International Metaverse Association

Metaverse Convergence Research Institute

ISSN 3059-0442

Journal of Virtual Convergence Research

Volume 1 Number 1 Jan.2024

Received: 30 October 2024. Accepted: 01 December 2024

Journal of Virtual Convergence Research
2025, VOL. 1, NO. 1, 114~147
https://intlmetaverse.com/home/journal?lang=en

International Metaverse Association &
Metaverse Convergence Research Institute

PoCS: Proof of Contribution Score Consensus Algorithm for Blockchain using Metaverse Clients

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Abstract

This paper proposes the Proof of Contribution Score(PoCS) algorithm to enhance blockchain consensus by integrating block verification capabilities into metaverse clients and quantifying individual node contributions. PoCS addresses the centralization issues inherent in the traditional Proof of Stake(PoS) algorithm by evaluating not only a node's stake but also other factors such as block generation frequency and network activity. A key innovation of PoCS is the introduction of a fairness baseline, which visualizes deviations in node contributions, effectively detecting imbalances and potential biases in the node selection process. This allows for fair evaluation and reward distribution, fostering long-term network stability and scalability. PoCS is particularly applicable in complex environments such as the metaverse, where it can contribute to building a fair and sustainable blockchain ecosystem. By providing a solid foundation for enhancing the fairness of leader-based consensus algorithms, PoCS can significantly strengthen the blockchain's capability in such dynamic environments.

Keywords : PoCS, metaverse, permissioned blockchain, hybrid consensus algorithm, PBFT

PoCS: Proof of Contribution Score Consensus Algorithm for Blockchain using Metaverse Clients

1. Introduction

Blockchain technology was first introduced in 2008 with the release of Bitcoin by the pseudonymous creator S. Nakamoto, marking a significant milestone in the development of decentralized systems. The first real-world application of blockchain was implemented in January 2009 with the launch of the Bitcoin network(Nakamoto, 2008). This groundbreaking innovation allowed for the secure transfer of digital assets without the need for a centralized authority, ensuring data integrity through cryptographic mechanisms(Zhou et al., 2023).

At the core of blockchain's functionality lies the consensus algorithm, which enables agreement among distributed nodes(Mingxiao, 2017). These algorithms are crucial for maintaining network stability, security, and reliability. One of the most widely used consensus mechanisms, Proof of Stake (PoS), offers an energy-efficient alternative to the computationally expensive Proof of Work (PoW) by assigning block generation rights based on the size of a node's stake in the network. However, despite its efficiency, PoS has been criticized for the potential centralization of power, as nodes with larger stakes are disproportionately rewarded with greater control over the network. This centralization could undermine the core principles of decentralization that blockchain technology aims to uphold(King & Nadal, 2024).

To address these limitations and introduce a more equitable and multi-faceted evaluation approach, this paper proposes Proof of Contribution Score (PoCS) algorithm.

By treating blockchain nodes as metaverse clients, PoCS comprehensively evaluates the various activities that nodes contribute to the network. The algorithm selects validator nodes using a node's stake and contribution factors and collects metrics such as block generation frequency and round-based coin acquisition to monitor the fairness of the consensus process. This enables PoCS to achieve a more comprehensive and equitable consensus process compared to PoS.

A comparative analysis of PoCS and PoS reveals that PoCS is more effective in accurately reflecting blockchain network contributions and mitigating the issue of centralization caused by stake. While PoS primarily relies on nodes with a high stake percentage, PoCS scores various contribution factors to fairly evaluate the activities of diverse participants, thus maintaining the health of the network. For example, while a few high-stake nodes can dominate block generation rights in PoS, PoCS distributes opportunities more fairly by considering various contribution factors.

Furthermore, PoCS algorithm can be seamlessly combined with leader-based consensus algorithms like Practical Byzantine Fault Tolerance (PBFT). PBFT is a well-known algorithm that ensures network stability and consensus reliability, primarily used in permissioned blockchains(Castro & Liskov, 1999; Wu et al., 2019). Combining PoCS with PBFT enables the achievement of fair consensus while maintaining network performance. This is particularly beneficial for blockchain environments with diverse participants, enabling stable and reliable consensus.

This research aims to propose a more fair and efficient consensus mechanism for blockchain networks through PoCS algorithm. By enabling blockchain services in the metaverse, maintaining network diversity, and contributing to the long-term development of the blockchain ecosystem, PoCS complements the limitations of existing PoS and realizes a more democratic and reliable blockchain consensus through a multifaceted evaluation of contribution factors.

The major contributions of PoCS algorithm presented in the paper are:

- Equitable Consensus Process: PoCS addresses the centralization issues of traditional PoS by evaluating not just stake but also various contribution factors like block generation and network activity.
- Combination with PBFT: PoCS can be seamlessly combined with PBFT to enhance stability and reliability in permissioned blockchains.
- Comprehensive Participation Metrics: PoCS ensures fairness by factoring in diverse participant contributions, promoting network health and long-term blockchain ecosystem development.
- Application in Metaverse: PoCS can be applied to metaverse blockchain clients, enabling innovative blockchain services.

The rest of this paper is structured as follows: Section 2 covers the background knowledge, while Section 3 addresses related work, including PoS, PBFT, hybrid consensus algorithms, and permissioned blockchains. Section 4 proposes a consensus process utilizing metaverse clients. Section 5 discusses PoCS algorithm, along with experiments and evaluations. Section 6 provides an analysis of the research findings and explores future directions. Finally, Section 7 presents the conclusion and potential implications of this study.

2. Background

A consensus algorithm is a protocol or mechanism designed to achieve agreement among nodes in a distributed network(Xiao et al., 2019). In the context of a blockchain network, these nodes are computers or devices that store and maintain a copy of the blockchain. The role of the consensus algorithm is to ensure that all nodes have a synchronized view of the blockchain and agree on the sequence of transactions. This is essential for maintaining the integrity, security, and consistency of the decentralized ledger, even in the presence of faulty or malicious nodes.

In 1999, Castro and Liskov introduced the practical Byzantine Fault Tolerance (PBFT) algorithm, which addressed the inefficiencies present in the original BFT system. This PBFT, a consensus algorithm resilient to Byzantine failures, ensures the continued operation of distributed systems despite up to f faulty or malicious nodes among 3f+1 total nodes. Through a multi-step message exchange involving a leader node and multiple validator nodes, consensus is achieved when more than 2f+1 nodes agree. This consensus process comprises three primary phases: Pre-prepare, Prepare, and Commit. The leader node initiates by proposing a new block, followed by validator nodes receiving and acknowledging this proposal with Pre-prepare messages. Subsequently, validator nodes verify the proposed block and exchange Prepare messages. Finally, in the Commit phase, a sufficient number of Prepare messages triggers the finalization of the block. Throughout this process, inter-node message exchanges guarantee the stability and reliability of the entire network, even in the face of malicious Byzantine nodes.

Various consensus algorithms, such as PoW, PoS, and PBFT, have been developed to meet the specific requirements of different blockchain networks. Each algorithm has its trade-offs in terms of security, energy efficiency, scalability, and resistance to attacks.

Table 1 *Comparative Analysis of Public and Permissioned Blockchain*

Aspect	Public Blockchain	Permissioned Blockchain
Access Control	Open to anyone (permissionless)	Restricted to authorized participants (permissioned)
Participants	Anonymous or pseudonymous	Known and trusted entities
Consensus Algorithm	PoW or PoS (decentralized and slow)	Faster mechanisms like PBFT, PoA, or Raft
Decentralization	Fully decentralized	More centralized (control lies with a single organization)
Scalability	Low due to the large number of participants	High due to limited participants
Speed	Slower due to complex consensus (e.g., PoW, PoS)	Faster due to limited nodes
Security	Very secure, but vulnerable to 51% attacks	Highly secure with trusted participants
Transparency	Fully transparent and open to the public	Less transparent, accessible only to participants
Examples	Bitcoin, Ethereum	Hyperledger Fabric, Corda

As shown in Table 1, different blockchain types offer distinct trade-offs between decentralization, security, transparency, and control. Public blockchains emphasize openness and decentralization, whereas private and consortium blockchains prioritize control and efficiency for enterprise use(Tomić, 2021; Min, 2020; Dabbagh et al., 2024).

The concept of the "Metaverse" was first introduced in 1992 by author Neal

Stephenson in his science fiction novel Snow Crash. In the book, Stephenson used the term to describe a computer-generated, 3D universe that users could experience through goggles. The word "Metaverse" is a combination of the prefix "meta" (meaning transcending) and "universe," implying a universe that goes beyond the physical world(Bale et al., 2022). The key requirements of the metaverse include data reliability, integrity, security, transparency, and decentralization. Blockchain technology stands out as one of the critical technologies capable of optimally fulfilling these requirements(Torky, 2023). By assigning validation roles to metaverse clients, these clients can participate in the verification process and earn rewards, such as coins. These coins can then be used to facilitate services within the metaverse, thereby enhancing the overall ecosystem and incentivizing participation.

PoCS algorithm is a novel consensus algorithm that combines the fast responsiveness of permissioned blockchains with robust consensus mechanisms, making it ideal for potential metaverse service applications. This innovative approach ensures secure, decentralized validation while accommodating the scalability and performance demands of metaverse environments. Traditional PoS algorithms can lead to centralization issues due to the concentration of stake among network participants. However, PoCS addresses this challenge by comprehensively evaluating contributions and activity, considering factors. This approach ensures that nodes contributing meaningfully to the network, not just those with high stakes, are selected for validation.

By incorporating a multifaceted evaluation system, PoCS ensures that nodes with diverse contributions are rewarded and selected for validation, thereby promoting the long-term stability and sustainability of the blockchain. This approach not only prevents the concentration of power among a few nodes but also encourages a more engaged and active network.

PoCS algorithm is particularly well-suited for emerging ecosystems like the metaverse, where user activity is diverse and widespread. In such environments, traditional consensus mechanisms may fail to capture the full range of user contributions. By incorporating contribution metrics alongside financial stake, PoCS ensures a more equitable distribution of rewards and decision-making power. This approach can be integrated with PBFT, combining the fairness of contribution-based validation with the reliability and fault tolerance of PBFT, especially in permissioned blockchain settings.

This research suggests the potential of PoCS to enhance the scalability and fairness of blockchain services, enabling effective consensus even in complex environments like the metaverse. This approach can be particularly beneficial in environments where traditional consensus mechanisms may struggle to capture the full range of user contributions.

Additionally, metaverse clients with block verification capabilities have the potential to generate new economic and social value through the adoption of blockchain technology. Metaverse clients serving as validator nodes can receive basic verification rewards as well as contribution rewards based on their activities within the metaverse. As shown in Table 5, when metaverse clients are used as validator nodes, key factors for evaluating node contributions are considered. This approach promotes the decentralization of the blockchain network and encourages users to actively contribute to the network.

The distributed nature and high participation rate of metaverse clients guarantee the fairness of contribution evaluation in PoCS, and rewards maximize user participation. As shown in Table 2, users already possess the specifications suitable for performing the role of a validator proposed in this study(Steam, 2024).

On the Steam platform, several metaverse games offer immersive and interactive experiences. Neos VR provides a versatile space for users to build, edit, and explore virtual worlds, offering tools for casual and professional use. The Sandbox, known for its blockchain integration, allows players to create, own, and monetize virtual assets. Rec Room is a social game where users can create and share content across devices, fostering community interaction. These games, along with others like VR Chat and Second Life, reflect the growing trend of creativity and social engagement within the metaverse.

3. Related Works

In this section, we examine blockchain consensus algorithms closely related to this study, including PoS, PBFT, and hybrid consensus algorithms, as well as permissioned blockchains that ensure fast responsiveness, which is essential for the metaverse.

3.1 Proof of Stake (PoS)

PoS is a consensus algorithm that determines the right to generate and validate

Table 2. *Average PC Specifications of Steam Users*

Component	Average Specification
CPU	Intel i5, 3.0 GHz
GPU	NVIDIA GeForce RTX 3060
RAM	16 GB
Storage	1 TB SSD
Operating System	Windows 11 64-bit

new blocks in a blockchain network based on the stake held by a nod(King & Nadal, 2012). Compared to the traditional Proof of Work (PoW) method, PoS has the advantages of lower energy consumption and faster transaction processing(Cao et al., 2020). In PoS, the probability of a node participating in block generation increases with the amount of stake it holds, and nodes that successfully validate a block receive transaction fees and new coins generated from that block as rewards. This plays a crucial role in maintaining the security and reliability of the network. However, PoS has limitations, such as the weakening of decentralization benefits as the gap in stakes between nodes widens and the problem of favoring a small number of nodes with large stakes(Nakamoto, 2008; Vries, 2018). PoCS introduces a deduction rate based on contribution scores to prevent specific nodes from being selected continuously and ensures fairness by allowing various nodes to participate in the consensus process.

3.2 Practical Byzantine Fault Tolerance (PBFT)

PBFT offers high efficiency and fast processing speed through this message exchange mechanism and is widely used in systems that require high reliability and security, such as financial transactions. In particular, when combined with PoS, PBFT can further enhance the fairness and efficiency of consensus by considering both a node's stake and its actual behavior(Hussein et al., 2023).

In recent literature, notable advancements in the PBFT algorithm have been proposed, primarily centered on optimizing communication efficiency and reducing complexity. For instance, HotStuff(Yin et al., 2019) innovates by employing threshold signature technology, thereby curtailing communication complexity to O(n). This approach replaces the conventional many-to-many broadcast with a mechanism where the primary node aggregates signatures, mitigating the overall communication overhead. However, this optimization comes at the cost of increased workload for the primary node, which can potentially lead to network congestion under heavy traffic conditions. Another critical area of improvement focuses on minimizing the number of nodes involved in the consensus process, as the participant count directly influences communication complexity. Algorithms like Delegated Byzantine Fault Tolerance (DBFT) and Tendermint address this challenge by strategically utilizing PoS mechanisms to select smaller, more efficient validator committees(Wang et al., 2020; Kwon, 2022). These approaches couple node participation with stakeholding, not only enhancing efficiency but also fostering greater engagement and participation in the consensus process(Jiang et al., 2023).

3.3 Hybrid Consensus Algorithm

Hybrid consensus algorithms are designed to overcome the limitations of traditional consensus algorithms, such as high latency, low throughput, and scalability issues, by combining the strengths of PoS and PBFT(Wu et al., 2019). Composed of two phases, Sortition and Witness, these algorithms reduce the number of nodes participating in consensus through random selection, thereby efficiently managing network resources. The selected nodes then validate transactions, enhancing both efficiency and security. With a dynamic node management function, the algorithm maintains high performance even when network load fluctuates.

Experimental results demonstrate superior performance in terms of scalability, throughput, and latency compared to existing algorithms. These hybrid consensus algorithms offer a practical and scalable solution for blockchain technology. Table 3 presents a comparison of consensus algorithms(Wu et al., 2019; Larimer, 2014; Cao et al., 2019; Nirvikar et al., 2023; Tang, 2023; King & Nadal, 2012).

Nevertheless, consensus algorithms exhibit varying degrees of suitability for different environments, with each protocol demonstrating strengths in specific contexts(Tomić, 2021).

3.4 Permissioned Blockchains

The integration of permissioned blockchains into metaverse services offers significant performance benefits. The restricted node count and simplified consensus mechanisms allow for higher transaction throughput (TPS) compared to public

Table 3. *Comparison of Consensus Algorithms*

Algorithm	Reward Distribution	Advantage	Disadvantage	Application
POW	Competing Competition	Decentralization	High consumption, high latency	Bitcoin
POS	Equity Competition	Low resource consumption	Low participation	Nxt
DPOS	Equity Election	High throughput, low latency	Producer evil	EOS
PBFT	Leader Node	High throughput, low latency	Poor scalability	Fabric
Raft	Leader Node	High throughput, low latency	No Byzantine fault tolerance	Etcd
PoCS	Contribution Evaluation	Encourages active participation	Complex to implement	Custom Systems
Hybrid (POS + PBFT)	Sortition + Witness	Low latency, high throughput, good scalability	Complexity in implementation	Blockchain Research

blockchains(Min, 2020), facilitating real-time interactions within the metaverse. However, this centralization can undermine decentralization principles and exclude certain users from network participation. While the performance gains expedite transaction processing, they are accompanied by the drawback of limiting open participation(Dabbagh, 2024). Table 4 compares the representative permissioned blockchains.

To sum up, Hyperledger Fabric is highly flexible but struggles with scalability as the network size increases. Quorum offers strong performance, particularly for privacy-centric applications, though it may face challenges in very large or complex environments. Corda excels in low-latency, financial use cases but is less scalable for broader applications.

Table 4. *Comparison of the performance evaluation of* permissioned *blockchain platform*

Blockchain Platform	Transaction Throughput (TPS)	Latency	Scalability	Use Cases
Hyperledger Fabric	Up to 10,000	Increases as the network size grows	Performance degrades with more nodes	General-purpose, supply chain, finance
Quorum	Up to 2,100	Good, but can increase with privacy settings	Limited scalability with complex privacy requirements	Finance, healthcare, privacy-focused use cases
Corda	Up to 1,700	Low latency in smaller networks	Struggles with general scalability in large networks	Financial services, low-latency transactions

4. The Proposed PoCS Consensus Utilizing Metaverse Clients

Consensus is a process of achieving agreement among individuals or groups regarding a specific decision or action. In blockchains, consensus algorithms ensure that all nodes in the network agree on the current state and the authenticity of transactions(Xiong et al., 2022). To achieve this consensus, utilizing metaverse clients as blockchain validator nodes offers several significant advantages. These benefits primarily stem from the synergy between the characteristics of metaverse clients and the requirements of blockchain networks.

This paper proposes a consensus algorithm for permissioned blockchains to provide stable storage and platform services. By incorporating external audits to address trust issues and utilizing decentralized metaverse clients as validators, we strengthen the verification process. Furthermore, we introduce the PBFT concept to enhance network reliability and fault tolerance, thereby improving real-time performance and security(Castro & Liskov, 1999). This hybrid approach promotes decentralization while activating metaverse clients to serve as validators, ensuring a trustworthy verification process.

4.1 Enhanced Decentralization

By leveraging globally distributed metaverse clients as validator nodes, we can significantly enhance network decentralization. Decentralized networks are more resilient to centralized attacks and lack a single point of failure. This plays a crucial role in improving the security and stability of blockchain networks. For example, Roblox boasts 65.5 million daily active users and 7.3 billion registered accounts(Roblox, 2024).

4.2 Utilization of Existing Infrastructure

Metaverse clients are already being used by millions of users worldwide. Utilizing them as blockchain validator nodes allows for efficient use of existing infrastructure without requiring new hardware investments or additional network setup. This not only reduces costs but also benefits the expansion of blockchain networks(Steam, 2024; Roblox, 2024).

4.3 High Availability

Metaverse clients tend to remain online continuously while users are engaged in the metaverse. This characteristic can contribute to higher availability of validator nodes in blockchain networks. Since validator nodes are essential for verifying network transactions and generating blocks, high availability enhances network performance and stability. Roblox users spend a cumulative 49.3 billion hours on the platform(Steam, 2024; Roblox, 2024).

4.4 Incentivizing Participation and Reward Structures

Players using metaverse clients can be incentivized to perform validator roles. For instance, players who act as blockchain validators can be rewarded with in-game items, tokens, or other rewards. This encourages player participation and ultimately leads to a larger number of nodes, enhancing network stability(Torky et al., 2023).

4.5 Large-Scale Network Effects

Metaverse communities typically have a large user base, and technologies can spread rapidly among them. These large-scale network effects can contribute to the expansion and growth of blockchain networks. By using metaverse clients as validator nodes, more users can participate in the blockchain network, improving network performance, security, and decentralization(Jafar et al., 2022; Gencer et al., 2018).

Leveraging the aforementioned benefits, we propose a blockchain network architecture in Figure 1 that integrates seamlessly with metaverse services. By employing PoCS consensus mechanism, metaverse clients are utilized as validator nodes. These nodes participate in transaction verification and block generation, with the node possessing the highest contribution score assuming the role of the primary leader (L1).

The following is a step-by-step explanation of the process depicted in Figure 2:

- Transaction Proposal: A new transaction request or proposal is submitted from a decentralized application (DApp) to the primary node (L1).
- Broadcast to Authorized Nodes: The primary node broadcasts the transaction to a committee of 2f+1 ledger nodes.
- Validation by Consensus Nodes: The selected ledger nodes perform internal validation and then send the results to the primary node to determine if a new block should be created.
- Validation by Metaverse Nodes: A committee of 2f+1 metaverse clients with the highest contribution scores is selected to validate the block.
- Consensus Reached: Upon reaching consensus among 2f+1 nodes, the primary node approves the block for storage. Otherwise, the block is discarded.
- Block Creation: If 2f+1 nodes successfully validate the block, the primary node requests the ledger nodes to record it.
- Forwarding: The primary node selects the next primary node and initiates the next round.
- Response: The final outcome of the block creation process is communicated back to the DApp.

Figure 1. *Configuration Diagram of Metaverse Services and Permissioned Blockchain*

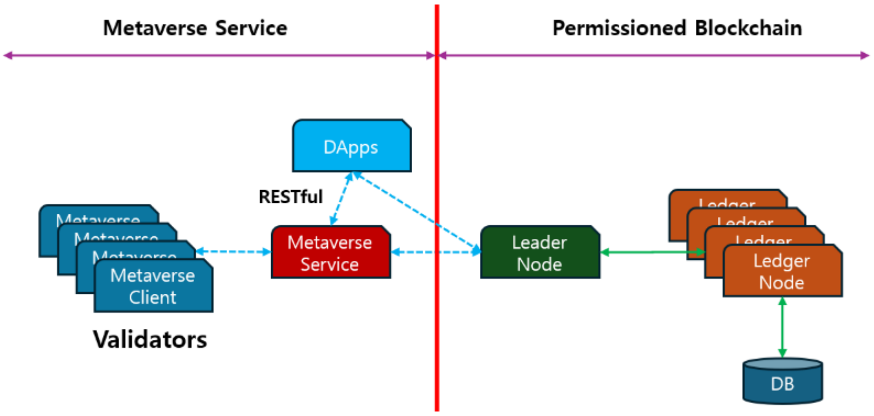


Figure 2. *Phases of PoCS*

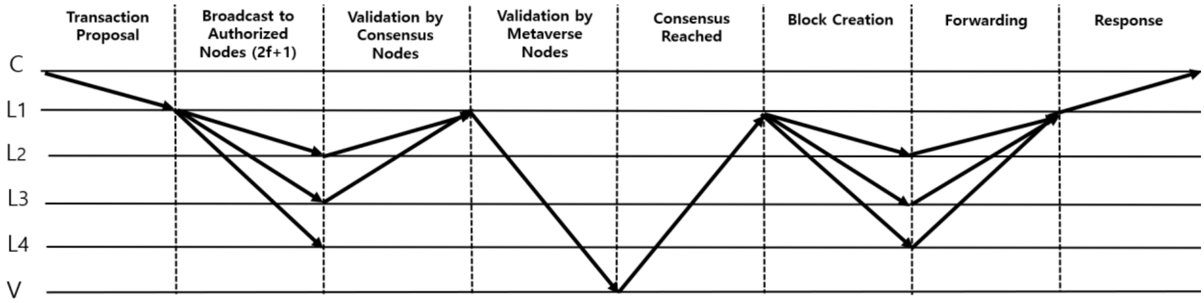
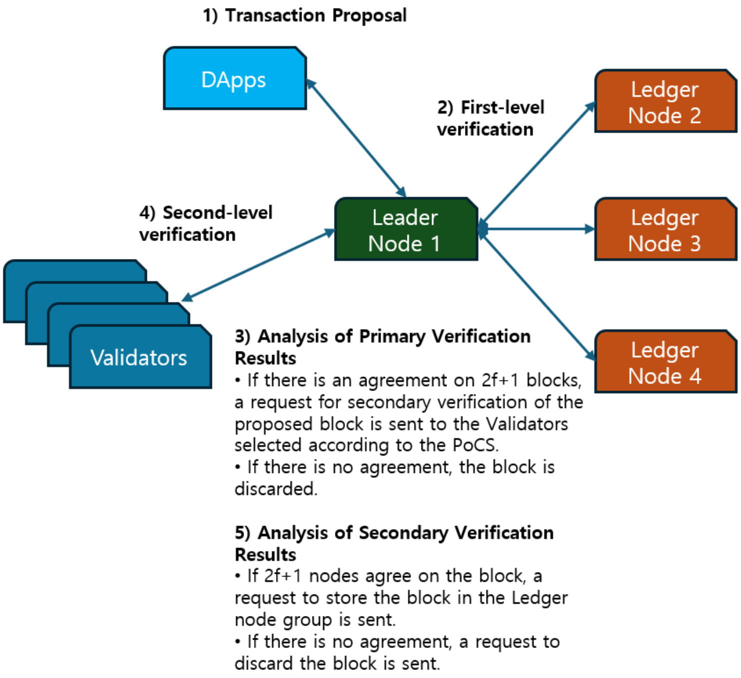


Figure 3. *PoCS Consensus Proess*



3) Analysis of Primary Verification Results

- If there is an agreement on 2f+1 blocks, a request for secondary verification of the proposed block is sent to the Validators selected according to the PoCS.
- If there is no agreement, the block is discarded.

5) Analysis of Secondary Verification Results

- If 2f+1 nodes agree on the block, a request to store the block in the Ledger node group is sent.
- If there is no agreement, a request to discard the block is sent.

5. The Proposed PoCS Algorithm

This paper aims to explore the potential of a novel blockchain consensus mechanism that incorporates various contribution factors through a comparison with PoS. By doing so, we seek to enhance the efficiency and fairness of blockchain networks while demonstrating its applicability in diverse use cases such as metaverse clients.

Table 5. *Contribution Factors*

Contribution Factors	Subcategory
1. In-Metaverse Activity Time	Total Playtime
	Consecutive Login Days
2. In-Metaverse Achievements	Quests Completed
	Level
	Items Acquired
3. Social Contributions	Cooperative Play
	Guild Contributions
	Community Participation
4. In-Metaverse Economic Activity	Transaction Count
	Asset Creation & Distribution
5. Competitive Performance	Ranking
	PvP Wins
	Tournament Achievements
6. Security and Fairness Contributions	Fair Play
	Bug Reports
	Abuse Reports
7. Long-Term Participation	Continuous In-Metaverse Activity
	Continuous Service Participation
8. Stake	

Table 6. *Contribution Score*

Contribution Score Delta = $W_1 \times S_{(\text{In-Metaverse Activity Time})} + W_2 \times S_{(\text{In-Metaverse Achievements})} + \cdots + W_7 \times S_{(\text{Long-Term Participation})} + W8 \times S_{(\text{Stake})}$

W_n represents the weight assigned by the metaverse designer to a specific activity or feature. It indicates the relative importance of that activity

S is the score achieved for that particular activity

Based on the contribution factors in Table 5, the contribution score (C) is calculated using the following formula in Table 6. This algorithm utilizes the contribution score to ensure fair reward distribution and to evaluate whether the reward ratio received by each node aligns with their stake. The reasonableness of this distribution is assessed using the formula for "Reasonable Nodes" presented in Figure 4.

- T: The number of coins rewarded per round.
- CSi : The contribution score of node i before the round.
- CSDi : The contribution score delta of node i before the round.
- Si : The stake of node i .
- AC i : The amount of coins acquired by node i.
- TC i : The initial value, or the total contribution score.
- α: The weight of the contribution score.
- β: The weight of the stake ($\alpha+\beta=1$).
- γ: The deduction rate, calculated as (the number of selected nodes) / (the total number of nodes).

Figure 4. *PoCS Equation*

Operation	Equation
Reward Distribution	$\mathbf{R_i} = \frac{\mathbf{S_i}}{\sum_{j \in N} \mathbf{S_j}} \times \mathbf{T}$
Selected Nodes	$\mathbf{CS_i} \leftarrow \max(\mathbf{0}, \mathbf{CS_i} - \boldsymbol{\gamma} \times \mathbf{CS_i})$
Unselected Nodes	$\mathbf{CS_i} \leftarrow \mathbf{CS_i} + \mathbf{CSD_i}$
Reasonable Nodes	$\left(\frac{\mathbf{S_i}}{\sum_k \mathbf{S_k}}\right) / \left(\frac{\mathbf{AC_i}}{\sum_k \mathbf{AC_k}}\right) \times \mathbf{100}$
Total Reasonableness	$\sum_{i=1}^{n} \mathbf{Reasonable\%_i}$
Total Contribution Score	$\mathbf{TC_i} = \boldsymbol{\alpha} \times \mathbf{S_i} + \boldsymbol{\beta} \times \mathbf{C_i}$

5.1 Experiment

In PoCS algorithm, validator nodes are selected or deselected based on their contribution scores in each round. The contribution scores are updated according to the formula in Figure 4. The leader node is selected from among the selected nodes based on the highest contribution score. Using the contribution factors in Table 6, the contribution scores are updated for each round by applying the formula in Figure 4 and the algorithm in Figure 5. After 20,000 iterations, the experimental results show that the rationality index of PoCS is 1.243, very close to 1, while the rationality index of the PoS-based random selection method is 6.671, indicating a relatively ignificant compromise in fairness. Additionally, Table 9 shows that Node 2, with a very small take, may experience unfair rewards, which could negatively impact the activation of the blockchain network. The results of the experiment conducted with this logic are as follows.

Table 7. *Experiment setting*

20,000 rounds: The experiment was conducted for 20,000 rounds.

20 nodes, 13 validator nodes selected (2f+1, f=6): Among 20 nodes, 13 validator nodes were selected for each round, following the formula 2f+1 where f=6.

1 coin distributed to selected validator nodes based on their stake per round: In each round, 1 coin was distributed among the selected validator nodes proportionally to their stakes.

PoS: 2f+1 validator nodes selected randomly based on their stake: In the PoS system, 2f+1 validator nodes were randomly selected based on their stakes.

PoCS algorithm is designed to fairly distribute rewards among nodes in a network based on their contributions in Figure 5. The total number of nodes is defined as N = 3f + 1, where each node is initialized with an initial contribution score delta CSDi, a contribution score CSi = CSDi, and a coin count Ci = 0. The number of selected nodes is determined by f = ((N-1) / 3), and in each round, the top S = 2f + 1 nodes with the highest contribution scores are selected, following the PBFT rules.

In each round, the total reward Rtotal = 1 is distributed among the selected nodes in proportion to their stakes. Each selected node receives a coin reward proportional to its stake, and its selection count SCi is incremented by 1. Subsequently, the contribution score of each node is adjusted according to a base penalty rate. For the selected nodes, the contribution score may decrease due to the adjusted penalty, while for non-selected nodes, the contribution score may increase or decrease depending on the contribution score delta, which is calculated based on network activity.

Figure 5. *PoCS Algorithm*

```
Input: Total number of nodes $N$, contribution score delta $CSD_i$ for each node $i$, base penalty rate $P_{base}$, base reward $R_{base}$, number of rounds $R$
Output: Selection counts, coin distribution, reasonable percentage
Initialize each node $i$ with: Contribution Score Delta $CSD_i$, Contribution Score $CS_i = CSD_i$, Coins $C_i = 0$, Selection Count $SC_i = 0$
Set number of selected nodes $f = \left\lfloor \frac{N-1}{3} \right\rfloor$, $S = 2f + 1$ based on PBFT rules

for each round $r = 1$ to $R$ do
    Node Selection:
    Sort nodes by their contribution scores $CS_i$
    Select top $S$ nodes with the highest $CS_i$
    Coin Distribution:
    Distribute total reward $R_{total} = 1$ among selected nodes proportional to their stakes $S_i$
    for each selected node $j$ do
        $C_j += \frac{S_j}{\sum_{k \in selected} S_k} \times R_{total}$
        $SC_j += 1$
    end for
    Contribution Score Adjustment:
    for each node $i$ do
        if node $i$ is selected then
            Adjusted penalty rate $P_{adjusted} = P_{base} \times \frac{S}{N}$  Update $CS_i = \max(0, CS_i - P_{adjusted} \times CS_i)$
        else
            Increase $CS_i = CS_i + CSD_i$
        end if
    end for
end for
Calculate Reasonable Percentage:
for each node $i$ do
    Calculate reasonable percentage $RP_i = \frac{S_i / \sum_{j=1}^{N} S_j}{C_i / \sum_{j=1}^{N} C_j}$
end for
Output the final results: Selection counts $SC_i$, coin distribution $C_i$, reasonable percentage $RP_i$
```

In the final step, the algorithm calculates the Reasonable Percentage (RP) for each node, which evaluates the fairness of the rewards by comparing the node’s contribution score and coin distribution. The RP is a key metric for assessing whether the rewards are proportionally distributed based on the node's contribution. The algorithm ultimately outputs the selection counts, coin distributions, and reasonable percentages, ensuring that the reward system reflects the contributions of nodes in a fair and transparent manner.

This PoCS algorithm serves as a robust mechanism for real-time assessment of nodes' contributions, balancing rewards and penalties based on performance and stake. It aims to enhance the fairness and stability of decentralized networks by implementing an equitable reward distribution framework.

5.2 Experiment Evaluation

Figure 6 shows that the Reasonable(%) of PoCS rationality index is very close to or slightly below the baseline of 1 for most nodes. In particular, the variation between nodes is not large, indicating that nodes are receiving relatively balanced rewards. The average value of PoCS (1.243%) is very close to the baseline of 1, indicating a very reasonable overall reward distribution.

The analysis of PoCS algorithm in Table 8 reveals that it generally distributes rewards more equitably among nodes with higher stakes and frequent selection rates, as evidenced by the Reasonable % metric for many nodes being close to 1, suggesting a balanced reward system. However, certain inefficiencies are observed, particularly for nodes with very low stakes, such as Node2 and Node6, which are outliers in the system. These nodes tend to receive rewards that are disproportionate to their contribution, as reflected by their higher Reasonable % values. This suggests that PoCS algorithm, while effective for most nodes, may require further optimization to ensure a more equitable distribution of rewards for smaller nodes or low-stake participants, preventing them from being either over-rewarded or under-rewarded.

The table 8 provides the following information for each column:

- Node: Represents the name or ID of the node.
- Stake(%): Indicates the percentage of stake held by the node.
- Selection(%): Represents the probability of the node being selected, expressed as a percentage.
- Total Acquired Coins: Shows the total number of coins acquired by the node.
- Coin(%): Denotes the percentage of coins acquired by the node.
- Reasonable(%): Represents the ratio of the node's coin acquisition rate to its stake percentage, expressed as a percentage.

Figure 6. *PoCS Reasonability Index*

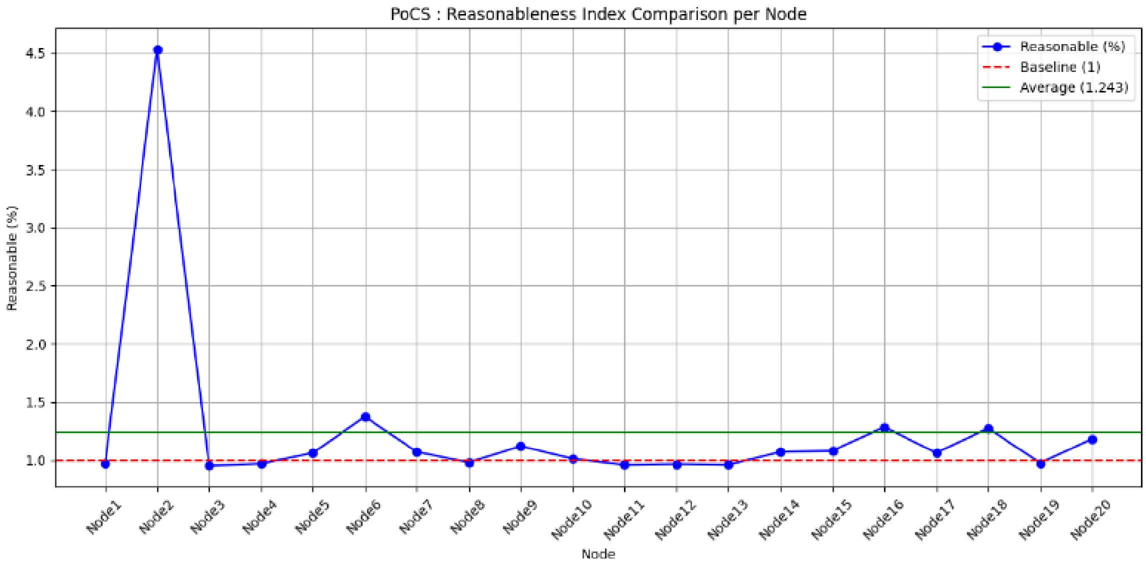


Table 8. *PoCS Experimental Results*

Node	Stake(%)	Selection (%)	Total Acquired Coins	Coin (%)	Reasonable (%)
Node1	6.28	74.14	1297.276942	6.49	0.968
Node2	0.09	14.84	3.785014252	0.02	4.533
Node3	17.59	79.01	3694.525778	18.47	0.952
Node4	6.21	74.13	1282.152302	6.41	0.969
Node5	1.98	66.57	373.7034322	1.87	1.062
Node6	1.06	50.57	153.8994915	0.77	1.373
Node7	4.21	66.68	785.6490101	3.93	1.071
Node8	5.98	72.95	1220.293458	6.1	0.98
Node9	1.83	63.02	327.6239404	1.64	1.12
Node10	5.07	70.32	1001.934655	5.01	1.012
Node11	8.52	74.89	1776.634581	8.88	0.959
Node12	9.99	74.91	2069.29532	10.35	0.966
Node13	8.69	74.91	1811.953432	9.06	0.96
Node14	3.78	66.66	705.7180814	3.53	1.071
Node15	4.73	66.8	875.6354242	4.38	1.08
Node16	1.29	55.39	200.1673602	1	1.285
Node17	4.07	66.67	766.2536852	3.83	1.062
Node18	1.3	55.49	204.247938	1.02	1.274
Node19	5.81	72.87	1192.248694	5.96	0.975
Node20	1.52	59.2	257.0014612	1.29	1.182

In Figure 7, the Reasonable(%) of the PoS rationality index shows a very high value of approximately 88.949% for a specific node (Node 2), which is significantly deviating from the baseline of 1. For most of the other nodes, the values are between 0 and 6, indicating that the PoS method tends to concentrate rewards on specific nodes. The average value of PoS (6.6716%) is higher than the baseline of 1, which means that the rewards are excessively concentrated on specific nodes, resulting in an unreasonable state.

The baseline of 1 represents the ideal rationality, which is achieved when rewards exactly match the contributions of nodes. In the case of PoCS, most nodes are close to this baseline, while in the case of PoS, there is a large deviation.

In summary, while both PoCS and PoS are effective consensus mechanisms, they differ in their reward distribution principles. PoS primarily rewards nodes based on stake, often favoring high-stake participants and potentially leading to centralization. In contrast, PoCS considers both stake and network contribution, resulting in a more equitable reward system. However, PoCS requires more complex implementation and can

Figure 7. *PoS Reasonability Index*

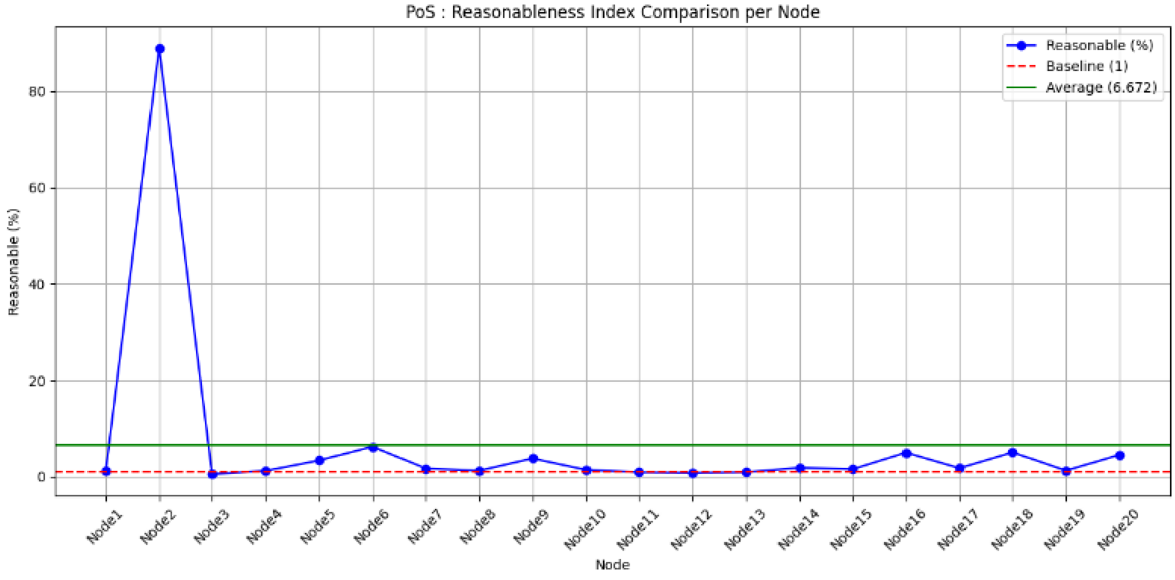


exhibit inefficiencies with low-stake nodes, necessitating further optimization for balanced participation and reward fairness.

6. Discussion and Future Directions

PoCS algorithm represents a significant advancement in consensus mechanisms

Table 9. *PoS Experimental Results*

Node	Stake (%)	Selection (%)	Total Acquired Coins	Coin (%)	Reasonable (%)
Node1	6.28	43.95	1051.220827	5.26	1.195
Node2	0.09	0.53	0.192879442	0	88.949
Node3	17.59	121.71	6666.363108	33.33	0.528
Node4	6.21	43.05	1019.782476	5.1	1.218
Node5	1.98	14.06	117.2694284	0.59	3.385
Node6	1.06	7.47	33.70695214	0.17	6.267
Node7	4.21	29.48	493.038581	2.47	1.706
Node8	5.98	41.78	960.747717	4.8	1.245
Node9	1.83	12.61	96.66978399	0.48	3.796
Node10	5.07	35.86	709.4848913	3.55	1.43
Node11	8.52	60.71	1888.765716	9.44	0.903
Node12	9.99	70.44	2495.15906	12.48	0.801
Node13	8.69	60.2	1899.162499	9.5	0.916
Node14	3.78	26.83	406.7210482	2.03	1.858
Node15	4.73	32.55	607.0004006	3.04	1.558
Node16	1.29	9.35	51.32884094	0.26	5.01
Node17	4.07	28.12	455.1822968	2.28	1.787
Node18	1.3	9.35	51.38325751	0.26	5.066
Node19	5.81	41.48	930.2429258	4.65	1.25
Node20	1.52	10.45	66.57731113	0.33	4.564

by offering a more equitable and inclusive evaluation process than traditional PoS. While PoS tends to centralize power among high-stake holders, PoCS diversifies consensus participation by incorporating multiple factors such as node activity, block generation, and contribution metrics. This not only enhances fairness but also strengthens the long-term sustainability of blockchain networks.

However, challenges remain, particularly regarding the precise calculation and weighting of contribution metrics. Ensuring that all aspects of network participation are fairly evaluated without introducing unnecessary complexity or vulnerabilities is an area that requires further refinement. The combination of PoCS with PBFT provides promising performance improvements, but the scalability of this combined approach in permissioned and permissionless blockchain environments warrants deeper exploration.

Future Directions:

- Refinement of Contribution Metrics: Further research is needed to develop optimal weighting mechanisms for contribution factors to maintain fairness without creating exploitable incentives.
- Scalability in Large Networks: While PoCS shows potential for diverse blockchain ecosystems, the algorithm's performance in large-scale networks remains to be evaluated, particularly with high node diversity and transaction volumes.
- Security and Resistance to Collusion: Future work should address potential security vulnerabilities that could arise from gaming the contribution metrics or colluding groups attempting to manipulate the scoring system.
- Machine learning-based PoCS: Explore how machine learning techniques can be used to optimize the selection of validator nodes and adjust the reward

distribution mechanism based on real-time network conditions.

- Performance evaluation in a metaverse: Implement PoCS algorithm in a metaverse environment to assess its scalability, security, and overall performance.

7. Conclusion

PoCS algorithm presents a novel approach to achieving fair and efficient consensus in blockchain networks. While traditional PoS algorithms can lead to centralization due to the concentration of stake among network participants, PoCS addresses this issue by comprehensively evaluating contributions and activity. By considering various contribution, PoCS more fairly evaluates the contributions of diverse nodes within the network, thereby promoting the long-term stability and sustainability of the blockchain. This research suggests the potential of PoCS to enhance the scalability and fairness of blockchain services, enabling effective consensus even in complex environments like the metaverse.

Furthermore, PoCS has demonstrated a more rational reward distribution, with most nodes maintaining values close to the baseline of 1. Therefore, PoCS is a more reasonable method for ensuring fair reward for contributions within the network. On the other hand, PoS shows results that significantly deviate from the baseline of 1, with rewards concentrated on specific nodes, indicating an imbalance and unfairness in reward distribution. Based on these findings, it can be concluded that PoCS is a more rational and fair reward distribution mechanism compared to PoS.

Core Features of PoCS Algorithm:

- Fairer Consensus Mechanism: PoCS addresses the centralization issues often associated with traditional PoS algorithms, where nodes with larger stakes dominate the consensus process. PoCS incorporates contribution metrics like block generation frequency and network activity, ensuring that not only high-stake nodes but also nodes with meaningful contributions are selected for validation.

- Combination with PBFT: PoCS can be combined with PBFT, particularly in permissioned blockchain environments, to enhance both stability and reliability. PBFT ensures that the network can tolerate Byzantine faults, while PoCS ensures that validation power is more fairly distributed based on contribution scores.
- Fairness Baseline: A notable innovation in PoCS is the introduction of a fairness baseline, which helps detect imbalances and biases in the node selection process. This baseline helps visualize deviations in node contributions, ensuring a balanced reward distribution and promoting long-term network sustainability.
- Applicability in Metaverse: PoCS is particularly well-suited for complex environments like the metaverse, where user activity is diverse and widespread. It ensures a more equitable distribution of rewards and decision-making power by incorporating both financial stake and contribution metrics.
- Decentralization in Permissioned Networks: While PoCS can be used in permissioned blockchains, it helps mitigate potential centralization issues by encouraging diverse participation. This approach balances the efficiency of permissioned networks with the decentralization goals of public blockchains.

Funding: This work was supported in part by the MSIT(Ministry of Science and ICT), Korea, under the Graduate School of Metaverse Convergence support program (202439002.01-RS-2022-00156318) supervised by the IITP (Institute for Information & Communications Technology Planning & Evaluation).

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