy to produce forks.

In the PoE consensus mechanism, candidate consensus nodes are generated according to the importance of nodes and a set proportion. The importance of nodes is generated by the ecological characteristics of convergence media and convergence operation combined with the PageRank algorithm. Accounting nodes are generated according to the credit of the candidate consensus node, combined with the half-life algorithm, verifiable random function algorithm and the threshold requirements. The probability of collision in the candidate consensus cycle depends largely on the PageRank convergence accuracy set in the system, which achieves strong consistency with the convergence accuracy above 1%. The accounting node is generated by candidate consensus node combined with credit influence, a verifiable random number algorithm and a system preset threshold, which has strong consistency. In conclusion, the PoE consensus can achieve a strong consistency.

4.3.2. Decentralization Degree and Energy Consumption

In the consensus process of the PoE, the candidate consensus node is generated by the participation and interaction stored on the blockchain combined with the idea of the PageRank algorithm; the accounting node is generated by the credit stored on the blockchain combined with the idea of the half-life algorithm and the verifiable random function algorithm, so the PoE algorithm does not rely on the centralized nodes, and the whole system has a high degree of decentralization.

In the consensus process of the PoE, the generation of candidate consensus nodes and accounting nodes does not require a continuous high-intensity calculation, and so their energy consumption is low.

4.3.3. Duration of Block Generation

The time to generate blocks in the PoE algorithm mainly consists of two parts: the candidate consensus cycle time and the accounting cycle time, where the candidate consensus cycle time is shared, and the time cycle distribution in the consensus cycle is shown in Figure 3.

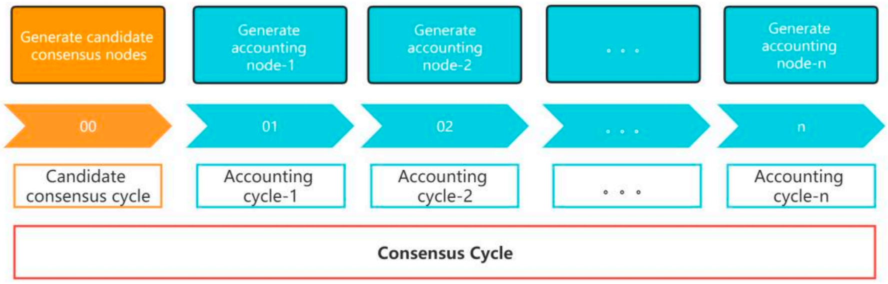

Figure 3. Consensus cycle time distribution.

Thus, the average time of generating blocks in the PoE is a comprehensive reflection of the candidate consensus cycle time and the accounting cycle time.

$$T(\text{PoE}) = \frac{t(\text{DC}) + \varphi \times t(\text{DA})}{\varphi} \tag{16}$$

where $t(\text{DC})$ is the duration of the candidate consensus cycle, $t(\text{DA})$ is the duration of the accounting cycle, φ is the number of the accounting cycle in the statistical consensus cycle. The duration of the candidate consensus cycle is related to the node size, and the average duration of the accounting cycle is related to the set threshold difficulty, node credit, accounting times, etc. When $\varphi \gg 1$, that is when there is more accounting cycle in a consensus cycle, the average time of generating blocks in the PoE is approximately equal to the average time of the accounting cycle.

$$T(\text{PoE}) \cong \frac{T(\text{TDA})}{N} \tag{17}$$

where $T(\text{TDA})$ is the total time of the statistical accounting cycle; N is the number of accounting cycles in the consensus cycle. In the case of low threshold difficulty, the average duration of the block generation can reach a very short time.

4.3.4. Duration of Block Confirmation

Due to the possibility of a bifurcation attack in the blockchain system, the blockchain system will generally set a certain time according to the specific situation of the system to ensure that the possibility of blockchain tampering is reduced to a low level, so there is a block confirmation time in some blockchain systems [50].

The PoE consensus mechanism, the generation of the candidate consensus node is combined with the state of the node and interactive relationship, the accounting node is combining node state randomly, has the characteristics of an unpredictable, uncontrollable, node that cannot initiate fork attack, so the PoE consensus mechanism can do block confirmation immediately, and block confirmation time is very short.

4.3.5. Token in Consensus Mechanism

Token is a certificate of equity existing in the form of numbers, which represents a right, an inherent and intrinsic value [51]. In the blockchain system, it exists mostly in the form of coins, stake, etc.

In PoE, the consensus cycle does not depend on the token system. The system can decide whether to set up the token system according to other functional needs, but it needs to maintain the node credit and participation system. We can understand the participation and credit of the nodes as the token of the nodes in the system.

4.3.6. Feature Contrast

Through the above analysis, the PoE and the mainstream consensus mechanism performance comparison are shown in Table 2 as follows.

Table 2. Performance comparison of PoE and mainstream consensus mechanism [52].

Consensus Mechanism	Decentration	Energy Consumption	Generation Duration	Confirmation Time
PoW	high	high	long	long
PoS	low	low	short	short
PBFT	low	low	short	immediate
PoE	high	low	short	immediate

4.4. Simple Safety Analysis

4.4.1. 51% Resource Attack

The 51% resource attack refers to an attack mode in which the evil node destroys the system balance by mastering 51% of the system resources in the system, so as to control the normal and orderly development of the system [53]. For example, in the proof of work consensus mechanism, evil nodes can launch a blockchain forking attack by mastering 51% of the computing power in the system. In the proof of stake consensus mechanism, if evil nodes master 51% of the stake in the system, it can launch a blockchain forking attack. Evil nodes can take advantage of this feature to use certain consumable resources (such as a token) in the system twice at the same time, resulting in the loss of resources of other nodes, so a 51% resource attack can also be called a double-spending attack.

The PoE consensus mechanism generates a candidate consensus node and accounting node based on the participation system, credit system, interactive relationship in convergence media ecology combined with the PageRank sorting, half-life algorithm, verifiable random function algorithm, etc. During the whole process, the nodes' control of resources is not completely controllable, and the accounting node generating in the system has a certain randomness. In a way, the evil node cannot lunch a 51% resource attack by accumulating resources, so the PoE consensus mechanism can be very good for resisting the 51% resource attack.

4.4.2. Sybil Attack

Sybil attack generally refers to a network node in the distributed system that constantly transforms identity through camouflage, so that other nodes in the same system mistake it for a different node, then the attack node can use these camouflaged node identities to destroy the normal operation of a distributed system [54].

In the PoE consensus mechanism, if evil nodes intend to disguise different nodes, it is necessary to have the common media ecological characteristics, such as participation, credit and node interaction, which greatly strengthens the cost of masquerading nodes. At the same time, in the accounting cycle, the data published by nodes need to be checked by other candidate consensus nodes on their public and private key pairs, which also eliminates the occurrence of disguised nodes from the perspective of identity authentication. So, the PoE consensus algorithm can resist sybil attack.

4.4.3. Selfish Mining Attack

The core idea of the selfish mining attack is that the selfish mining pool deliberately delays the publication of its new calculated blocks, and constructs a private branch under its own control, while taking advantage of its accounting rights to create a fork of the chain [55]. Its purpose is not to undermine the whole blockchain mechanism, but to reap additional benefits and let honest miners to make invalid calculations.

In the PoE consensus mechanism, accounting rights are generated by candidate consensus nodes taking turns to calculate verifiable random numbers according to the number of seeds in each cycle, and the seeds vary in each cycle. If node A that meets the required random number is the delay publishing block, it will be replaced by another node B that meets the required random number; moreover, node A cannot guarantee the possibility of obtaining the accounting right in the next accounting cycle, so the node cannot make forks on the blockchain by delaying the announcement of blocks. So, PoE can resist selfish mining attacks.

4.4.4. Nothing at Stake Attack and Long-Range Attack

Nothing at Stake Attack refers to the evil node in the blockchain system by using certain rules to attack the system without much loss of interest [56]. Long-range attack means that the attacker, instead of forking an existing chain from its current location, goes back to some earlier stage of the blockchain and builds a new, longer chain, fooling the network nodes into mistaking it for the main chain [57]. Nothing at stake attack and long-range attack are common in the consensus mechanism associated with stake, and they are all forked attack on the main chain.

We analyze the characteristics of the PoE and find the following characteristics:

(1) Candidate consensus nodes in the PoE are determined by node importance in a certain proportion according to the participation and interaction of nodes in the system. It is extremely difficult for evil nodes to compete for candidate consensus nodes by increasing relevant media ecological characteristics, which is uncontrollable;
(2) In the PoE consensus algorithm, the accounting node is determined according to the relationship between the credit influence of the node, the set threshold and the generated random number. Credit influence is the credit processing by half-life algorithm, and the node credit influence will decrease with the increase in node accounting times. Random number generation is unpredictable, and the evil nodes cannot directly improve the probability of fighting for accounting rights by increasing the relevant media ecological characteristics;
(3) The credit system of the PoE consensus mechanism has credit punishment for evil nodes.

Based on the above features, the PoE consensus mechanism can better defend against long-range attacks and it may be launched by nothing at stake attacks, but the internal mechanism can reduce the effect of nothing at stake attacks to some extent.

4.4.5. Analysis of Adversary Model

An adversary model is a formalization of an attacker in a computer or networked system. Depending on how complete this formalization is, the adversary may be an algorithm or may simply be a series of statements with regards to capabilities and goals. There are a number of approaches in various fields of computer security that fit within this umbrella [58].

Generally, we use f to represent the number of enemies, n represents the total number of nodes in the network, and the relationship between n and f is used to represent the adversary model. In the current mature consensus mechanism, PoW requires at least

51% computing power attack, that is $n \geq 2f + 1$; PoS consensus mechanism requires 51% financial ratio, that is $n \geq 2f + 1$, but it is not worth it for the nodes that occupy 51% of the financial resources to launch attacks on the system, because the cost is that the value of the current system is damaged, and the original financial resources of the nodes will be correspondingly damaged; PBFT consensus mechanism requires more than two times more loyal nodes, namely $n \geq 3f + 1$ [59].

PoE is based on the node's credit, participation, interaction relationship and other data, combined with PageRank algorithm, half-life algorithm, and verifiable random function algorithm. The generation of candidate consensus nodes in the PageRank model depends not only on the importance of each node in the system but also on the interrelationship between the nodes. If a node is an evil node, the active interaction that other nodes initiate is uncontrollable to this node, so it greatly increases the difficulty of attacking the evil nodes; the half-life algorithm updates the influence of the node credit according to the accounting times of this node, and this also makes it more difficult for nodes to attack based on their credit rating; the credit system will affect the node's credit of the attack, increase the cost of doing evil, and so it is not worth it to attack for the enemy node. In conclusion, when the number of honest nodes in the PoE consensus mechanism is larger than the evil nodes, it is difficult for the evil nodes to launch an effective attack, that is $n \geq 2f + 1$ in the adversary model of PoE.

5. Experiment Results and Analysis

5.1. Experimental Purpose

In order to test the comprehensive performance of the PoE consensus mechanism, test the comprehensive operation efficiency of the PoE in the media ecology, and analyze the performance differences between the PoE consensus mechanism and other mainstream consensus mechanisms, we use the PoE consensus mechanism to simulate the process of generating consensus in the media ecology.

5.2. Experimental Environment

In the experiment, we simulate the nodes, characteristics and behaviors of the convergence media ecosystem using program, and the total program including the PoE consensus algorithm is implemented by Python. The hardware configuration in the experiment is shown in the Table 3 as follows:

Table 3. Experimental environment.

Configure	Detailed Information
Operating system	windows 10 pro lite 64-bit
CPU	intel core i9-10900 @ 2.80ghz
Memory	8 Gb (2933 Mhz)
Network	Gigabit LAN

5.3. Experimental Scheme

We use digital simulate node status in the system, including the number of nodes, node credit, participation, currency, computing power, etc. In the experiment, PoW, PoS and PoE are used to generate accounting nodes, respectively, and we analyze the state attributes of generating the accounting node and the efficiency of the whole algorithm.

In the experiment, we simulate 1000 nodes, and each node simulates initial participation, credit, interaction relationship and token, which is represented by a random number of 0–100. In each round of candidate consensus, 20 candidate consensus nodes are selected. The initial accounting times of candidate consensus nodes is set as 0, and the half-life of accounting times is set as 100. The threshold of VRF random number is set as 20 (the first 20 digits of threshold binary representation are 0), and the credit of accounting increases by 50.

5.4. Experimental Result

5.4.1. The Average Block Generation Time

The average block generation time in the PoE is mainly reflected in two parts: the time to generate the candidate consensus node and the time to generate the accounting node. A consensus cycle contains a candidate consensus cycle and multiple accounting cycles, so the average block-out time in the PoE is mainly reflected in the time which was spent on generating the accounting node.

The time to generate the candidate consensus node depends on the size of the node, the complexity of the node interaction relationship, etc., and the relationship between the time and the node size under the same node interaction complexity is shown in Figure 4. The time of generating an accounting node depends on VRF random number, threshold range, credit of the node and accounting times, etc. We calculate the average time of generating blocks increasing by 10 blocks, and the average time of generating blocks of 1000 blocks in the experiment is shown in Figure 5.

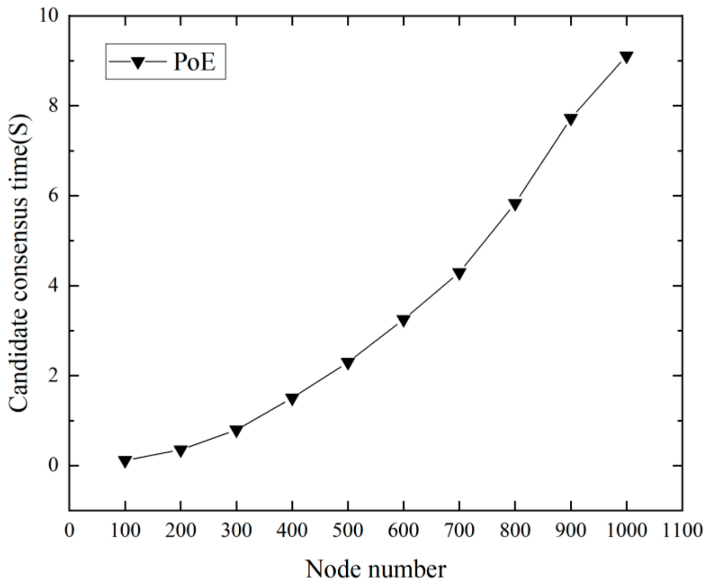

Figure 4. PoE node number and candidate consensus time relation.

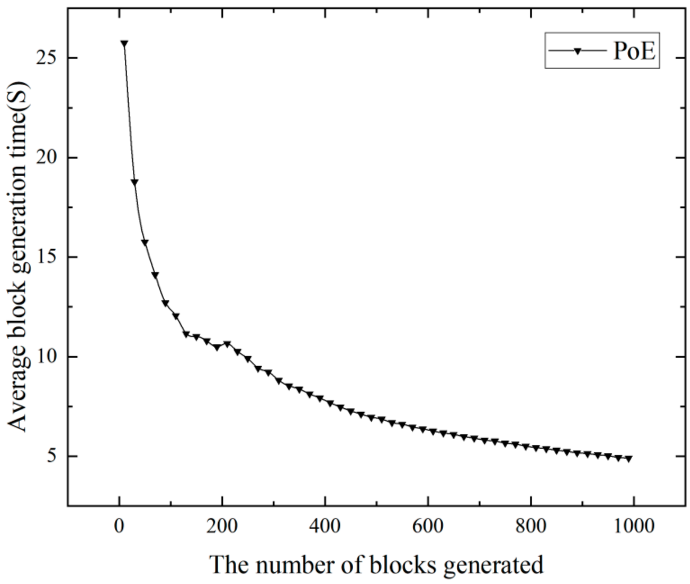

Figure 5. PoE average block generation time.

Through the experiment, we can see that the average block generation time is about 25 s at the beginning. With the increase in the subsequent blocks generated, the average block generation time drops sharply, and the subsequent average block generation time is basically maintained at about 5 s. It should be emphasized that the average block generation time can be adjusted for most of the applications of consensus mechanism. Generally, in order to ensure the stability of the whole system, the consistency of consensus mechanism, the scale of nodes in the system, communication efficiency and other factors are taken into consideration to control the block generation time of consensus mechanism. For example, Bitcoin adjusts the consensus difficulty of the PoW consensus mechanism based on the computing power of the whole network to maintain an average block generation time of around 600 s. Therefore, the consensus mechanism cannot blindly improve the average block generation time while ignoring the stability of the whole system. The average block generation time of the PoE and current typical blockchain applications is compared as shown in Figure 6.

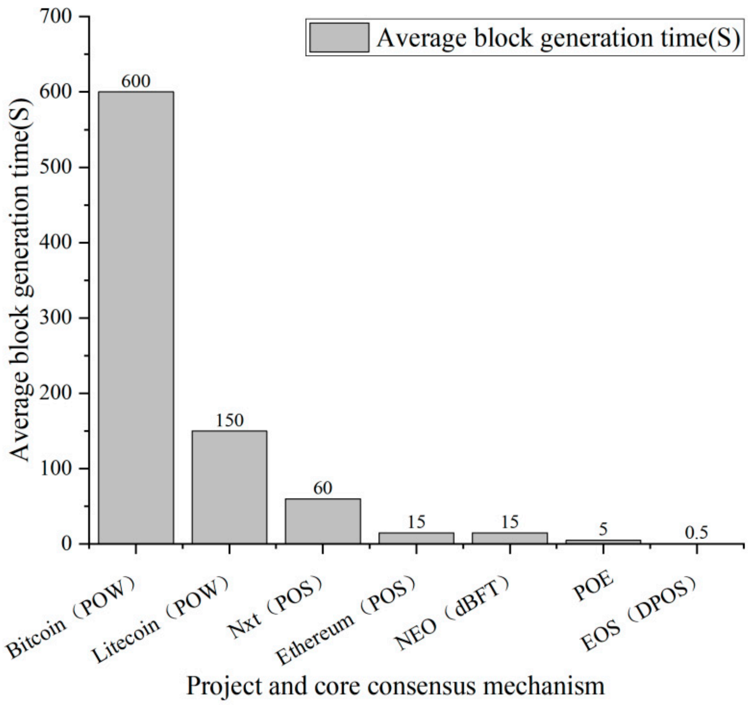

Figure 6. Comparison of the consensus mechanism's average block generation time [60].

5.4.2. Throughput

Throughput (TPS) refers to the number of transactions handled by the system per second. In the blockchain-based convergence media ecosystem, the system throughput can be the number of recording convergence media transactions per second, and the convergence media transactions can be content distribution, content forwarding, copyright registration or resale, etc.

$$\text{TPS} = \frac{\sum TX_{db} + TX_{fw} + TX_{rt} + TX_{rs} + TX_{other}}{\Delta t} \tag{18}$$

where TX_{db}, TX_{fw}, TX_{rt}, TX_{rs} and TX_{other} respectively stand for content distribution, content forwarding, copyright registration, copyright resale and other transactions, and Δt is the statistical period.

In fact, the network bandwidth can fundamentally limit the throughput of the blockchain. Our experiment is carried out in the laboratory LAN environment. In actual operation, the throughput of the system will vary with the node scale, the volume of transactions actually generated by the system, the average network bandwidth and other factors. We designed the storage of each block to be 1M bytes, and the average storage space of interactive transactions is about 250 bytes. The throughput of the system tested in the laboratory environment is shown in the Figure 7.

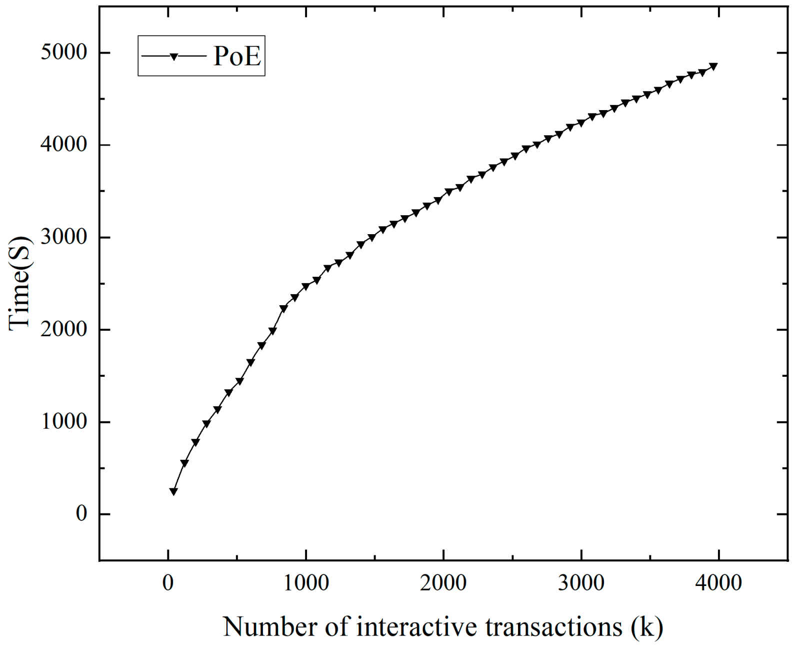

Figure 7. Throughput of PoE.

After experimental tests, the PoE consensus throughput is about 820 transactions per second. The throughput comparison of the PoE consensus with other typical blockchain projects is shown in Figure 8.

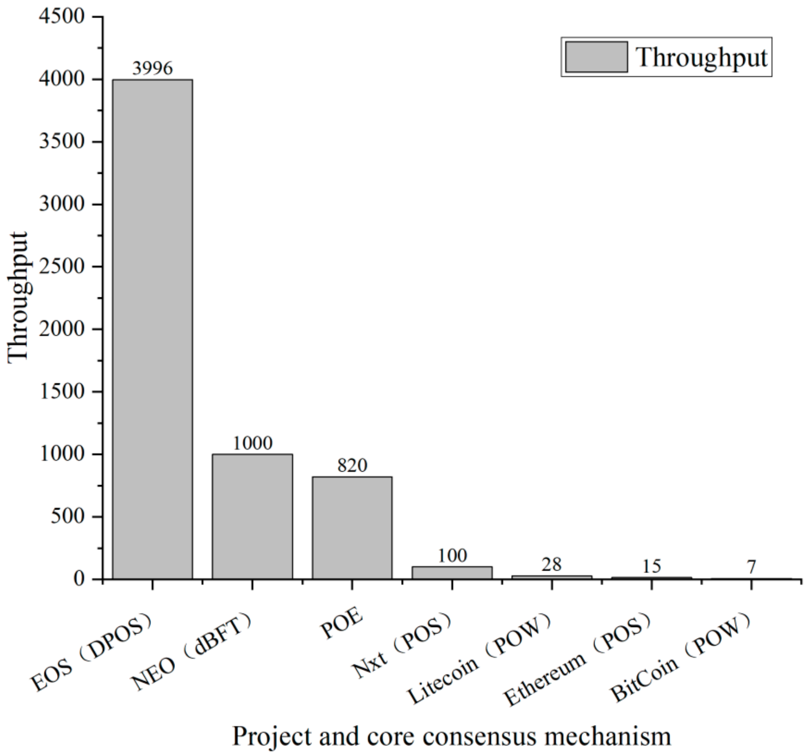

Figure 8. Comparison of the consensus mechanism's throughput [60].

In the blockchain system, we need to pay attention not only to the high value of TPS, but also to consider the concurrency, blockchain structure, security performance and other aspects comprehensively, so that the blockchain system can meet the market demand.

5.4.3. Block Confirmation Time

Block confirmation time is an index that is influenced by comprehensive conditions, such as the design of consensus algorithm, the scale of system nodes and the degree of consensus consistency. In PoE consensus algorithm, there is a certain randomness in the process of reaching consensus, and the candidate consensus nodes try to compete for accounting rights in turn, so there should be no collisions during operation in theory. After 1000 simulations, the PoE consensus was immediately confirmed without fork.

5.4.4. Comprehensive Effectiveness

In the consensus mechanism, there is a certain randomness in the generation of candidate consensus nodes and accounting nodes, and at the same time, there is a certain correlation with some characteristics of nodes, which directly affects the consensus results of a consensus mechanism and the operations promotion of the system. According to the set experimental scheme, we simulated 1000 times of candidate consensus node generation, and each round of consensus produced 20 candidate consensus nodes, then we analyzed the relationship between candidate consensus nodes and other participation nodes.

From the experimental results, it can be seen that the generation of candidate consensus nodes has a certain relationship with the value of node participation. The node with high participation is more likely to be selected as the candidate consensus node, but this is not exactly equal to the ranking of node participation. The node with participation ranking lower than 20 may still be selected as the candidate consensus node. It can be seen that the PoE consensus reflects the participation of nodes in the system to some extent, which reflects the interaction between nodes. The relationship between the times of selecting as candidate consensus node and the participation ranking is shown in Figure 9.

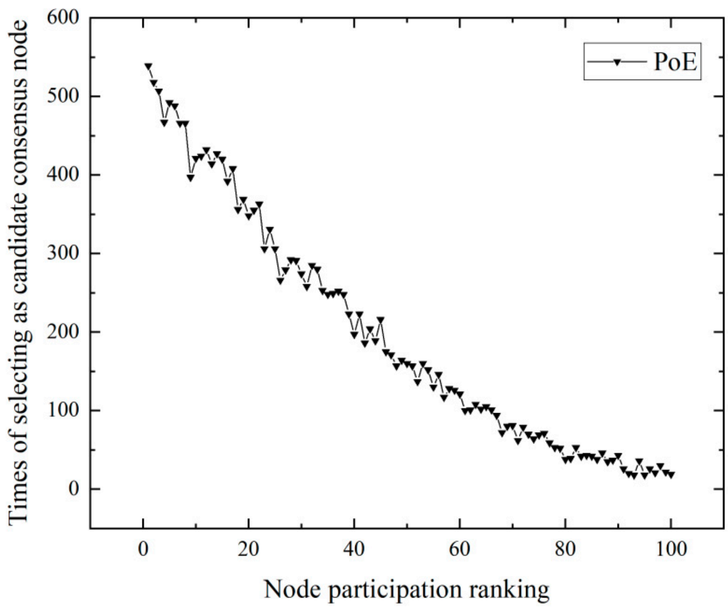

Figure 9. Candidate consensus nodes and rank of participation.

We randomly selected 10 groups of candidate consensus data from 1000 groups of consensus data, and the boxplot of their participation ranking is shown in Figure 10.

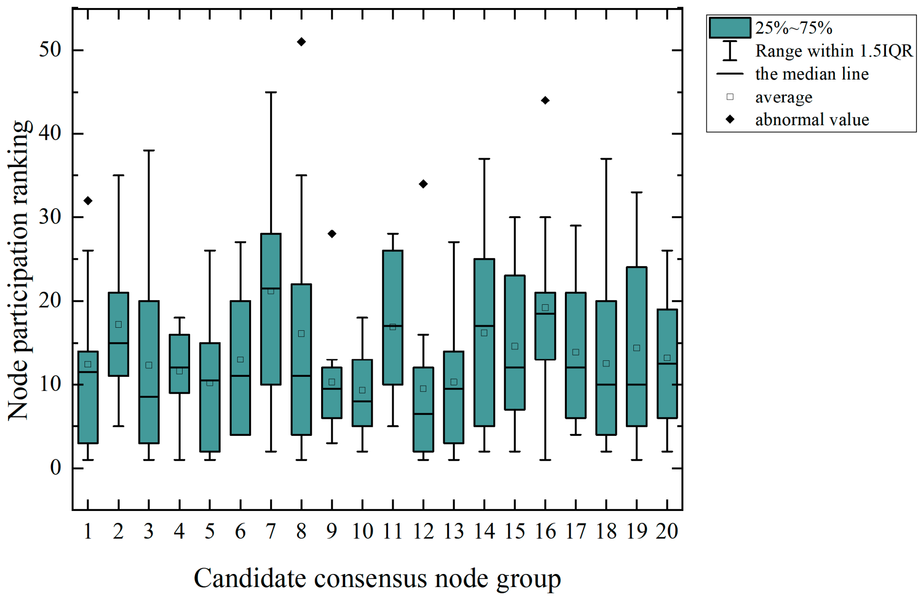

Figure 10. Boxplot of candidate consensus node and participation rank.

In the accounting cycle of the consensus, the PoE uses the combination of VRF, credit rating and accounting times to generate accounting nodes. We simulate 10,000 accounting cycles, and the relation of credit ranking and accounting times distribution of accounting nodes are shown in Figure 11.

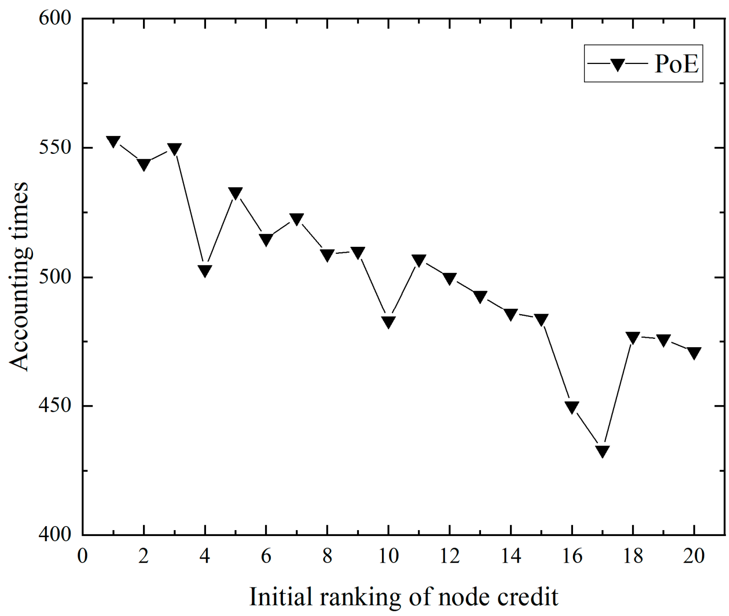

Figure 11. Credit ranking and accounting times.

It can be seen that the candidate consensus node with the high credit degree obtained the accounting right more times, but the node with the highest credit degree did not continuously obtain the accounting right and did not form the Matthew effect. At the same time, the node which is selected as the accounting node has a certain randomness.

5.5. Experimental Analysis

Through the experiment results, we analyze the PoE consensus mechanism as follows:

(1) The total block generation time of the PoE consensus mechanism is mainly reflected in the generation process of the candidate consensus nodes. With the increasing number

of block generation, the average block generation time gradually decreases until it becomes stable, and the average block generation time is about 5 s.
(2) In the PoE consensus mechanism, as the number of output blocks increases, the system throughput gradually increases until it becomes stable. The throughput is about 820 transactions per second, which is between the PoW and PoS consensus mechanism.
(3) There is a certain randomness in the process of reaching consensus in the PoE consensus mechanism, and candidate consensus nodes take turns to try to compete for accounting rights. Theoretically, collisions are not easy to occur, and the consensus can be confirmed immediately; moreover, it is not easy to occur fork.
(4) The candidate consensus nodes generated by the algorithm are closely related to node participation, but they are not completely generated according to the initial participation, and it comprehensively reflects the interaction between nodes.
(5) In the consensus cycle, the accounting node is generated by combining the VRF algorithm, which has a certain randomness and is closely related to the credit of the node. The node with higher credit has a higher probability of obtaining the accounting right. At the same time, the Matthew effect in the process of node accounting is better solved by combining the times of node accounting and half-life algorithm.

6. Conclusions

In this paper, we introduced the development process of convergence media and analyzed the current development status of blockchain and consensus mechanisms, then we preliminarily described a convergence media ecosystem, and established some basic operation and maintenance rules in the ecosystem simultaneously. Furthermore, we designed and implemented a consensus mechanism named "Proof of Efficiency" in the blockchain-based convergence media.

After analysis, the PoE can provide high security and resist 51% resource attack, sybil attack, selfish mining attack, long-range attack, etc. The experimental results show that the PoE has the characteristics of decentralization, strong consistency, low energy consumption, short average block generation time, high throughput and short block confirmation time.

The research on convergence media consensus mechanism based on blockchain is of great significance for the coordinated development of convergence media ecology. With the decentralized, traceable and tamper-resistant characteristics of blockchain, we can design or optimize the fields which the media industry urgently needs to improve. Consensus mechanism is the core of blockchain technology, but there is a lack of practical research on the consensus mechanism of convergence media. Compared with the current mainstream consensus mechanism, the PoE consensus mechanism can better reflect the media ecological attributes of nodes in the consensus process such as node participation, node interaction, node credit, number of node accounting, etc., and better solve the Matthew effect generated in the consensus process. In this way, it can stimulate the activity of the entire media ecology, so as to improve the efficiency of ecological operation and maintenance.

The PoE consensus mechanism achieves a certain degree of decentralized governance, but it also faces the inevitable contradiction between consensus efficiency and degree of decentralization. There is still a gap in consensus efficiency between the PoE and other mainstream consensus mechanisms, and the robustness of the PoE consensus mechanism still has room for improvement. In the future, we will continue to study these issues raised above which need to be improved, and further study how to combine consensus mechanisms and smart contracts to serve convergence media ecology based on blockchain.

Author Contributions: Conceptualization, Y.W.; methodology, H.H. and Y.W.; formal analysis, Y.W.; investigation, H.H.; writing—original draft preparation, H.H.; writing—review and editing, Y.W.; visualization, H.H.; project administration, Y.W.; funding acquisition, Y.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Key R&D Program of China, grant number 2019YFB1406201.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data is contained within the article.

Acknowledgments: The authors greatly appreciate the editor and anonymous reviewers for their comments, which helped to improve this paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Spilioti, T. Media convergence and publicness: Towards a modular and iterative approach to online research ethics. *Appl. Linguist. Rev.* **2017**, *8*, 191–212. [CrossRef]
2. Choi, H. Broadcasting and Telecommunications Industries in the Convergence Age: Toward a Sustainable Public-Centric Public Interest. *Sustainability* **2018**, *10*, 544. [CrossRef]
3. Tulisova, V.A. Transformation of the media from traditional media to new media. *Theor. Pract. Issues J.* **2017**, *6*, 228–244.
4. Abascal, M.L.Z. Transmedia intertextualities in educational media resources: The case of BBC Schools in the United Kingdom. *New Media Soc.* **2016**, *18*, 2629–2648. [CrossRef]
5. Almalki, F.A.; Aljohani, M.; Algethami, M.; Soufiene, B.O. Incorporating Drone and AI to Empower Smart Journalism via Optimizing a Propagation Model. *Sustainability* **2022**, *14*, 3758. [CrossRef]
6. Drula, G. Forms of Media Convergence and Multimedia Content—A Romanian Perspective. *Comunicar. Media Educ. Res. J.* **2015**, *22*, 131–140. [CrossRef]
7. Kuo, T.T.; Kim, H.E.; Ohno-Machado, L. Blockchain distributed ledger technologies for biomedical and health care applications. *J. Am. Med. Inform. Assoc.* **2017**, *24*, 1211–1220. [CrossRef]
8. Cao, B.; Zhang, Z.; Feng, D.; Zhang, S.; Zhang, L.; Peng, M.; Li, Y. Performance analysis and comparison of PoW, PoS and DAG based blockchains. *Digit. Commun. Netw.* **2020**, *6*, 480–485. [CrossRef]
9. Kümpel, A.S. The Matthew Effect in social media news use: Assessing inequalities in news exposure and news engagement on social network sites (SNS). *Journalism* **2020**, *21*, 1083–1098. [CrossRef]
10. Zheng, K.; Zhang, Z.; Gauthier, J. Retraction Note: Blockchain-based intelligent contract for factoring business in supply chains. *Ann. Oper. Res.* **2022**, *308*, 777–797. [CrossRef]
11. Zhang, C.; Zhou, G.; Li, H.; Cao, Y. Manufacturing Blockchain of Things for the Configuration of a Data- and Knowledge-Driven Digital Twin Manufacturing Cell. *IEEE Internet Things J.* **2020**, *7*, 11884–11894. [CrossRef]
12. Yan, S.J. Convergence Ecology, Value Co-creation and In-depth Empowerment: The Core Logics of Future Media Development. *Journal. Commun.* **2019**, *26*, 12.
13. Huang, C.X. Integration and Development of Chinese Media in 2020. *Mod. Commun.* **2021**, *43*, 9–14.
14. Lin, Y. Analysis of Problems and Countermeasures for County Level Media Integration Development. *TV Res.* **2020**, *9*, 64–66.
15. Malmelin, N.; Villi, M. Media work in change: Understanding the role of media professionals in times of digital transformation and convergence. *Sociol. Compass* **2017**, *11*, e12494. [CrossRef]
16. Li, X.; Gong, X.; Mou, R. Pioneering the media convergence: Lifestyle media production in the digital age in China. *J. Media Bus. Stud.* **2021**, *18*, 304–320. [CrossRef]
17. Wang, W. Research on the Influencing Factors of Network Public Opinion Dissemination Behavior in User-Generated Content of Mobile Video Clips from the Perspective of Information Ecology. *Inf. Stud. Theory Appl.* **2020**, *43*, 24–30.
18. Peciulis, Z. Digital era: From mass media towards a mass of media. *Filos.-Sociol.* **2016**, *27*, 240–248.
19. Guo, H. The development and application of new media technology in news communication industry. *Int. J. Electr. Eng. Educ.* **2021**, 0020720921996593. [CrossRef]
20. Srivastava, A.K.; Mishra, R. Analyzing Social Media Research: A Data Quality and Research Reproducibility Perspective. *IIM Kozhikode Soc. Manag. Rev.* **2021**, 22779752211011810. [CrossRef]
21. Zhou, N.; Huang, G.; Zhong, S. Big Data Validity Evaluation Based on MMTD. *Math. Probl. Eng.* **2018**, *2018*, 8058670. [CrossRef]
22. Salvatore, C.; Biffignandi, S.; Bianchi, A. Social Media and Twitter Data Quality for New Social Indicators. *Soc. Indic. Res.* **2021**, *156*, 601–630. [CrossRef]
23. Manoharan, S.; Senthilkumar, R. An Intelligent Fuzzy Rule-Based Personalized News Recommendation Using Social Media Mining. *Comput. Intell. Neurosci.* **2020**, *2020*, 3791541. [CrossRef]
24. Yang, B.J. Algorithmic Journalism: Ethical Risk, Ethical Subject, and Ethical Principle. *J. Northwest Norm. Univ.* **2019**, *56*, 27–36.
25. Ciampaglia, G.L. Fighting fake news: A role for computational social science in the fight against digital misinformation. *J. Comput. Soc. Sci.* **2018**, *1*, 147–153. [CrossRef]
26. Cybenko, A.K.; Cybenko, G. AI and Fake News. *IEEE Intell. Syst.* **2018**, *33*, 3–7. [CrossRef]
27. Fraga-Lamas, P.; Fernandez-Carames, T.M. Fake News, Disinformation, and Deepfakes: Leveraging Distributed Ledger Technologies and Blockchain to Combat Digital Deception and Counterfeit Reality. *IT Prof.* **2020**, *22*, 53–59. [CrossRef]
28. Li, Z. Intelligent media computing technology and application for media convergence. *CAAI Trans. Intell. Technol.* **2022**, *7*, 329–330. [CrossRef]

29. Zhang, Y.; Luo, W.; Yu, F. Construction of Chinese Smart Water Conservancy Platform Based on the Blockchain: Technology Integration and Innovation Application. *Sustainability* **2020**, *12*, 8306. [CrossRef]
30. Xue, Z.Y.; Wang, M.; Zhang, Q.Y.; Zhang, Y.F.; Liu, P.D. A Regulatable Blockchain Transaction Model with Privacy Protection. *Int. J. Comput. Intell. Syst.* **2021**, *14*, 1642–1652. [CrossRef]
31. Wei, H.; Guan, S. Path and Mechanism of Blockchain Embedded in Innovation Management of Cultural and Creative Industrial Park. *Discret. Dyn. Nat. Soc.* **2021**, *2021*, 9574223. [CrossRef]
32. Wang, H.J.; Yong, J.; Liu, Q.W.; Yang, A. A Novel GLS Consensus Algorithm for Alliance Chain in Edge Computing Environment. *CMC-Comput. Mater. Contin.* **2020**, *65*, 963–976. [CrossRef]
33. Gatteschi, V.; Lamberti, F.; Demartini, C.; Pranteda, C.; Santamaria, V. To Blockchain or Not to Blockchain: That Is the Question. *IT Prof.* **2018**, *20*, 62–74. [CrossRef]
34. Morkunas, V.J.; Paschen, J.; Boon, E. How blockchain technologies impact your business model. *Bus. Horiz.* **2019**, *62*, 295–306. [CrossRef]
35. Kudva, S.; Badsha, S.; Sengupta, S.; Khalil, I.; Zomaya, A. Towards secure and practical consensus for blockchain based VANET. *Inf. Sci.* **2021**, *545*, 170–187. [CrossRef]
36. Yang, F.; Zhou, W.; Wu, Q.; Long, R.; Xiong, N.N.; Zhou, M. Delegated Proof of Stake with Downgrade: A Secure and Efficient Blockchain Consensus Algorithm with Downgrade Mechanism. *IEEE Access* **2019**, *7*, 118541–118555. [CrossRef]
37. Huang, J.; Kong, L.; Chen, G.; Wu, M.-Y.; Liu, X.; Zeng, P. Towards Secure Industrial IoT: Blockchain System with Credit-Based Consensus Mechanism. *IEEE Trans. Ind. Inform.* **2019**, *15*, 3680–3689. [CrossRef]
38. Zou, J.; Ye, B.; Qu, L.; Wang, Y.; Orgun, M.A.; Li, L. A Proof-of-Trust Consensus Protocol for Enhancing Accountability in Crowdsourcing Services. *IEEE Trans. Serv. Comput.* **2019**, *12*, 429–445. [CrossRef]
39. Liu, L.; Zhang, W.; Han, C. A survey for the application of blockchain technology in the media. *Peer-to-Peer Netw. Appl.* **2021**, *14*, 3143–3165. [CrossRef]
40. Chen, Q.; Srivastava, G.; Parizi, R.M.; Aloqaily, M.; Al Ridhawi, I. An incentive-aware blockchain-based solution for inter-net of fake media things. *Inf. Processing Manag.* **2020**, *57*, 102370. [CrossRef]
41. Ma, Z.; Guan, J.; Li, R.Y.M. Research on Innovative Teaching Mode of Art Education in the Age of Convergence of Media. *Int. J. Emerg. Technol. Learn. (iJET)* **2021**, *16*, 272–284. [CrossRef]
42. Gómez, R. Communication industries in North America after 20 years of North American Free Trade Agreement: Media policy, regulatory bodies and concentration. *Int. Commun. Gaz.* **2016**, *78*, 177–199. [CrossRef]
43. Xiao, L.; Huang, W.; Xie, Y.; Xiao, W.; Li, K.-C. A Blockchain-Based Traceable IP Copyright Protection Algorithm. *IEEE Access* **2020**, *8*, 49532–49542. [CrossRef]
44. Zhu, S.; Song, M.L.; Lim, M.K.; Wang, J.L.; Zhao, J.J. The development of energy blockchain and its implications for China's energy sector. *Resour. Policy* **2020**, *66*, 101595. [CrossRef]
45. Huang, M.-L.; Liao, S.-Y.; Lin, K.-C. Augmented Half-Life Estimation Based on High-Frequency Data. *J. Forecast.* **2015**, *34*, 523–532. [CrossRef]
46. Page, L.; Brin, S.; Motwani, R.; Winograd, T. The PageRank Citation Ranking: Bringing Order to the Web. Stanford Digital Libraries Working Paper 1998. Available online: http://ilpubs.stanford.edu:8090/422/ (accessed on 28 July 2022).
47. Yao, S.; Zhang, D. An Anonymous Verifiable Random Function with Applications in Blockchain. *Wirel. Commun. Mob. Comput.* **2022**, *2022*, 1–12. [CrossRef]
48. Wang, Q.; Feng, R.; Zhu, Y. Verifiable random functions with Boolean function constraints. *Sci. China Inf. Sci.* **2018**, *61*, 039105. [CrossRef]
49. Xu, X.-H.; Zhong, X.-Y.; Chen, X.-H.; Zhou, Y.-J. A dynamical consensus method based on exit–delegation mechanism for large group emergency decision making. *Knowl.-Based Syst.* **2015**, *86*, 237–249. [CrossRef]
50. Li, W.Y.; Feng, C.L.; Zhang, L.; Xu, H.; Cao, B.; Imran, M.A. A Scalable Multi-Layer PBFT Consensus for Blockchain. *IEEE Trans. Parallel Distrib. Syst.* **2021**, *32*, 1146–1160. [CrossRef]
51. Guo, C.; Zhang, P.; Lin, B.; Song, J. A Dual Incentive Value-Based Paradigm for Improving the Business Market Profitability in Blockchain Token Economy. *Mathematics* **2022**, *10*, 439. [CrossRef]
52. Salimitari, M.; Chatterjee, M.; Fallah, Y.P. A survey on consensus methods in blockchain for resource-constrained IoT networks. *Internet Things* **2020**, *11*, 100212. [CrossRef]
53. Sayeed, S.; Marco-Gisbert, H. Assessing Blockchain Consensus and Security Mechanisms against the 51% Attack. *Appl. Sci.* **2019**, *9*, 1788. [CrossRef]
54. Zhang, S.; Lee, J.-H. Double-Spending With a Sybil Attack in the Bitcoin Decentralized Network. *IEEE Trans. Ind. Inform.* **2019**, *15*, 5715–5722. [CrossRef]
55. Motlagh, S.G.G.; Misic, J.; Misic, V.B. The Impact of Selfish Mining on Bitcoin Network Performance. *IEEE Trans. Netw. Sci. Eng.* **2021**, *8*, 724–735. [CrossRef]
56. Li, A.; Wei, X.; He, Z. Robust Proof of Stake: A New Consensus Protocol for Sustainable Blockchain Systems. *Sustainability* **2020**, *12*, 2824. [CrossRef]
57. Deirmentzoglou, E.; Papakyriakopoulos, G.; Patsakis, C. A Survey on Long-Range Attacks for Proof of Stake Protocols. *IEEE Access* **2019**, *7*, 28712–28725. [CrossRef]

58. Do, Q.; Martini, B.; Choo, K.-K.R. The role of the adversary model in applied security research. *Comput. Secur.* **2019**, *81*, 156–181. [CrossRef]
59. Zhang, P.; Hu, C.Q.; Wu, S.T.; Gong, R.Y.; Luo, Z.M. Event-Triggered Resilient Average Consensus With Adversary Detection in the Presence of Byzantine Agents. *IEEE Access* **2021**, *9*, 121431–121444. [CrossRef]
60. Bamakan, S.M.H.; Motavali, A.; Bondarti, A.B. A survey of blockchain consensus algorithms performance evaluation criteria. *Expert Syst. Appl.* **2020**, *154*, 113385. [CrossRef]