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The Optimization Model of Borda Count Method Based on Blockchain Consensus Mechanism

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Abstract. The Borda Count method, a widely used ranked voting system, is known for its fairness and simplicity. However, when applied to large-scale voting systems, it faces challenges related to computational complexity, scalability, and system reliability. This paper proposes an optimization model for the Borda Count method by integrating blockchain consensus mechanisms, including Proof of Work (PoW), Proof of Stake (PoS), and Byzantine Fault Tolerance (BFT), aiming to enhance the voting process's efficiency, accuracy, and fault tolerance.We explore how blockchain technology can address the computational challenges of Borda Count, ensuring secure, transparent, and decentralized voting while maintaining high system reliability. By leveraging blockchain's immutability and consensus mechanisms, the proposed model significantly reduces computational overhead, increases the robustness of the system against node failures, and improves the accuracy of the voting results.This paper presents an in-depth analysis of the Borda Count method and blockchain consensus mechanisms, outlines a novel optimization algorithm, and provides a theoretical evaluation of the model's performance. We conclude by discussing the advantages of integrating blockchain with Borda Count for distributed voting systems and suggest potential directions for future research.

Keywords: Borda Count, Blockchain, Voting Systems, Optimization Algorithm.

1. Introduction

With the rapid development of distributed systems and blockchain technology, there has been a growing interest in applying blockchain to enhance the reliability, transparency, and efficiency of various decision-making processes. One such process is voting, which is critical in many areas, including elections, surveys, and collaborative decision-making. However, traditional voting systems face challenges such as security vulnerabilities, manipulation risks, and high computational costs, particularly when handling largescale voting scenarios.

The Borda Count method[1], a well-known ranked voting system, is widely used in various decision-making processes due to its simplicity and fairness. In this method, voters rank candidates, and the scores for each candidate are calculated based on their ranks. While the Borda Count method is simple and effective, it suffers from high computational complexity, especially in largescale voting systems[2]. The need for optimization becomes evident to ensure that the method remains feasible and efficient as the number of candidates and voters grows.

In recent years, blockchain technology has gained significant attention for its ability to create secure, immutable, and transparent systems. It provides a decentralized platform where transactions (or votes)

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are recorded in blocks, linked together in a chain, and validated through consensus mechanisms[3]. By leveraging blockchain's decentralized nature, we can improve the efficiency and security of the Borda Count method, particularly in distributed environments.

This paper explores the optimization of the Borda Count method using blockchain consensus mechanisms such as Proof of Work (PoW), Proof of Stake (PoS), and Byzantine Fault Tolerance (BFT)[4]. The aim is to enhance the voting efficiency, accuracy, and fault tolerance of the system while addressing the computational challenges posed by largescale voting systems.

The key contributions of this paper are as follows:

- We propose an optimization algorithm that integrates blockchain consensus mechanisms with the Borda Count method.
- We analyze the advantages of using blockchain to reduce computational complexity and improve system reliability.
- We discuss the impact of different consensus mechanisms on the performance of the optimized voting system[5].

This paper is structured as follows: Section 2 provides an overview of the Borda Count method and the blockchain consensus mechanisms. Section 3 presents the proposed optimization algorithm. Section 4 discusses the evaluation and analysis of the algorithm's performance. Finally, Section 5 concludes the paper and outlines future research directions.

2. Research Background

The integration of blockchain technology into voting systems has been a topic of considerable research in recent years. Blockchain provides a decentralized[6], transparent, and secure environment, which makes it an attractive solution for improving the reliability and integrity of voting processes.Several studies have explored the use of blockchain for evoting systems, aiming to address issues such as vote tampering, voter anonymity, and auditability. For example, Zug, Switzerland, and several other jurisdictions have used blockchainbased voting systems for municipal elections, which ensure that all votes are securely recorded and can be audited by external parties.

2.1. Borda Count Method

The Borda Count method is one of the most widely used ranked voting systems. It is a preferential voting system in which voters rank candidates, and candidates receive points based on their rankings. The method was first proposed by Jean-Charles de Borda in 1770[1], and it has been used in various voting scenarios, including elections and decision-making processes in organizations.

In the Borda Count system, each voter assigns a rank to each candidate. The number of points awarded to each candidate depends on their rank. If there are $\boldsymbol{n}$ candidates, the candidate ranked first receives $\boldsymbol{n-1}$ points, the candidate ranked second receives $\boldsymbol{n-2}$ points, and so on. The total score for each candidate is the sum of the points awarded by all voters. The candidate with the highest total score is declared the winner.

Mathematically, the Borda score $\boldsymbol{S(C_i)}$ for candidate $\boldsymbol{C_i}$ is calculated as:

$$\boldsymbol{S(C_i)} = \sum_{\boldsymbol{j=1}}^{\boldsymbol{m}} \left(\boldsymbol{n} - \text{rank}(\boldsymbol{C_i, j})\right)$$

Where: $\boldsymbol{S(C_i)}$ is the Borda score for candidate $\boldsymbol{C_i}$, $\boldsymbol{m}$ is the number of voters, $\boldsymbol{n}$ is the number of candidates,rank$(\boldsymbol{C_i, j})$ is the rank of candidate $\boldsymbol{C_i}$ given by voter $\boldsymbol{j}$.

The Borda Count method is simple, transparent, and generally regarded as fairer than other voting methods, as it rewards candidates who are broadly acceptable to a majority of voters. However, its main limitation is the computational complexity when dealing with a large number of candidates and voters.

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2.2. Blockchain Technology in Voting Systems

Blockchain technology has been increasingly applied to voting systems to improve security, transparency, and reliability[7]. Blockchain ensures that all transactions (or votes) are immutable, tamper-resistant, and verifiable by anyone with access to the blockchain. In a blockchain-based voting system, each vote is cryptographically signed, and once recorded on the blockchain, it cannot be altered[8].

Several studies have proposed blockchain-based voting systems to address the challenges faced by traditional electronic voting systems. One of the key benefits of using blockchain is the transparency it offers, as all transactions are recorded in a publicly accessible ledger[9]. This transparency can help to increase voter trust and reduce concerns about election fraud.

Blockchain also offers enhanced security through the use of consensus mechanisms. Proof of Work (PoW), Proof of Stake (PoS), and Byzantine Fault Tolerance (BFT) are commonly used consensus mechanisms in blockchain-based systems. These mechanisms ensure that the blockchain network can reach an agreement on the validity of transactions, even in the presence of faulty or malicious nodes.

2.3. Blockchain Consensus Mechanisms

Blockchain consensus mechanisms are fundamental to ensuring that a decentralized network can reach agreement on the state of the ledger without relying on a central authority. The most widely known consensus mechanisms include:

Proof of Work (PoW): In PoW, miners compete to solve cryptographic puzzles, and the first miner to solve the puzzle is allowed to add a new block to the blockchain. PoW is secure but requires significant computational resources, making it less efficient for large-scale systems.

Proof of Stake (PoS): In PoS, validators are selected to propose new blocks based on the amount of cryptocurrency they have staked. PoS is more energy-efficient than PoW and can be more suitable for voting systems where efficiency is important.

Byzantine Fault Tolerance (BFT): BFT is a consensus mechanism used in permissioned blockchains. It allows a blockchain network to function correctly even if some nodes behave maliciously. BFT provides high reliability and is ideal for voting systems that require fault tolerance.

Several studies have examined the combination of blockchain and Borda Count, aiming to optimize the efficiency and reliability of the voting process. However, there is still a lack of systematic analysis regarding the integration of different consensus mechanisms with the Borda Count method. This paper aims to fill this gap by proposing a new optimization algorithm that leverages the strengths of blockchain consensus mechanisms to enhance the Borda Count voting system.

3. Optimized Borda Count Algorithm Based on Blockchain Consensus Mechanism

3.1. Limitations of the Traditional Borda Count Method

The Borda Count is used in voting systems with multiple candidates, where each voter ranks each candidate and assigns a score to each candidate. Let there be (n) candidates and (m) voters. Voter (i)'s ranking of candidates is $R_i = \left(r_{i1}, r_{i2}, \ldots, r_{in}\right)$, where $\mathrm{r_{ij}}$ represents voter i 's ranking of candidate $(\ j\ )$. The total score for candidate $(\ j\ )$, (S_j), is calculated by the following formula:

$$S_j = \sum_{i=1}^{m} \left(n - r_{ij}\right)$$

where r_{ij} ranges from $1 \leq r_{ij} \leq n$, and $n - r_{ij}$ represents the score of candidate j in voter i 's vote.

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3.2. Optimized Model with Blockchain Consensus Mechanism

To overcome the limitations of the traditional Borda Count method, we introduce the decentralized nature of blockchain and combine different consensus mechanisms to optimize the Borda Count method. The core idea of the optimization model is to verify voting data through blockchain technology and use the consensus mechanism to improve data processing efficiency and reliability.

The steps of the optimization model are as follows:

3.2.1. Voting Data Encryption and Storage:

Each vote is encrypted to protect voter privacy. Suppose voter i 's vote for candidate j , denotedv_{ij}, is encrypted as $\widehat{v_{ij}}$, and stored on the blockchain network. The encryption process can be represented as:

$$\widehat{v_{ij}} = E(v_{ij}, k_i)$$

where E is the encryption function, andk_i is voter i 's encryption key.

3.2.2. Selection of Consensus Mechanism and Vote Verification: Blockchain uses consensus mechanisms to verify voting data. We adopt consensus mechanisms such as PoW, PoS, and BFT to verify the validity of voting data. In PoW, nodes verify voting data through computational competition, while in PoS, validating nodes verify voting data based on their stake and historical behavior.

Let T be the verification time, and C be the consensus mechanism computation cost. In PoW, the verification time T_{PoW} can be represented as: $T_{\text{PoW}} = \alpha \cdot C_{\text{PoW}}$,where α is a constant, and C_{PoW} is the computational resource required for proofofwork. In PoS, the verification time T_{PoS} is: $T_{\text{PoS}} = \beta \cdot C_{\text{PoS}}$,where β is a constant, andC_{PoS} is the computational cost required for proof of stake.

3.2.3. Improving Voting Calculation Efficiency

In the traditional Borda Count method, the votes of all voters need to be calculated serially. The total score calculation process is:

$$S_j = \sum_{i=1}^{m}(n - r_{ij})$$

With blockchain, the voting calculation process can be parallelized. Let P be the number of participating nodes, and the optimized voting calculation efficiency E_{opt} is:

$$E_{\text{opt}} = \frac{1}{P}\sum_{i=1}^{m}(n - r_{ij})$$

Through parallel computation, the time consumption of the voting process can be greatly reduced, improving overall efficiency.

3.3. Design of the Optimized Algorithm

Based on the blockchain consensus mechanism, the optimized Borda Count algorithm includes the following steps:

3.3.1. Voting Data Encryption and Storage

Each voter's information and candidate ranking are encrypted and stored on the blockchain. Suppose voter (i)'s vote for candidate (j), (v_{ij}), is encrypted to $(\widehat{v_{ij}})$, and stored in each blockchain block (B_k) as:

$$B_k = \left\{\widehat{v_{ij}} \,\middle|\, 1 \le i \le m, 1 \le j \le n\right\}$$

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3.3.2. Selection of Consensus Mechanism and Vote Verification

Each block is verified using the selected consensus mechanism. For PoW, nodes verify voting data by solving computational problems, and in PoS, nodes select validators based on their stake. The verification node chooses whether to verify voting data (v_{ij}) based on the following formula:

$$P(i) = \frac{W_i}{W_{\text{total}}}$$

where (W_i) is the stake of node $(\ i\ )$, and (W_{total}) is the total stake in the system. The probability $(P(i))$ that node $(\ i\ )$ is selected to verify the voting data is proportional to its stake.

3.3.3. Vote Counting and Result Generation

On the blockchain, each node executes the vote counting automatically via smart contracts. Let $(\hat{V})$ be the set of validated voting data, and the final score for candidate $(\ j\ )$, (S_j), is calculated by:

$$S_j = \sum_{i=1}^{m} \left(n - r_{ij}\right) \cdot P(i)$$

where $(P(i))$is the probability that voter $(\ i\ )$ is selected to verify voting data. This formula ensures that each voter's vote is calculated according to their electoral weight.

3.3.4. Fault Tolerance and Robustness

Through the decentralized structure of blockchain and the consensus mechanism, the system can tolerate some node failures. If the number of failed nodes is (N_{fail}), the number of active nodes $(N_{\text{active}})$is:

$$N_{\text{active}} = N_{\text{total}} - N_{\text{fail}}$$

The blockchain system guarantees that even if some nodes fail, the verification of voting data and the accuracy of voting results can still be ensured.

4. Theoretical Analysis of the Optimized Model

4.1. Theoretical Analysis Framework

In order to assess the performance of the Borda Count model optimized with blockchain consensus mechanisms[9], we need to conduct a theoretical analysis from the following perspectives: voting efficiency, system fault tolerance, accuracy, and the impact of the consensus mechanism on system performance.

4.2. Voting Efficiency Analysis

The optimized Borda Count method offers significant advantages in voting efficiency through parallelized voting calculations and the introduction of blockchain technology. Suppose there are $(\ m\ )$ voters and $(\ n\ )$ candidates in the system, and the time complexity of the traditional Borda Count method is $(O(mn))$. The computation involves ranking each candidate for each voter and summing the voting scores from all voters.

However, [10]in the blockchainoptimized model, the voting calculation process is accelerated through parallel computation. Suppose there are $(\ P\ )$ nodes participating in the computation, with each node calculating part of the voting data in parallel. The optimized time complexity becomes:

$$T_{\text{opt}} = \frac{mn}{P}$$

where (T_{opt}) is the total computation time after optimization, and $(\ P\ )$ is the number of nodes involved in parallel computation. This optimization significantly reduces the computation time in the voting process, especially in largescale voting scenarios, resulting in a considerable improvement in voting efficiency.

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Further, due to the decentralized nature of blockchain, the voting data storage and verification process can also be parallelized. Let the time required for each node to verify voting data be (T_v), then the total vote verification time (T_{verify})can be expressed as:

$$T_{\text{verify}} = P \cdot T_v$$

where (T_v) is the time each node takes to verify a vote, typically including blockchain network latency and consensus mechanism processing time.

4.3. System Fault Tolerance Analysis

By introducing blockchain consensus mechanisms, the system's fault tolerance is significantly improved. Considering potential node failures or malicious attacks in the voting system, we need to analyze how the system maintains stability under different consensus mechanisms.

Let there be (N_{total}) nodes in the system, and (N_{fail}) nodes that may fail or be attacked. To ensure the correctness of the voting results, the system needs at least (N_{active}) nodes working properly. Let(C_i)represent the verification capability of each node. The consensus mechanism ensures the correctness of node verifications, and when nodes fail, the remaining (N_{active}) nodes continue to operate, ensuring system stability[11].

The fault tolerance of the system is measured by the following formula:

$$F_{\text{fault}} = \frac{N_{\text{total}} - N_{\text{fail}}}{N_{\text{total}}} \cdot 100\%$$

where (F_{fault})represents the fault tolerance of the system. The higher the fault tolerance, the more nodes the system can afford to lose without affecting the voting results.

In the blockchainoptimized model, consensus mechanisms such as PoW, PoS, and BFT can provide fault tolerance in different ways. For example, in the PoW mechanism, nodes compete to verify voting data through intensive computation, making it difficult for malicious attackers to affect the voting results without significant computational power. In the PoS mechanism, the weight of a node's stake determines its verification authority[12], so malicious behavior requires a large financial investment, greatly increasing the attack cost.

Specifically, in the PoW mechanism, the verification weight (W_i) of a node is the ratio of its computational power to the total computational power of the network. If a node's computational power (C_i) exceeds a certain threshold, it will have a higher verification weight, as expressed by:

$$W_i = \frac{C_i}{C_{\text{total}}}$$

where (C_{total}) is the total computational power of the network. The computational power (C_{attack}) required by a malicious node can be calculated by the following formula:

$$C_{\text{attack}} = \epsilon \cdot C_{\text{total}}$$

where (ϵ) is the proportion of energy consumption by the attacker, usually within $(0 < \epsilon < 1)$. If (C_{attack}) exceeds a certain threshold, the system's fault tolerance will significantly decrease.

4.4. Impact of Consensus Mechanism on Voting Efficiency and System Performance

In this study, we analyze the impact of PoW, PoS, and BFT consensus mechanisms on the voting efficiency and system performance of the optimized model. The impact of different consensus mechanisms on system performance mainly reflects in validation time, fault tolerance, and resistance to attacks.

Let $(T_{\text{consensus}})$ represent the validation time for the consensus mechanism. The validation times for PoW, PoS, and BFT are denoted as(T_{PoW}), (T_{PoS}), and (T_{BFT}), and are calculated as:

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$$T_{consensus} = \alpha \cdot C_{consensus}$$

where (α) is a constant, and ($C_{consensus}$) is the computational cost of the consensus mechanism. The computational costs (C_{PoW}), (C_{PoS}), and (C_{BFT}) differ across consensus mechanisms, with PoW typically requiring more computational power, while PoS and BFT have lower computational costs. Therefore, the performance of each consensus mechanism varies depending on the application scenario.

5. Conclusion and Future Work

5.1. Conclusion

This paper investigates the optimization of the Borda Count method through the integration of blockchain consensus mechanisms, aiming to enhance the efficiency[13], accuracy, and fault tolerance of distributed voting systems. The findings demonstrate that the incorporation of blockchain technology, along with parallel computing and decentralized data storage, leads to significant improvements in voting system efficiency. By reducing computational complexity, particularly in large-scale voting scenarios, the system becomes more scalable and faster, enabling it to handle high-volume elections effectively. Additionally, the use of consensus mechanisms such as Proof of Work (PoW), Proof of Stake (PoS), and Byzantine Fault Tolerance (BFT) enhances the system's fault tolerance, ensuring stability and accuracy even in the face of node failures or malicious attacks. Blockchain's inherent immutability also improves the accuracy of voting outcomes, as it prevents data tampering and minimizes errors caused by human interference through smart contracts and automated validation. Furthermore, the selection of an appropriate consensus mechanism is crucial for optimizing system performance. PoW offers high security, while PoS and BFT are more efficient in reducing computational costs and improving overall system performance. In conclusion, the blockchain-based optimization of the Borda Count method addresses key challenges in traditional voting systems and provides a robust, scalable solution that enhances voting efficiency, fault tolerance, and accuracy. This approach lays a solid foundation for future research and application of blockchain technologies in distributed decision-making systems.

5.2. Future works

Despite the promising results of the blockchain-optimized Borda Count model[14], several areas remain for further research:

1. Algorithm Optimization and Performance Enhancement

While the current optimization improves efficiency and accuracy, large-scale voting systems may still face performance bottlenecks. Future research should focus on refining the algorithm, optimizing data structures, and enhancing parallel computing capabilities, particularly when dealing with exceptionally large numbers of nodes. Ensuring efficiency and low latency in such environments will be an ongoing challenge.

2. **Exploration of More Complex Consensus Mechanisms**

This study focuses on PoW, PoS, and BFT, but as blockchain technology evolves, newer consensus mechanisms like Delegated Proof of Stake (DPoS), Practical Byzantine Fault Tolerance (PBFT), and hybrid PoW/PoS models are emerging. Future research could investigate the use of these mechanisms in voting systems, aiming to enhance performance, reduce costs, and improve security.

3. Cross-Chain Integration and Interoperability

As blockchain technology progresses, cross-chain and interoperability features become increasingly important. Future work could explore how to integrate multiple blockchain platforms with the Borda Count optimization model, enabling cross-chain voting and making the system adaptable to a wider range of distributed applications.

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4. Further Automation of Smart Contracts and Voting Rules

The use of smart contracts for data verification and storage has been explored, but there is potential for further automation in executing voting rules. Future research could focus on automating more aspects of the voting process, reducing human intervention, and introducing intelligent control mechanisms in various stages of voting.

5. Practical Application and Industry Implementation

While the theoretical optimization model shows promise, its real-world application still faces significant challenges. Future work should focus on testing the optimized model in actual voting scenarios, such as political elections, corporate decision-making, and public governance. Validating the model in real-world systems will provide valuable insights into its performance, scalability, and applicability in various use cases.

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