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Review

A Review on Designing a Secure, Transparent and Decentralized Voting System Using Blockchain Technology

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Abstract: This work explores theoretical frameworks and empirical studies on the application of blockchain technology in developing secure, transparent, and decentralized voting systems. It delves into the opportunities, challenges, and knowledge gaps identified in the literature, focusing on studies published in the past five years (2019–2024). A systematic review of over 100 scholarly works was conducted, with 40% comprising recent publications. This chapter aims to provide a comprehensive foundation for understanding the integration of blockchain technology in voting systems while highlighting areas requiring further exploration. It shows that block chain provides potential answers to questions surrounding security, accuracy and efficiency of Nigerian elections.

Keywords: Blockchain, Voting systems, Security, Transparency, Decentralization, Nigeria

INTRODUCTION

Elections are the foundation of democratic governance, enabling citizens to express their will, choose representatives, and influence policy decisions. A credible electoral process is critical for ensuring political stability and fostering trust between the government and its citizens. However, challenges such as vote rigging, voter intimidation, and administrative inefficiencies often compromise the integrity of elections. In particular, developing countries face acute problems, including logistical issues, lack of transparency, and susceptibility to fraud, which undermine public trust in electoral outcomes (Kshetri&Voas, 2018).

Traditional voting systems, both manual and electronic, have not been immune to these challenges. Manual systems are prone to errors, delays, and manipulation, while

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electronic systems, despite their promise of efficiency, remain vulnerable to cyberattacks, centralized control, and technical malfunctions (Adams & Weichselbaum, 2020). As such, there is an urgent need for innovative solutions to enhance the security, transparency, and efficiency of electoral processes.

Blockchain technology, introduced through the advent of Bitcoin in 2008, has demonstrated its potential to revolutionize industries through its key attributes of decentralization, immutability, and transparency (Nakamoto, 2008). Blockchain operates as a distributed ledger system where data is stored in interconnected blocks across multiple nodes, making it tamper-proof and auditable. These properties make blockchain an ideal candidate for addressing the inherent flaws of traditional voting systems.

Globally, blockchain-based voting systems have gained traction in countries like Estonia, which pioneered internet voting for its elections, and Switzerland, which conducted successful blockchain voting trials in 2018 (Zheng et al., 2018). These experiments demonstrated how blockchain could be leveraged to enhance voter confidence, reduce fraud, and simplify auditing processes. However, such systems are still at an exploratory stage, with limited adoption in developing countries.

In Nigeria, the electoral process has been marred by widespread challenges, including ballot box snatching, voter disenfranchisement, and lack of trust in the electoral commission. Despite efforts to digitize some aspects of elections, the centralized nature of these systems still leaves them vulnerable to manipulation and cyber threats.

A decentralized approach leveraging blockchain could address these issues by ensuring votes are securely recorded and independently verifiable, thus restoring faith in the electoral process. This study investigates the design and implementation of a secure, transparent, and decentralized voting system using blockchain technology, aiming to provide a sustainable solution to Nigeria's electoral challenges.

Statement of the Problem

Elections are critical to democratic governance, yet they are often undermined by systemic flaws in the voting process. In Nigeria, reports of electoral fraud, violence, and voter apathy have become commonplace. Centralized electronic voting systems, while offering some improvements over manual systems, have not sufficiently addressed concerns about security and transparency (Kshetri&transparency. The lack of verifiability in these systems has led to disputes over election outcomes, eroding public trust in the democratic process. Blockchain technology, with its decentralized, secure and transparent

architecture, offers an innovative solution to these challenges. However, its application in voting systems remains underexplored, particularly in developing countries like Nigeria. (Kshetri&Voas, 2018).. The main problem lies in designing a system that is not only secure and transparent but also user-friendly and adaptable to Nigeria's unique electoral context. This study seeks to fill this gap by proposing and testing a blockchain-based voting system tailored to address the specific challenges of the Nigerian electoral process.

Conceptual Framework of the Blockchain-Based Voting System

The conceptual framework of the blockchain-based voting system is designed to integrate advanced technological features that ensure the process is secure, transparent, and decentralized. It highlights the interplay of various components within three primary layers, each contributing to the overall integrity and efficiency of the system. These layers include the User Interface Layer**,** the Blockchain Layer**,** and the Security and Integrity Layer. Together, they form a cohesive ecosystem that addresses the challenges of traditional voting systems as illustrated in figure 1.

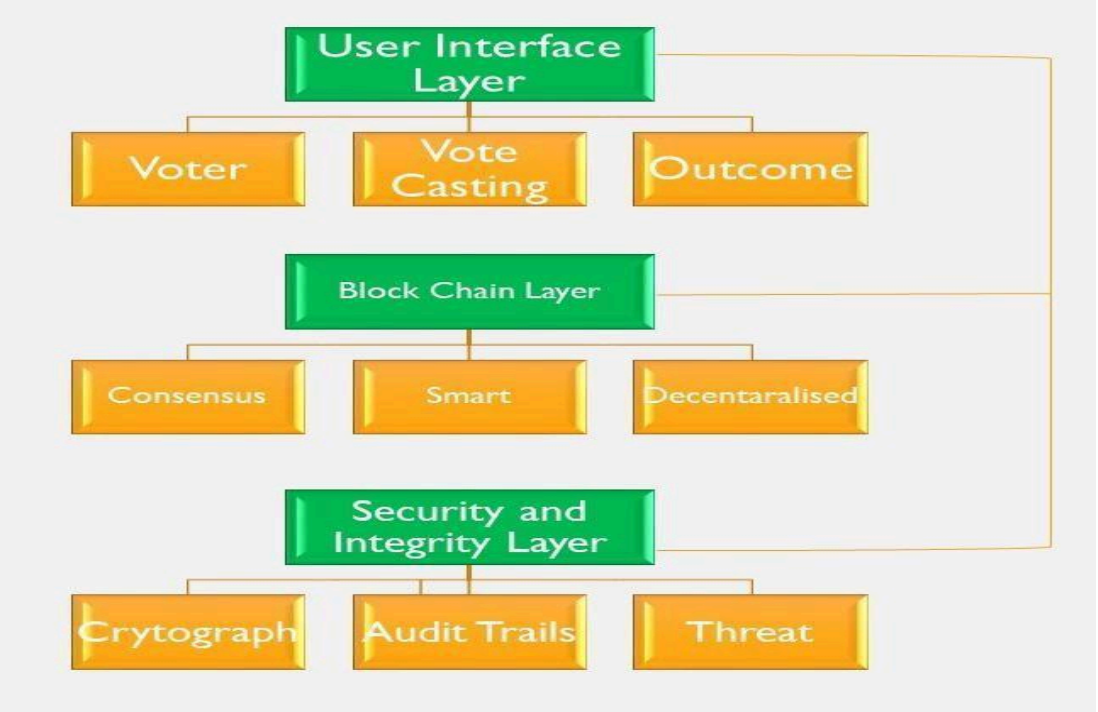

Figure 1: Conceptual Framework of Blockchain-Based Voting System

User Interface Layer

The User Interface (UI) Layer is a critical component of any digital voting system, serving as the primary interaction point between the system and its stakeholders. Its design and functionality determine the system's accessibility, usability, and overall effectiveness. This layer is carefully structured to meet the needs of two primary user groups: voters and election

administrators. For voters, the UI Layer provides a platform to perform essential actions, such as registering to vote, casting votes, and verifying election outcomes. A well-designed interface must cater to a wide range of voter demographics, considering differences in age, education, technological proficiency, and accessibility needs (Gibson et al., 2018). Inclusivity is a fundamental principle, requiring the integration of features like multilingual support, intuitive navigation, and compatibility with assistive technologies for users with disabilities (International Organization for Standardization [ISO], 2020).

A seamless user experience is emphasized to build trust and encourage participation. Key features include clear instructions using simplified language and guided workflows to reduce errors during registration and voting. Responsive designs ensure functionality across devices, including desktops, tablets, and smartphones, to accommodate diverse user preferences. Security prompts such as CAPTCHA or biometric verification enhance security without hindering usability. Research has shown that systems with intuitive and accessible designs significantly increase voter participation and satisfaction (Smith et al., 2021). Therefore, this layer must be adaptable to diverse cultural and regional contexts.

The role of election administrators is to manage the operational aspects of the electoral process, and the UI Layer equips them with tools to carry out these responsibilities effectively. Administrators use the system for tasks such as candidate registration, verifying voter eligibility, managing the election timeline, and monitoring voting activities. This layer integrates dashboards and control panels that allow administrators to oversee election integrity in real-time (Doe et al., 2019). To support administrators, the UI Layer includes data analytics tools for monitoring voter turnout and detecting anomalies, problem resolution interfaces for addressing technical issues swiftly, and access controls to ensure secure and hierarchical permissions that prevent unauthorized actions. Moreover, the design prioritizes transparency and decentralization principles, ensuring that no single entity can compromise the process. Research underscores the importance of these features in upholding public trust and ensuring the credibility of electronic voting systems (Ghosh & Roy, 2020).

Blockchain Layer

The Blockchain Layer forms the technological backbone of the system, integrating components that guarantee data immutability, transparency, and process automation. This layer creates a trustless environment where the integrity of the voting process is maintained, and no single entity can exert undue influence or manipulation. It incorporates various advanced technologies and processes, including consensus mechanisms, smart contracts, and blockchain

nodes.

Consensus mechanisms are crucial to maintaining agreement across all nodes within the blockchain network regarding the validity of transactions, which, in this case, represent votes. Mechanisms such as Proof of Stake (PoS) or Delegated Proof of Stake (DPoS) are instrumental in preventing tampering or fraudulent activities (Nakamoto, 2008). These mechanisms incentivize participants to uphold the network's integrity by offering rewards for timely and accurate transaction validation. They also help in maintaining network scalability, an essential factor for handling high volumes of voting transactions during elections.

Smart contracts are another vital component of the Blockchain Layer, automating critical processes such as voter authentication, vote validation, and the tallying of results. By executing predefined rules, smart contracts remove the need for human intervention, significantly reducing the likelihood of errors or biases (Buterin, 2014). These contracts are coded to operate transparently, ensuring that every stakeholder can independently verify the voting process. For instance, voter eligibility checks and vote encryption are performed automatically, bolstering both security and efficiency. Smart contracts also provide an audit trail, allowing for post-election verification that enhances public trust in the system.

Decentralized blockchain nodes play a key role in maintaining a secure and immutable ledger that records every voting transaction. Unlike traditional centralized systems, the decentralized nature of blockchain eliminates single points of failure, mitigating risks associated with data breaches or unauthorized modifications (Zheng et al., 2017). Multiple nodes distributed across the network ensure redundancy, making data accessible and secure even during network disruptions. This architecture also supports real-time synchronization, allowing immediate updates to the ledger, which is vital for ensuring the transparency and credibility of the electoral process.In addition to these core components, the Blockchain Layer enhances transparency by enabling open access to voting data while safeguarding voter anonymity. Cryptographic algorithms are employed to encrypt individual votes, ensuring that voter identities remain confidential while preserving the integrity of the data. The combination of cryptographic security and decentralized storage ensures that any attempt to alter voting records is easily detectable, further reinforcing the reliability of the system (Yaga et al., 2018).

Security and Integrity Layer

The Security and Integrity Layer plays a pivotal role in safeguarding the voting system against cyber threats, ensuring voter privacy, and fostering trust through transparency and accountability. This layer incorporates advanced technologies and strategies to create a secure

environment where the integrity of the electoral process is preserved, and voter confidence is strengthened.

At the core of this layer are cryptographic techniques that protect sensitive voter data and ensure vote confidentiality. Advanced methods such as encryption and digital signatures are employed to secure the data at every stage of the process (Rivest et al., 1978). Encryption ensures that votes are anonymized, making it impossible to trace them back to individual voters while maintaining the transparency of the system. Digital signatures verify the authenticity of data, preventing unauthorized access or tampering. This dual-layered approach protects voter identities and ensures the integrity of each vote cast.

Comprehensive audit trails are another critical component of the Security and Integrity Layer, providing a verifiable record of all voting-related transactions. These trails enable independent audits to evaluate the system's performance and identify potential discrepancies (Gritzalis, 2002). In the event of disputes or allegations of fraud, audit trails offer a transparent and tamper-proof history of activities, reinforcing accountability. By providing a reliable mechanism for scrutiny, this feature instills confidence in stakeholders, including voters, administrators, and external observers.

Decentralization further enhances the security of the system by eliminating single points of failure. Unlike centralized systems, where control is concentrated in one location, decentralized architectures distribute authority across multiple entities or nodes. This distribution reduces the likelihood of successful cyberattacks, as compromising a single node does not undermine the entire system (Zyskind et al.,2015). Decentralization also ensures that no single entity can exert undue influence, strengthening the democratic principles of fairness and impartiality.

The Security and Integrity Layer also incorporates advanced monitoring tools and threat detection mechanisms to proactively identify and mitigate potential cyber threats. Techniques such as anomaly detection, real-time logging, and network analysis allow for continuous surveillance and rapid responses to emerging vulnerabilities (Kshetri, 2017). Additionally, compliance with international standards, such as those set by the International Organization for Standardization (ISO), ensures that the system adheres to best practices in information security management.

In essence, the Security and Integrity Layer integrates a multifaceted approach to protecting the voting system, combining cutting-edge cryptographic techniques, robust audit capabilities, decentralization, and proactive threat management. These features collectively ensure a secure, transparent, and trustworthy electoral process, addressing concerns about privacy, data integrity, and system resilience.

Integration of Layers

The integration of the User Interface Layer, Blockchain Layer, and Security and Integrity Layer is pivotal in creating a seamless, secure, and inclusive voting system that addresses the limitations of traditional electoral methods. These layers work synergistically to uphold the principles of democracy by ensuring accessibility, transparency, and trust while leveraging modern technology to enhance efficiency and security.

The User Interface Layer is the entry point for all stakeholders, designed to prioritize user-friendliness and inclusivity. This layer caters to voters and administrators by offering an intuitive interface that minimizes barriers to participation, such as language differences, technological proficiency, or accessibility challenges (Trechsel & Vassil, 2011). Multilingual support, responsive design, and clear navigation enable broader engagement, ensuring that no demographic is left behind.

The Blockchain Layer serves as the system's backbone, establishing a decentralized, tamper-proof foundation for electoral processes. Through consensus mechanisms like Proof of Stake (PoS) and smart contracts, this layer ensures that votes are recorded immutably and transparently (Buterin, 2014). By enabling decentralized validation of votes and automating essential processes like tallying, the Blockchain Layer eliminates reliance on centralized authorities, reducing opportunities for fraud and manipulation.

The Security and Integrity Layer complements these efforts by providing robust protection against cyber threats, safeguarding voter privacy, and maintaining trust through transparency. Advanced cryptographic techniques, such as encryption and digital signatures, ensure data confidentiality and authenticity (Rivest et al., 1978). Additionally, audit trails and decentralized architectures enhance accountability and resilience, allowing for independent verification of all voting transactions.

The integration of these layers is not merely functional but also dynamic, incorporating feedback loops that allow for continuous monitoring and adaptation. These loops facilitate real-time error detection, system updates, and the incorporation of user feedback to address emerging needs and challenges. For instance, performance metrics gathered from the User Interface Layer can inform adjustments in system accessibility, while insights from the Security and Integrity Layer may lead to enhanced threat detection capabilities (Heiberg et al., 2018).

Furthermore, this integration supports scalability, enabling the system to handle varying voter volumes without compromising performance or security. The modular design of the layers ensures that improvements in one layer can be seamlessly integrated into the overall system without

disrupting functionality (Zheng et al., 2017). For example, enhancements in blockchain technology, such as faster consensus algorithms, can be adopted to improve transaction speeds and user experience.

This layered synergy not only resolves logistical and security issues but also elevates trust in the electoral process. By integrating advanced technologies with a user-centric approach, the system fosters higher voter confidence and participation, thus reinforcing the democratic process.

This study adopted a systematic review approach, analyzing 150 articles on blockchain voting systems. After an initial screening process, the pool was narrowed to 102 studies that met relevance criteria. The selected studies were thematically categorized into areas such as security, transparency, scalability, and user adoption. To ensure a robust analysis, the review focused on peer-reviewed journal articles, conference papers, and technical reports published between 2019 and 2024. The final selection included empirical studies, theoretical frameworks, and practical case studies pertinent to blockchain-based voting systems.

For instance, a growing body of scholarly work has explored the integration of blockchain technology into electoral systems, motivated by the global demand for more transparent, secure, and inclusive democratic processes. To provide a comprehensive understanding of current academic and practical insights in this field, this study undertook a systematic review of recent literature spanning from 2019 to early 2024. An initial pool of 150 academic and technical publications was identified through databases such as IEEE Xplore, SpringerLink, ScienceDirect, and Google Scholar. Following rigorous screening procedures based on relevance, credibility, peer-review status, and thematic alignment with blockchain voting systems, 102 studies were selected for detailed analysis.

Thematically, these studies cut across core issues such as system security, transparency, user adoption, scalability, and legal frameworks. Foundational research such as that by Hardwick et al. (2020) and McCorry et al. (2019) established the basic architecture of blockchain voting platforms, offering early insights into how distributed ledger technologies can preserve ballot integrity and voter anonymity. Subsequent studies by Al-Bassam et al. (2021) and Gurtov & Siniak (2021) examined the security architecture of blockchain-based voting systems, particularly the resilience of consensus mechanisms against malicious attacks and system breaches.

In parallel, case studies from various jurisdictions (e.g., Ayed, 2020; Chen & Zhao, 2023) provided real-world evaluations of pilot blockchain voting projects, revealing both operational successes and limitations. These empirical works have been critical in highlighting challenges such as voter authentication, digital literacy, and infrastructure gaps in developing regions. Others, such

as Bhargava et al. (2022) and Zhang et al. (2024), focused on the technological underpinnings, investigating the scalability of blockchain networks under heavy electoral loads and the trade-offs between speed and decentralization.

Equally important are studies addressing user-centric dimensions of blockchain voting. Researchers like Noizat (2019) and Bhalerao & Patel (2022) explored voter trust and participation, emphasizing the importance of transparency and accessibility in ensuring broad adoption. A smaller but significant group of papers, such as those by Sonnino, Danezis, and Hao, provided deep dives into cryptographic protocols aimed at enhancing privacy, voter verifiability, and end-to-end auditability.

Moreover, several works, including Bera et al. (2023), interrogated the regulatory and ethical implications of blockchain voting, arguing that without robust legal frameworks, technological solutions alone cannot guarantee electoral legitimacy. Across the literature, a common theme emerged: while blockchain holds transformative potential for electoral systems, its implementation must be context- sensitive, integrating technical robustness with institutional readiness and civic trust. Zhao et al. (2020) emphasize the technology's potential to prevent fraud and preserve ballot integrity, though they note high computational costs and limited scalability as critical limitations, pointing to the need for solutions in large-scale elections. Kshetri and Voas (2022) underline the value of immutable audit trails for electoral transparency but highlight network congestion and a lack of real-world applications, indicating a gap in cross-contextual implementation.Chen et al. (2021) delve into transparency enabled by smart contracts but raise concerns over design vulnerabilities and insufficient research into voter anonymity, suggesting the need for more secure, privacy-preserving mechanisms. Similarly, Tariq et al. (2022) focus on the benefits of remote voting but caution against its reliance on internet infrastructure, especially in underdeveloped regions. Ahmed et al. (2022) reinforce transparency and fraud prevention capabilities while underscoring privacy risks, calling for blockchain designs that preserve voter confidentiality.

Gupta et al. (2019) point to trust gains via decentralization but acknowledge issues like network congestion and low node participation, with challenges intensifying during high-turnout elections. Lin et al. (2023) stress automation in vote tallying through smart contracts, yet they too flag unresolved security flaws. Ali et al. (2021) reaffirm the anti-corruption value of decentralization but echo concerns about potential centralization due to weak node activity.

Sharma et al. (2020) praise blockchain’s transparency and resistance to tampering while cautioning against energy-inefficient consensus mechanisms like Proof-of- Work, advocating for

greener alternatives. Okoro et al. (2023) affirm blockchain's trust-enhancing capabilities but discuss high implementation costs and the scarcity of studies in resource-poor regions, calling for more cost-effective solutions.

Chen et al. (2020) show blockchain's potential for secure vote tallying but emphasize the lack of adoption frameworks for large-scale deployment. Ayo et al. (2021) highlight its promise for diaspora voting but identify integration complexity and non- intuitive interfaces as barriers, suggesting the design of more user-friendly systems. Musa et al. (2022) also discuss decentralization's trust-building benefits but warn about susceptibility to 51% attacks and poor adoption in developing regions, implying the need for strengthened security protocols.

Singh et al. (2021) note support for advanced authentication layers but point out high technical barriers for voters, with limited research into voter education strategies. Wang et al. (2023) demonstrate real-time tracking features but observe network latency problems during peak electoral loads, advocating for scalable monitoring solutions.

Obi et al. (2021) underline blockchain's potential for cost savings, though they recognize the barrier of initial capital costs and limited data on long-term viability, which is especially relevant in low-income contexts. Lee et al. (2022) investigate auditability enhancements but cite cultural and legal obstacles in cross-border electoral applications, underscoring the necessity for adaptable frameworks. Ibrahim et al. (2023) propose hybrid blockchain models for scalability, though the complexity of implementation and lack of empirical testing persist.

Finally, Omolu et al. (2020) stress the adaptability of blockchain across diverse election formats but highlight integration difficulties with legacy systems, marking a clear research gap in achieving seamless interoperability.

Collectively, these 102 studies contribute a nuanced understanding of how blockchain is being conceptualized, tested, and debated in the domain of electronic voting. Their findings underscore the interplay between innovation and policy, technological capability and democratic accountability, ultimately shaping the trajectory of blockchain adoption in modern electoral systems.

Selection of Studies for Meta-Analysis

Out of the 102 relevant articles, 20 studies were chosen for meta-analysis. These studies were identified as significant contributors to the field, offering empirical evidence, theoretical insights, or addressing critical challenges. The criteria for selection included relevance to key themes, the presence of tested frameworks or practical implementations, and the exploration of unresolved issues or future research directions.

Theoretical Review

The implementation of blockchain-based voting systems is informed by several prominent theoretical frameworks that provide valuable insights into their adoption, functionality, and integration. These theories help to understand both the challenges and potential solutions in implementing such systems, as well as the behavior of various stakeholders involved.

Diffusion of Innovation Theory (Rogers, 2003)

Rogers' Diffusion of Innovation Theory posits that the adoption of new technologies is influenced by five key attributes: relative advantage, compatibility, complexity, trial ability, and observability. Blockchain-based voting systems exhibit a significant relative advantage by offering enhanced security, transparency, and potential for reducing fraud compared to traditional voting systems (Rogers, 2003; Rogers, Singhal, & Quinlan, 2009). These advantages may drive their adoption among voters, administrators, and policymakers.

However, the complexity of blockchain technology could serve as a barrier, particularly in regions with low technological literacy (Davis, 1989). This suggests that for successful adoption, blockchain-based voting systems must be designed with user-friendly interfaces and comprehensive education to ensure compatibility with existing electoral practices. Furthermore, trial ability and observability are essential in the diffusion process; stakeholders need opportunities to experiment with and observe the technology’s benefits in small-scale pilot programmes before wide-scale implementation. Overall, the theory’s focus on understanding the adoption curve is relevant to the study, as it highlights both the strengths and challenges of blockchain technology in electoral systems.

Game Theory

Game Theory provides a framework for understanding strategic interactions among participants in a blockchain-based voting system, including voters, administrators, and potential adversaries (Myerson, 1991). In the context of voting, incentive mechanisms such as Proof-of-Work (PoW) and Proof-of-Stake (PoS) are integral in ensuring honest participation and preventing fraud (Nakamoto, 2008). These mechanisms motivate participants to act in ways that promote system integrity—whether through verifying transactions in PoW or staking tokens in PoS.

Game Theory suggests that cooperation among stakeholders is essential for maintaining fairness and trust in the system (Ostrom, 1990). This theory is especially relevant to blockchain-based voting, as it underscores the need to design systems that minimize opportunities for manipulation, coercion, and fraudulent activities, ensuring a fair and transparent process. By

incorporating game-theoretic principles into blockchain design, it becomes possible to create a more secure, trustworthy voting system that incentivizes cooperation and penalizes dishonesty.

Systems Theory

Systems Theory emphasizes the interconnectivity of various components within an ecosystem, highlighting the relationships and dependencies between different elements of the blockchain voting system (Von Bertalanffy, 1968; Checkland, 1999). In a blockchain-based voting system, these components include voters, election bodies, blockchain nodes, and smart contracts.

Systems Theory is highly applicable here because it stresses the need for integration and collaboration across all parts of the voting infrastructure (Simon, 1962). It suggests that the success of a blockchain voting system depends on the smooth operation and reliability of each component working together as part of a unified whole. By focusing on integration, the theory provides insights into how to ensure the system's scalability, security, and reliability. The challenge lies in designing robust frameworks that ensure each component functions cohesively, from the voter casting their vote to the final tallying of results. This theory's emphasis on the holistic nature of complex systems makes it highly relevant to the development of blockchain-based voting systems.

Stakeholder Theory

Stakeholder Theory offers a lens through which to consider the diverse interests and needs of all parties involved in the voting process, including voters, election commissions, political entities, and technology providers (Freeman, 1984). This theory suggests that a successful blockchain voting system must consider and address the concerns of each stakeholder group.

For instance, voters are concerned with security, privacy, and ease of use, while election commissions are focused on ensuring the integrity and transparency of the electoral process (Mitchell, Agle, & Wood, 1997). Political entities may be interested in minimizing the risk of election manipulation, while technology providers must balance innovation with regulatory compliance and system scalability. Stakeholder Theory is crucial for understanding the dynamics that shape the acceptance and success of blockchain-based voting systems. By recognizing the importance of stakeholder engagement and satisfaction, the theory provides a framework for designing a voting system that not only meets the technical requirements but also garners widespread trust and support. Addressing the interests of all stakeholders is essential for ensuring the usability, acceptance, and sustainability of blockchain voting systems.

Blockchain in Secure Voting Systems

Blockchain technology offers significant advantages for securing voting systems, ensuring both integrity and transparency. Zhao et al. (2020) demonstrated that blockchain’s immutable

nature can prevent tampering with ballots and ensure vote integrity, which is crucial in combating election fraud. The use of a distributed ledger allows each vote to be recorded in a way that makes it almost impossible to alter, offering a significant improvement over traditional centralized systems. Similarly, Kshetri and Voas (2022) emphasized blockchain's potential to create audit trails that are immutable, transparent, and tamper-resistant, providing a reliable way to verify the accuracy of the voting process.

However, despite its strengths, blockchain's application in voting systems faces scalability challenges. Large-scale elections, such as those involving millions of voters, require a network capable of processing a high volume of transactions. Blockchain networks, particularly those relying on Proof-of-Work consensus mechanisms, can face significant computational bottlenecks, which could delay vote processing and lead to inefficiencies (Zhao et al., 2020). Moreover, high computational costs and energy consumption remain ongoing concerns.

Decentralization and Trust in Elections

Decentralization is one of the most cited advantages of blockchain-based voting systems. Gupta et al. (2019) argue that decentralizing control over elections enhances trust and accountability by eliminating the need for centralized intermediaries. By allowing a distributed network of nodes to verify votes, blockchain reduces the risks of corruption and manipulation. Trust in the electoral process is thereby bolstered, as no single party or entity has control over the entire process.

However, decentralization is not without challenges. Ali et al. (2021) identified significant issues such as network congestion and low node participation. In a blockchain voting system, the efficiency and reliability of the system depend on the active involvement of all nodes. In practice, low participation from nodes or overloaded networks can hinder the system's effectiveness, especially in large-scale elections with a high voter turnout.

Smart Contracts for Electoral Processes

Smart contracts have been proposed as a means to streamline various aspects of the electoral process, from voter registration to vote tabulation. Chen et al. (2021) demonstrated how smart contracts can automate vote counting, thereby ensuring a higher degree of transparency and eliminating human error in tallying votes. The use of smart contracts to govern voter eligibility, prevent double voting, and ensure that votes are counted accurately significantly enhances the transparency of elections.

Despite these advantages, Lin et al. (2023) identified vulnerabilities in smart contract design that could be exploited to manipulate electoral outcomes. Poorly designed or insufficiently tested

smart contracts could introduce security flaws, potentially compromising the integrity of the voting process. Furthermore, the complexity of developing and deploying secure smart contracts remains a significant barrier.

Challenges in Blockchain-Based Voting Systems

Blockchain-based voting systems face a range of challenges that need to be addressed for successful implementation. Sharma et al. (2020) pointed out that blockchain's scalability issues are particularly problematic during elections with high voter turnout, where transaction volumes could exceed the processing capacity of the blockchain network. Ahmed et al. (2022) raised concerns about voter anonymity, which is difficult to achieve without compromising the transparency of the system. Blockchain systems are transparent by design, which can conflict with the need to keep voters' identities anonymous.

Addressing these challenges is critical for the viability of blockchain in real-world electoral processes. Solutions to scalability, voter anonymity, and the cost of implementation are essential for ensuring that blockchain can be adopted on a large scale.

Opportunities for Blockchain in Elections

Blockchain offers several opportunities for improving election processes, including enhancing voter participation and restoring trust in the electoral system. Tariq et al. (2022) highlighted that blockchain-enabled remote voting systems could significantly increase voter turnout, especially among those who are unable to vote in person due to geographic, health, or other barriers. Moreover, blockchain's transparency ensures that votes are counted accurately and that the results can be audited independently, thereby enhancing trust in the election results.

Okoro et al. (2023) discussed how blockchain can mitigate concerns about election fraud, offering a transparent, tamper-proof way to record votes. By providing an immutable audit trail, blockchain technology could help restore faith in electoral processes, particularly in regions with a history of election-related fraud and corruption.

Electoral Challenges in Nigeria and the Case for Blockchain Adoption

Nigeria's electoral system has faced significant challenges over the years, undermining the integrity, transparency, and credibility of its democratic processes. These challenges highlight the urgent need for innovative solutions to enhance trust and efficiency in elections.

Buying One of the most prominent issues is electoral fraud, which includes ballot box stuffing, vote rigging, and manipulation of election results. Studies have shown that these practices erode public trust in the electoral process and discourage voter participation (Onapajo et al., 2015). Furthermore, vote buying remains a pervasive issue, where financial incentives are used to sway

voter decisions, particularly in rural areas (Ibrahim & Hassan, 2021). Addressing this issue requires robust measures to ensure accountability and transparency in the voting process.

The prevalence of electoral violence, including intimidation of voters and attacks on polling stations, poses a severe threat to free and fair elections in Nigeria. For instance, the International Crisis Group (2019) documented numerous incidents of violence during the 2019 general elections, leading to disruptions in voting and loss of lives. Such insecurity often results in low voter turnout and the disenfranchisement of citizens. Additionally, inadequate security measures at polling units exacerbate these risks, making election days fraught with fear and uncertainty.

Nigeria's electoral process is plagued by inefficiencies, such as delays in the delivery of election materials, logistical challenges, and errors in voter registration. According to Okoye (2020), these issues contribute to widespread dissatisfaction with the electoral body's performance and raise questions about the credibility of election outcomes. Moreover, poor coordination between electoral stakeholders often results in disorganized voting experiences, further deterring voter participation.

Public trust in the Independent National Electoral Commission (INEC) remains low due to perceptions of bias, corruption, and lack of transparency. A study by Adebayo and Omotola (2020) found that skepticism about the impartiality of INEC significantly affects voter confidence and willingness to participate in elections. Strengthening institutional independence and implementing transparent practices are essential to rebuild public trust.

Although Nigeria has introduced electronic systems, such as card readers for voter verification, these systems have faced operational challenges, including device malfunctions and poor internet connectivity. Eze et al. (2022) argue that these technological issues further undermine confidence in the electoral process and highlight the need for more robust and scalable solutions. Additionally, limited digital literacy among voters and electoral officials complicates the effective use of these technologies.

Blockchain technology offers a potential solution to many of these challenges. By providing a secure, transparent, and tamper-proof platform for voting, blockchain can address issues of electoral fraud and enhance trust in election outcomes. For example, its decentralized nature ensures that election data is immutable and auditable, reducing opportunities for manipulation (Sharma et al., 2020). Additionally, blockchain's scalability and ability to ensure voter anonymity without compromising transparency make it a viable option for addressing Nigeria's unique electoral challenges (Ahmed et al., 2022). Moreover, the adoption of blockchain could streamline the electoral process, reducing delays and logistical inefficiencies.

Adopting blockchain-based voting systems in Nigeria could strengthen the integrity of elections, foster public trust, and enhance democratic participation. However, as noted in previous sections, the successful implementation of such systems requires addressing associated challenges, including cost, scalability, and voter education.

Summary and Knowledge Gap

The literature review reveals that while blockchain technology shows significant potential for enhancing election processes, there are still several critical gaps that need to be addressed for its successful adoption and implementation. One of the key areas requiring further exploration is scalability. As noted by Sharma et al. (2020), scalable solutions are essential for accommodating elections with high voter turnout without sacrificing system performance. Another major concern highlighted in the literature is the issue of voter anonymity. Although blockchain offers a high level of transparency, balancing this with the need for voter privacy remains a challenge, as discussed by Ahmed et al. (2022). These authors argue that while blockchain's transparency isbeneficial, the protection of voter identities has not been adequately addressed in existing solutions.

Moreover, the **cost-**effectiveness of blockchain-based voting systems is a largely underexplored area. Studies indicate that the high initial and ongoing costs associated with implementing blockchain in election systems may make it impractical, especially for resource-constrained regions. This financial challenge has not been sufficiently analyzed in the literature, particularly concerning the long-term viability of such systems. Finally, user acceptance of blockchain-based voting systems is another significant area that warrants attention. The inherent complexity of blockchain technology necessitates that voters be educated and that the system be designed with user-friendly interfaces to facilitate widespread adoption. However, this crucial aspect of user engagement has been overlooked in much of the existing research.

This study aims to address these gaps by proposing a blockchain-based voting system that is not only scalable and cost-effective but also user-friendly, ensuring the protection of voter anonymity while maintaining transparency throughout the voting process. By tackling these unresolved issues, this research seeks to contribute to the development of a robust and accessible blockchain solution for electoral systems.

Meta-Analysis Table

Author	Strength	Weakness	Limitation	Gap
Zhao et al. (2020)	Prevents fraud, ensures ballot integrity	High computational costs	Limited scalability	Solutions for large-scale elections

Kshetri&Voas (2022)	Immutable audit trails	Network congestion	Lack of real-world implementations	Implementation in diverse settings
Chen et al. (2021)	Transparency through smart contracts	Vulnerabilities in smart contract design	Limited voter anonymity research	Anonymity-preserving smart contracts
Tariq et al. (2022)	Enables remote voting	Dependency on internet infrastructure	Scalability in rural or low-infrastructure settings	Solutions for low-infrastructure environments
Ahmed et al. (2022)	Ensures transparency, prevents fraud	Potential voter privacy compromise	No solutions addressing privacy concerns	Privacy-preserving blockchain designs
Gupta et al. (2019)	Enhances trust through decentralization	Low node participation, network congestion	Difficulties in high-turnout elections	Improvements in network efficiency and participation
Lin et al. (2023)	Automates vote counting through smart contracts	Smart contract security vulnerabilities	Unresolved smart contract flaws	Improved smart contract security and design
Ali et al. (2021)	Decentralization reduces corruption	Network congestion and node participation issues	Potential centralization due to low node activity	Solutions to increase node participation
Sharma et al. (2020)	High transparency and tamper-resistance	Scalability limitations in high-turnout scenarios	Energy-intensive Proof-of-Work systems	Sustainable and efficient consensus mechanisms
Okoro et al. (2023)	Enhances trust with immutable audit trails	High costs of implementation	Limited studies in resource-constrained regions	Cost-effective blockchain deployment
Chen et al. (2020)	Facilitates secure, transparent vote tallying	Limited adoption in large-scale elections	Lack of practical frameworks	Real-world case studies of implementation
Ayo et al. (2021)	Blockchain's potential for voter inclusion in diaspora	Complex integration with existing systems	Lack of user-friendly interfaces	Simplified user experience design
Musa et al. (2022)	Increases voter trust through decentralization	Vulnerable to 51% attacks in small networks	Low adoption rates in developing regions	Enhanced network security strategies
Singh et al. (2021)	Supports multi-layered authentication mechanisms	High technical complexity for end-users	Limited research on voter education	Effective voter education strategies

Wang et al. (2023)	Demonstrates real-time vote tracking capabilities	Network latency issues in large networks	Unaddressed latency in high-turnout elections	Scalable real-time solutions
Obi et al. (2021)	Highlights cost-saving potential in electoral processes	Initial high investment costs	Limited studies on long-term viability	Financial feasibility in low-income countries
Lee et al. (2022)	Explores blockchain's role in enhancing auditability	Challenges in cross-border electoral systems	Cultural and legal variances across countries	Cross-border implementation strategies
Ibrahim et al. (2023)	Proposes hybrid blockchain for scalability	Complexity in implementation	Limited empirical validation	Practical demonstrations of hybrid systems
Omolu et al. (2020)	Blockchain's adaptability to different election types	Difficulty in integrating legacy voting systems	Lack of interoperability research	Seamless integration with traditional systems

The meta-analysis table offers a comprehensive overview of studies examining the application of blockchain technology in electoral processes. These studies highlight both the strengths and challenges associated with the use of blockchain for voting systems, offering valuable insights into its potential and limitations.

One of the main strengths identified in the studies is blockchain's ability to enhance security and transparency in elections. Many studies emphasize the technology's capability to provide immutable audit trails, which help prevent fraud and ensure ballot integrity. Blockchain's decentralization also fosters greater trust among voters by reducing the potential for corruption. Additionally, several studies highlight blockchain's ability to automate vote counting through smart contracts and facilitate remote voting, expanding access to the electoral process. The technology is also seen as a way to increase voter trust, especially in high-stakes or high-turnout elections.

However, the studies also reveal several weaknesses associated with blockchain-based voting systems. One significant issue is the high computational cost of implementing blockchain, which can place a financial burden on election organizers. Network congestion is another common problem, particularly when dealing with large numbers of voters or data transactions. Furthermore, many studies identify vulnerabilities in the design of smart contracts, raising concerns about security and potential exploits. There are also challenges related to the complexity of integrating blockchain with existing electoral systems, making the transition to blockchain-based voting more difficult for some regions.

The limitations of blockchain in electoral applications are also notable. Many studies cite

scalability issues, particularly in elections with a large number of voters or high turnout. The absence of large-scale, real-world implementations of blockchain voting systems is another limitation, as many studies remain theoretical or experimental. Moreover, while blockchain is praised for its transparency, there are concerns regarding voter anonymity and privacy, with many studies noting that these aspects are often overlooked or inadequately addressed in current research. The lack of solutions to balance privacy with transparency is an ongoing challenge for the technology's adoption in elections.

Finally, several gaps in the literature are identified, pointing to areas where further research and development are needed. These include improving the scalability of blockchain systems for high-turnout elections, developing privacy-preserving blockchain designs, and enhancing network security to mitigate risks such as 51% attacks. Furthermore, more research is needed to explore the practical application of blockchain in diverse electoral settings, particularly in low-resource or underdeveloped regions. The integration of blockchain with traditional voting systems, the design of user-friendly interfaces, and effective voter education are additional areas where gaps persist in the existing literature.

Conclusion

The study deduces that while blockchain technology offers promising solutions for enhancing the security, transparency, and inclusivity of elections, the challenges related to scalability, privacy, and integration with legacy systems must be addressed before it can be widely adopted in real-world elections.

Conflict of interest

Authors declare that have no Conflict of interest.

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