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Blockchain-Based Electronic Voting Systems

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Abstract

This research examines the feasibility of implementing blockchain-based electronic voting systems in India to enhance electoral transparency and integrity. The study employs a methodology that combines Distributed Permission Ledger Technology (DPLT) and the Solana blockchain, resulting in a multilayered system. The main findings highlight the effectiveness of blockchain technology in mitigating electoral fraud and manipulation when implemented with precision, underscoring the importance of meticulous design and execution. These findings contribute significantly to discussions surrounding the modernization of electoral processes in the digital age and support the hypothesis that blockchain can address vulnerabilities in traditional voting methods. Moreover, the study marks a significant step toward modernizing elections, preserving democratic principles, and reinforcing the role of technology in addressing persistent electoral challenges, ultimately enhancing accessibility, security, and transparency in elections and strengthening democracy in the digital era.

Keywords: Blockchain; Electronic Voting; Solana; Distributed Permission Ledger Technology; Election; Democracy.

How to Cite This Article

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Introduction

In an era characterized by rapid technological advancement, the concept of trust has evolved significantly, extending its roots deep into the digital landscape [1]. Trust is the foundation upon which our in-teractions in healthcare [2,3], finance [4], economics [5], and politics are built [6]. And, as the global community steadily embraces digital transformation [7,8], the need for robust, secure, and transparent sys-tems becomes more imperative than ever. Blockchain technology emerges as a disruptive force within this dynamic tapestry of techno-logical innovation [9], wielding the potential to reshape the core of societal mechanisms [10].

The quest for secure and verifiable digital ecosystems led to the birth of blockchain technology, as conceptualized by the mysterious Naka-moto [11]. This cryptographic marvel presents a distributed ledger a single source of truth replicated across many nodes that has ushered in a new age of trust [12]. Its application transcends boundaries, with diverse industries being penetrated, from sensitive medical records [13] safeguarding [14] to financial transactions streamlined [15], economic infrastructure fortified [16], and even the very foundations of demo-cratic processes influenced [17]. At the heart of this blockchain revo-lution lies transparency a quality contributing to its widespread adoption [18]. This transparency is the beacon guiding our exploration into its potential as a solution to the complex challenge of electronic voting systems.

India, a nation steeped in history and culture, is a pivotal case study in pursuing secure and transparent elections. The current voting process (Fig. 1) in *India* relies on a paper-based ballot system, a method riddled with vulnerabilities and inefficiencies. Voters must physically travel to designated polling stations, present identification, mark paper ballots, and trust in the manual counting process. Empow-erment is not provided to voters by the existing voting method to verify whether any unfair votes were added or deleted, undermining the integrity and reliability of results. Moreover, the process is time-consuming, with high setup costs for election preparation, supervision, and post-election operations [19]. The outbreak of global pandemics, such as COVID-19 [20], has further exacerbated these challenges, leading to lower voter turnout [21].

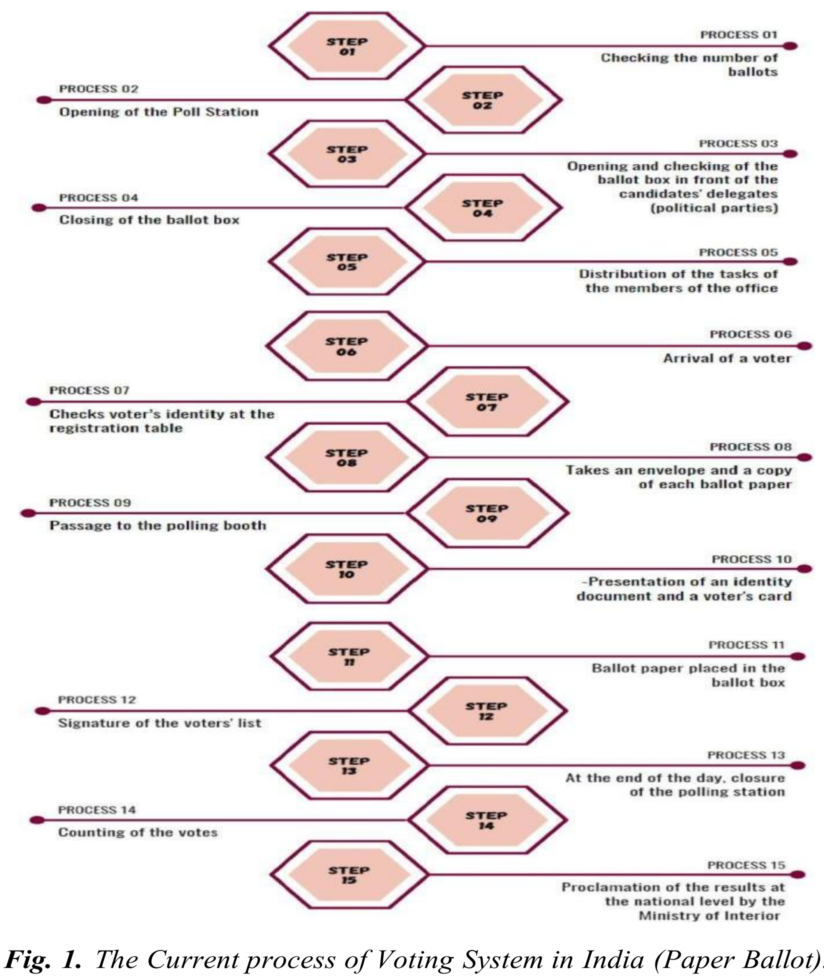

Fig. 1. *The Current process of Voting System in India (Paper Ballot).*

In this context, our research embarks on a journey to investigate the transformative potential of blockchain technology in the context of electronic voting systems, focusing on *India* as our case study. The central research question guiding our inquiry is:

“Can a blockchain-based electronic voting system enhance the integrity, security, and transparency of the electoral process in *India*?"

The importance of this research cannot be overstated. Elections are the cornerstone of democratic societies, ensuring the people’s voice shapes the nation’s trajectory [22,23]. The integrity and transparency of these elections are not only fundamental democratic principles but also a means to bolster voter confidence and hold authorities accountable. By delving into the application of blockchain technology to this crucial domain, our research aims to address existing gaps in the literature.

While various e-voting systems have been proposed [24–27], they often overlook critical aspects, such as transparency in vote result storage and end-to-end verifiability. Our study seeks to fill these gaps by proposing a comprehensive solution that leverages blockchain’s inherent characteristics to ensure anonymity, integrity, accuracy, and verifiability in the voting process. Moreover, utilizing the Solana blockchain, renowned for its speed, scalability, and security [28], adds a layer of innovation and feasibility to our proposed system.

In this exploration of blockchain-based electronic voting systems in *India*, we hope to contribute to the academic discourse and the practical enhancement of democratic processes. Our findings hold the potential to revolutionize how elections are conducted, making them more accessible, secure, and transparent, ultimately safeguarding the essence of democracy in a digital age. This transformation is vital to overcome existing obstacles and bolster democracy, foster dialogue between citizens and government officials [29], and explore new forms of creative democratic involvement [30].

The following are some of the issues that e-voting system (Fig. 2) based on blockchain can help to solve.

- Anonymity: The identities of voters and the candidates for whom they vote should not be revealed [31].
- Integrity: maintaining the integrity of the political process is critical, to filter out foreign interferences or immaterial effects [32].
- Accuracy: A vote cannot be changed or removed by anybody other than the voter [33].
- Verifiability: All transaction is validated by dedicated blocks [34].
- Availability: Each sign-in to vote has a limited time during a specific time frame.
- Eligibility: Only those who are registered to vote should be allowed to vote [35].
- Democracy: It only allows eligible people to vote once [36].
- Opposition: Because voting may be done from anywhere, no one can add unverified ballots or prevent anybody from coming to the polls.

E-voting proposed in this paper it will be a solution to the gap [37] in the traditional voting systems. Thus, to ensure accuracy and bias-free elections [25]; The purpose is that the user can see how their votes have been saved and to prevent others from monitoring who has voted. The paper is organized as follows: Section 2 delves into the back-ground and context of existing research, shedding light on key insights and methodologies that have paved the way for our investigation. Sec-tion 3 presents the specific research question at the heart of our inquiry and discusses its significance. Section 4 details the methodology and system design, providing a comprehensive overview of our proposed blockchain-based electronic voting system. Section 5 presents the results of our research, highlighting key findings and their implications. Section 6 discusses the results scientifically, compares them to previous research and addresses their significance and limitations. Section 7 explores the factors of law and politics in e-voting. Finally, Section 8 offers a scien-tific conclusion summarizing the main findings, restating the impor-tance of our research, and suggesting directions for future study or applications. Throughout the paper, we aim to thoroughly examine the transformative potential of blockchain-based electronic voting systems and their role in modernizing electoral processes.

Related works

Blockchain concepts

The blockchain concept is an ever-evolving living process that will continue to exist for as long as it can successfully transmit its genetic code from one generation of blocks to the next [11,38,39]. Information written on a following block is verified and validated by software pro-grams in the blockchain, and any peer on the network can do so by utilizing a hash code to make a verification [40,41]. This particular blockchain will be updated with several cutting-edge technologies in the form of computational elements to simplify and expedite conducting financial transactions [42]. These transactions are logged in the distributed ledger, ensuring transparency and the inability to alter previous records [43]. While it is theoretically possible to tamper with the data recorded on the blockchain, this would require the majority of peers to be corrupt and willing to participate in the tampering, and it would have to be done systematically and without interruption. The blockchain is decentralized, meaning that no one controls the ledger and copies of the ledger are always accessible to all peers. New data is recorded to a single block that many peers can verify, and the data from all previous blocks is combined into a single ledger distributed among peers; this is not possible in a public blockchain network that is inde-pendently controlled [44]. Therefore, blockchain helps ensure the safety and openness of digital government records while contributing to their decentralization and adaptability [44]. Utilizing technology can signif-icantly enhance essential governmental functions within the E-core, including overseeing decentralized government information databases and validating diverse public transactions and digital services for citi-zens and businesses. These technological solutions have the potential to substantially elevate trust in the e-voting system, thereby fostering greater public confidence in its reliability and effectiveness.

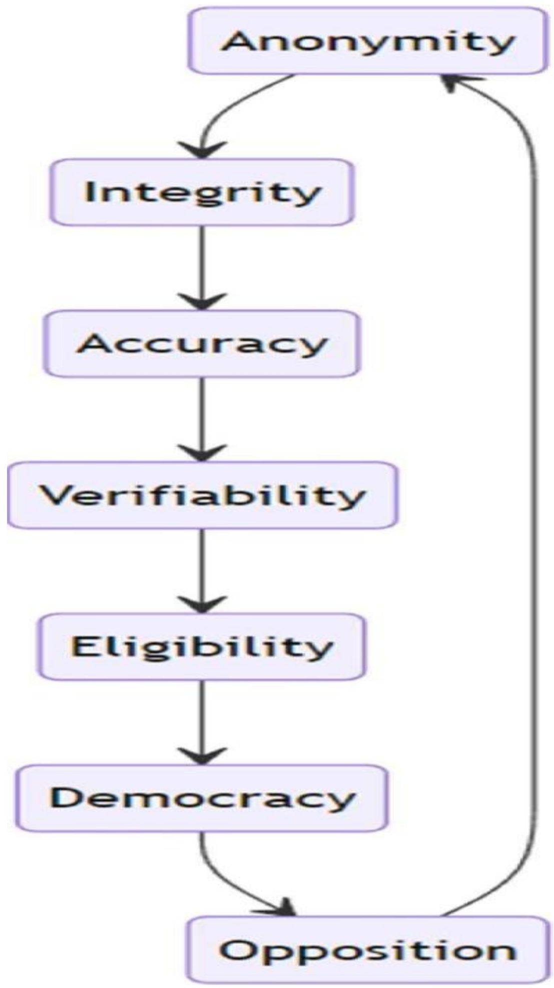

Fig. 2. *Characteristics e-voting system.*

Background and context in existing research

To understand the transformative potential of blockchain-based electronic voting systems, it is essential to navigate the existing body of literature that has illuminated the path to secure and transparent elections. This section delves into the background and context provided by previous research, shedding light on the key insights, methodologies, and findings that have paved the way for our investigation.

The specific research question

At the heart of our inquiry lies a specific research question: "Can a blockchain-based electronic voting system enhance the integrity, secu-rity, and transparency of the electoral process in *India*?" This ques-tion encapsulates the essence of our research endeavor and serves as the compass guiding our exploration into the realm of blockchain-based e-voting systems.

The significance of this research

The significance of our research cannot be overstated, especially considering the pivotal role elections play as the cornerstone of demo-cratic societies [45]. Elections serve as the bedrock of citizen partici-pation, allowing individuals to voice their preferences and shape the trajectory of their nations [23]. However, the integrity and transparency of these electoral processes have faced persistent challenges, as high-lighted by recent studies [21,37,46]. Traditional voting methods, as noted in Ref. [37], have been vulnerable to various threats, leading to delayed result declarations [46] and, more critically, facing disruptions such as those caused by the COVID-19 pandemic [21]. These challenges not only hinder the efficiency of the electoral process but also erode public trust in the outcomes.

Our research focuses on the potential of blockchain technology to revolutionize electronic voting, aligning with the findings of [47] that extensively elaborate on blockchain's core attributes: immutability, transparency, security, and decentralization. By leveraging these attri-butes, we aim to significantly enhance the integrity of electoral results significantly, ensuring tamper-proof and transparent voting mecha-nisms. This aligns with the urgent need for resilient, technologically advanced solutions that can adapt to evolving societal and global cir-cumstances. While our citations primarily highlight foundational studies, we acknowledge the expansive literature landscape in this field. In future iterations, we intend to broaden our literature review to encompass a more comprehensive array of works while emphasizing the relevance of our proposed solution. Our research endeavors not only to fortify the foundations of democracy in *India* but also to contribute innovative approaches that could have a transformative impact on electoral systems globally. The importance of our research lies in its potential to offer a robust and adaptable solution to the persistent challenges facing electoral processes, as identified in many scholarly works. By integrating the principles of blockchain technology into electronic voting systems, we aspire to address vulnerabilities, stream-line result declarations, and uphold the democratic values essential to societies worldwide.

Addressing gaps in existing literature

While the literature has explored various e-voting systems and their potential [24–27], it is apparent that several critical gaps persist, echoing the need for innovative solutions in the domain of electoral integrity.

Several prior studies have proposed electronic voting systems, each bringing unique insights. For instance, Arthur's two-tier design [24] introduced a system with a front-end interface for collecting votes and a back-end server for processing and storing votes. However, this design inherently relies on a persistent internet connection, rendering it chal-lenging to implement in regions with limited connectivity, as exempli-fied in certain areas of Ghana.

Rexha et al.'s methodology for increasing authenticity and trans-parency in e-voting systems [48] presents a dynamic queue-based approach that allows voters to participate from anywhere. While inno-vative, this approach needs to fully address the security of the central-ized database used for verification before voting commences, and it neglects the need to ensure the integrity of cast ballots during the voting process.

Kurbatov et al.'s ring signature-based e-voting system [49]priori-tized voter anonymity through ring signatures. Their design encom-passed validators, user identity verification, and end users for vote casting. However, it needed to adequately address the transparency of vote result storage, which remains crucial in guaranteeing the integrity and credibility of election outcomes.

In light of these prior studies and their respective limitations, our research endeavors to comprehensively bridge these gaps in the litera-ture. We present a holistic solution that leverages blockchain's inherent qualities to ensure anonymity, integrity, accuracy, and verifiability in the voting process. Moreover, integrating the Solana blockchain into the proposed system adds a layer of innovation and feasibility.

As we navigate the terrain of existing research, it becomes evident that our study holds the potential to advance the discourse on secure and transparent electronic voting systems, not only academically but also in practical applications. By addressing the gaps left by prior research and embracing the unique attributes of blockchain technology, we aim to contribute to the evolution of democratic processes and the safeguarding of democratic values in an ever-evolving digital landscape.

Methodology and system design

Methodological framework and system prerequisites

Establishing a robust foundation is paramount to revolutionizing the electoral process in *India* through blockchain technology. This foundation necessitates a clear delineation of essential system re-quirements and objectives that will govern the development of our blockchain-based electronic voting system. The research methodology must be presented with utmost clarity to determine the suitability of the chosen techniques and methods for achieving the anticipated outcomes. Our principal objectives encompass affordability, accessibility, integ-rity, privacy, and transparency.

The vision of remote and on-site functionality

Our vision transcends traditional polling stations, aiming to empower voters by enabling them to remotely cast their ballots using smartphones or laptops from any location. This approach enhances accessibility and mitigates challenges related to physical travel to poll-ing places. However, considering *India*'s infrastructural diversity and developmental status, reliance on remote voting may pose com-plexities [30,50,51]. Consequently, we propose a hybrid system seam-lessly integrating remote and on-site voting options to accommodate diverse electoral needs.

Technical aspect: multilayer architecture

Our proposed solution adopts a multilayer architecture (illustrated in Fig. 3) built upon the robust Solana blockchain. This architecture comprises two fundamental layers: a Distributed Permission Ledger Technology (DPLT) layer responsible for data verification and validation and a Solana blockchain layer dedicated to ensuring data immutability and decentralization. These two layers collaborate to provide a secure and verifiable voting environment throughout the electoral process.

Solana blockchain and its role in E-voting

The Solana blockchain assumes a pivotal role as the cornerstone of our proposed electronic voting system. Solana is renowned for enabling smart contracts, non-fungible tokens (NFTs), and decentralized appli-cations (dApps) and facilitating high-speed, secure, and scalable trans-actions [52]. With the capacity to handle up to 50,000 transactions per second (TPS) and block times of 400 milliseconds, Solana offers the speed and scalability necessary for a nationwide voting system. It aims to demonstrate the feasibility of a blockchain embodying scalability, security, and decentralization. Under typical conditions, the system can sustain up to 710,000 TPS on a standard gigabit network and reach 28.4 million TPS on a 40-gigabit ethernet [53], positioning it as one of the world's preeminent decentralized computer networks. The second layer continuously maintains a hash of the most recent transaction, enhancing transparency, security, and system integrity.

First layer: Distributed Permission Ledger Technology (DPLT)

The first layer introduces Distributed Permission Ledger Technology (DPLT), enabling authorized participants to submit digitally signed messages and statements. The distributed storage system safeguards and verifies voting by transferring validated data to the blockchain. Throughout the voting procedure, the first layer serves as the primary communication conduit, maintaining an immutable record of all data. Cryptographically authenticated symbols validate referenced blocks, facilitating swift verification even on resource-constrained devices. Each block within this layer includes essential components such as the root hash, unique identification hash, hash linkage to the preceding block, mediator server nodes, and bidirectional connections to other blocks.

DPLT and security

The security of the first layer is reinforced by involving authorized external organizations responsible for certifying transactions and up-holding data integrity within Moroccan elections. Nodes within the network store transactions, and each new transaction is incorporated into blocks through a consensus process involving all nodes. Consensus node rotation prevents centralization, with impartial mediator servers and independent third parties overseeing management at various loca-tions. The consensus nodes' primary objectives include verifying ballots as the legitimate work of authorized voters, decrypting and validating content, and conducting post-election decryption for ballot counting.

Second layer: logging method on solana

The first layer is connected to the second layer, a logging method for recording historical transaction information This second layer is built on the Solana blockchain, ensuring that our permission layer's data is immutable and tamper-proof. The Solana blockchain has low latency (0.4 s per transaction), low costs (average fee of $0.00001 per trans-action), and high throughput (over 50,000 transactions per second), making it possible for full nodes to run on any device.

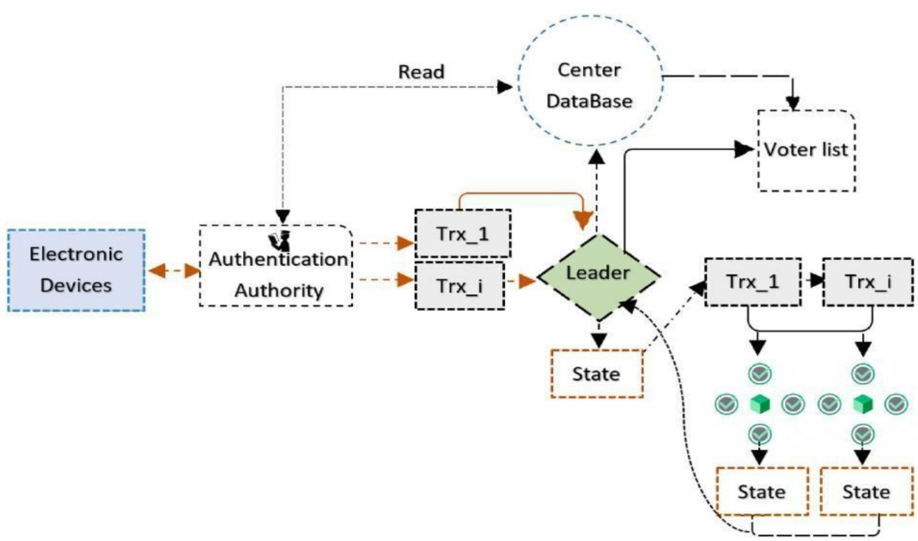

Fig. 3. *Transaction Flow in Moroccan's Blockchain system.*

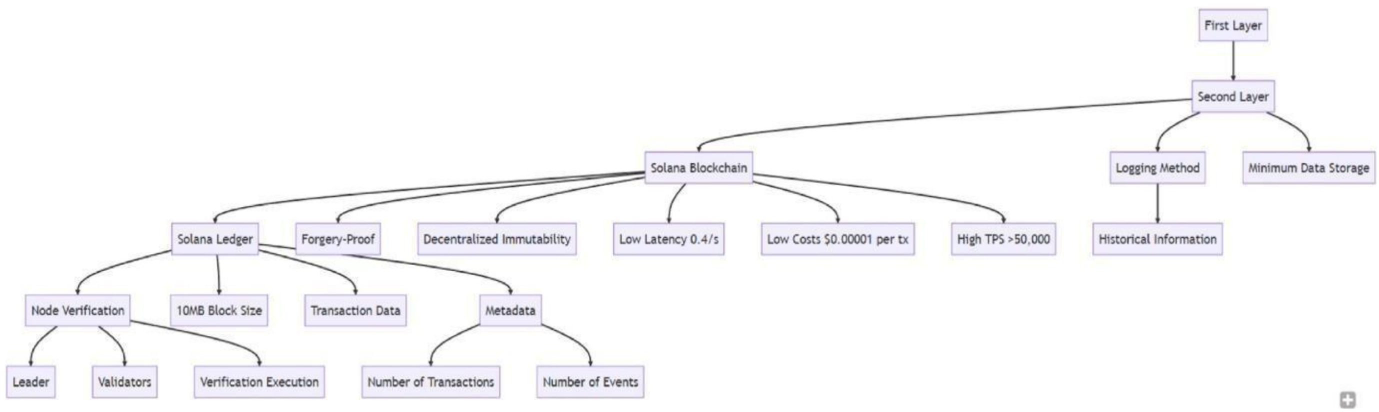

Fig. 4. *System architecture with Solana blockchain.*

In the System Architecture with Solana (Fig. 4), each block in the blockchain is 10 MB in size and contains a specific number of trans-actions. Each block also includes metadata, such as the number of transactions and events it contains, and input and output hashes. When a node claims to have produced a new block, other nodes can verify this claim. The node that created the block is called the leader, while the nodes that perform the verification are called validators.

The second layer was designed to leverage the data security features of the Solana blockchain while requiring minimal data storage.

The second-layer log comprises regular updates originating from the first layer, which are subsequently stored on the distributed nodes of both the Impartial Mediator servers and the Solana blockchain. To initiate the creation of a new collective Solana address, the Mediator server undertakes the signing and broadcasting of the genesis trans-action, denoted as txid(0) of the block(0), onto the Solana network. This pivotal transaction serves as the foundation for the second-layer log. It includes essential elements such as the public key to the Impartial Mediator server and an initial payment, denoted as S(0), directed to-wards the newly established address.

To extend the entries within the log, the Impartial Mediator server proceeds to broadcast a Solana transaction bearing the identifier txid(i). Following this, a subsequent statement is made wherein txid(i) desig-nates an allocation of Solana funds, specifically represented as b(i-1) and derived from the output of txid(i-1), directed towards the nominated address of the governing authorities. This iterative process culminates in generating a series of interconnected transactions, effectively con-structing an immutable and tamper-resistant log of assertions, as illustrated in Fig. 5.

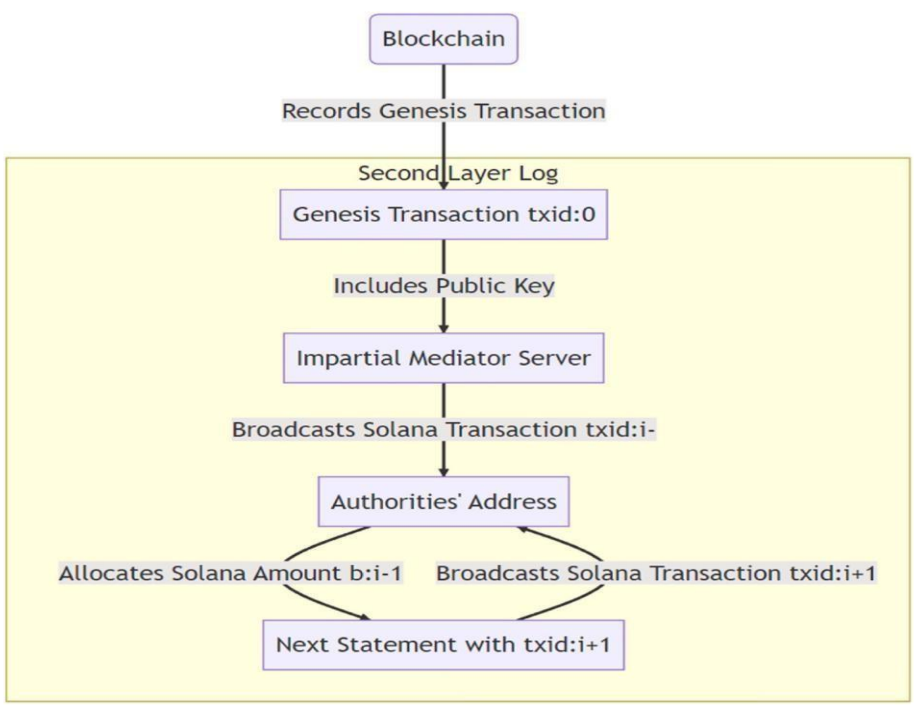

Fig. 5. *Figure Building a tamper-proof log of assertions through transactions.*

Combining the two proposed layers provides decentralization, scalability, and security at a lower cost and with high data throughput.

Polling booth program interface

In a network election, authorized voters can participate by using the polling booth program interfaces. This program retrieves information from the election configuration, presenting voters with candidate lists and options. Voters make selections on encrypted ballots, processed within the first layer. The polling booth program interface expedites the voting process and empowers voters to verify device functionality and ballot accuracy. Our prototype ensures end-to-end verifiability, decen-tralization, scalability, and adherence to technological requisites for successful elections. Through this system, we aim to enhance democratic processes, enabling fully verified digital elections for the Moroccan government. Subsequent sections will delve into the technical intricacies of our blockchain-based electronic voting system, emphasizing security, transparency, and innovation, while adhering to the research methodology.

Results

This section presents the results of our proposed blockchain-based electronic voting system's development and testing. We highlight key findings and outcomes based on the methodology and system design detailed in previous sections.

System architecture

Fig. 6 illustrates the system architecture of our blockchain-based electronic voting system. Authorized voters interact with the system to cast their ballots. The system comprises two fundamental layers: the Distributed Permission Ledger Technology (DPLT) layer, responsible for data verification and validation, and the Solana blockchain layer dedi-cated to data immutability and decentralization. The DPLT layer facili-tates transaction validation, cryptographic verification, and the storage of validated data on distributed nodes. The Solana blockchain layer maintains an immutable transaction log, enhancing transparency and security.

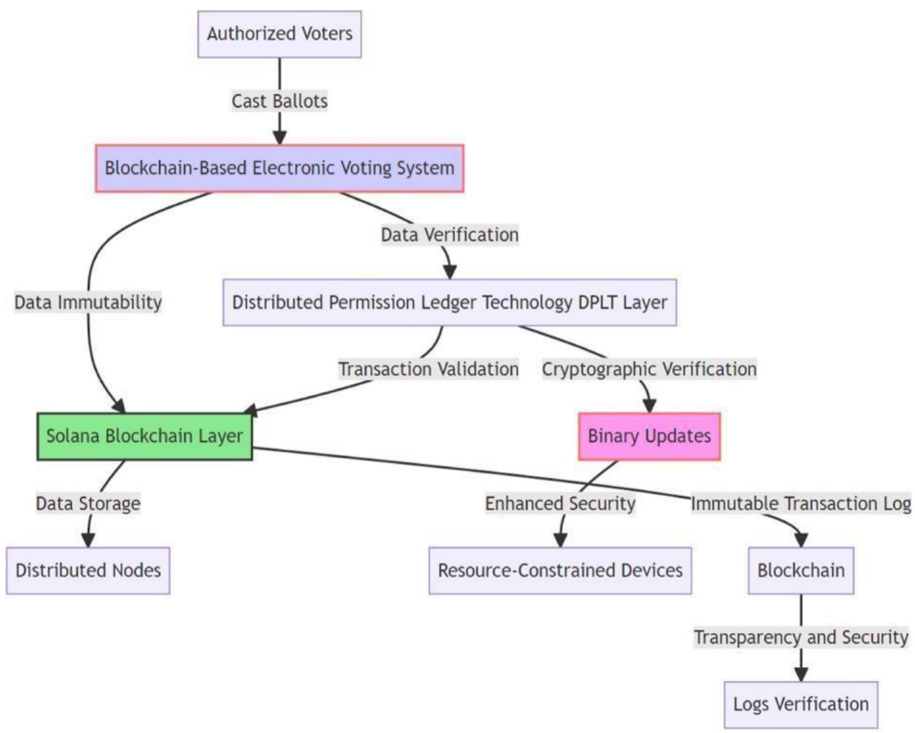

Fig. 6. *Figure Building a tamper-proof log of assertions through transactions.*

System performance evaluation

In Fig. 7 below, we present a sequence diagram illustrating the performance assessment of our voting system. This diagram outlines the transaction processing sequence from the voters' perspective and the system.

Fig. 7 illustrates the transaction processing sequence in our system. Voters cast their ballots, initiating transaction processing. The loop demonstrates the system's capability to handle a high transaction rate efficiently by verifying transactions before providing voters with confirmation.

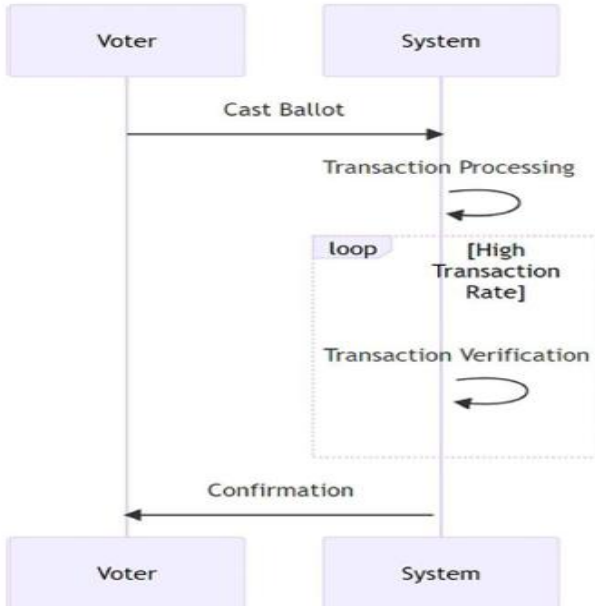

Fig. 7. *Transaction processing sequence.*

Security measures in the DPLT layer

Security is a critical aspect of our system. We employed multiple security measures within the Distributed Permission Ledger Technology (DPLT) layer. Fig. 8 represents the distribution of these security measures.

Fig. 8 provides an overview of the distribution of security measures within the DPLT layer. It emphasizes the importance of cryptographic verification, the involvement of authorized external organizations, consensus node rotation, impartial mediator servers, and independent third parties in ensuring the security and integrity of the voting process.

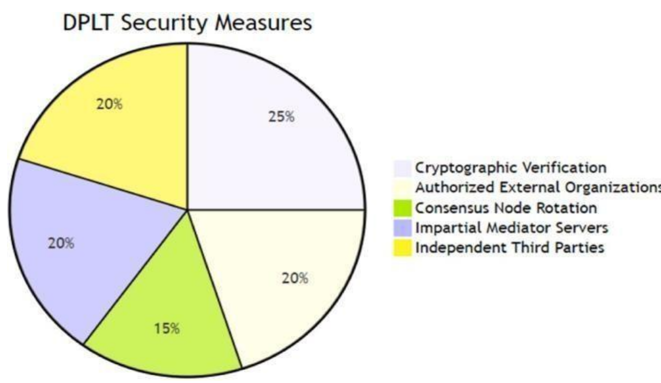

Fig. 8. *Distribution of DPLT security measures.*

Transparency verification in the second layer

Transparency and verifiability are integral to the electoral process. Fig. 9 demonstrates how our system ensures transparency in the second layer.

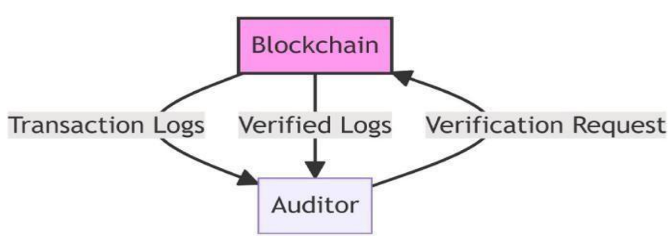

Fig. 9. *Transparency verification flow.*

Fig. 9 depicts the transparency verification flow in our system's second layer. The Blockchain provides transaction logs to the Auditor, who can request verification. Upon verification, the Blockchain returns verified logs to the Auditor, ensuring transparency and accountability in the electoral process. Fig. 9 complements the sequence diagram pre-sented earlier, visually representing the verification flow.

User interface flow

The user interface plays a pivotal role in the voting experience. Fig. 10 outlines the user interface flow in our system.

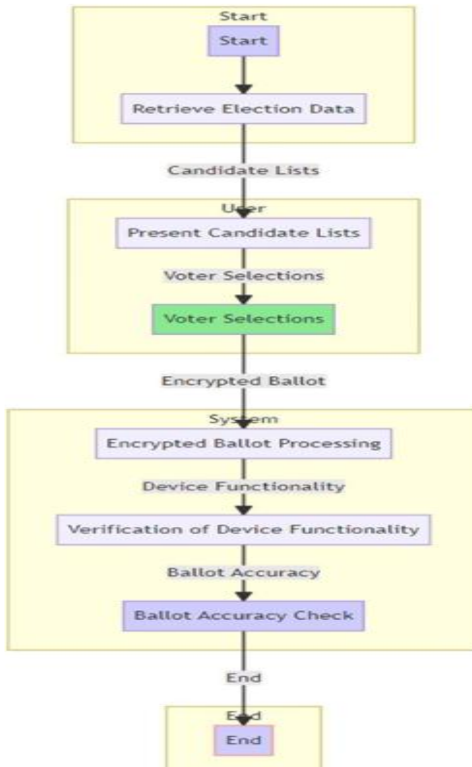

Fig. 10. *Flowchart depicting the user interface flow of the system.*

1. Start (A): The flow begins with the “Start" point, where the user initiates the voting process.
2. Retrieve Election Data (B): The system retrieves essential election data, including candidate lists, from the database.
3. Present Candidate Lists (C): The user is presented with a list of candidates to choose from. This step enables voters to make informed selections.
4. Voter Selections (D): Voters make their selections from the pre-sented candidate lists. This interaction is a crucial part of the elec-toral process, allowing voters to choose their preferred candidates.
5. Encrypted Ballot Processing (E): Once the voter selections are made, the system processes the choices and generates an encrypted ballot, ensuring the security and confidentiality of the vote.
6. Verification of Device Functionality (F): The system verifies the functionality of the user’s device, ensuring that it can securely transmit the encrypted ballot. This step is vital to guarantee that the vote is accurately recorded.
7. Ballot Accuracy Check (G): The final step involves a ballot accuracy check, ensuring that the voter’s selections are accurately recorded before the vote is officially cast.
8. End (H): The flow concludes with the “End" point, marking the completion of the voting process.

This user interface flow ensures a seamless and intuitive voting experience for users while maintaining the integrity and accuracy of the electoral process. It empowers voters to make informed choices and verifies the accuracy of their selections before finalizing their ballots.

Comparative analysis of e-voting features

To fully comprehend the potential of our system in shaping a more secure, transparent, and efficient e-voting landscape, we embark on a comprehensive comparative analysis. This analysis juxtaposes the key features, benefits, and challenges of traditional e-voting systems with those of a blockchain-integrated model.

The following tables (Table 1, Table 2, Table 3) illuminate the transformative potential of this technology, paving the way for a more resilient and inclusive democratic process.

This comparative framework will serve as a foundation for exploring the theoretical and practical implications of implementing a blockchain-based e-voting system, paving the way for a more secure, transparent, and inclusive democratic experience.

Our blockchain-based electronic voting system prototype, starting with the presentation of the system architecture, not only meets but even exceeds the requirements of a modern, secure, and transparent electoral process. The potential to revolutionize elections is offered, ensuring that each vote is counted accurately and that the process remains open to scrutiny. These results provide a strong foundation for our prototype's future adoption and refinement in Moroccan elections and beyond. Further technical details and discussions can be found in subsequent sections.

Table 1. *Comparison of Pre-Blockchain and Blockchain-Based E-Voting Features*

Features	**Pre-Blockchain E-Voting**	**After Implementation**
Security	Relied on centralized systems, vulnerable to hacking and tampering.	Enhanced security through decentralized storage, cryptographic algorithms, and consensus mechanisms, reducing risks of tampering and fraud.
Transparency	The lack of transparent processes made verification challenging, potentially compromising the integrity of the election.	Every transaction is transparent and immutable, ensuring verification and integrity of the entire process.
Cost	Required significant resources for infrastructure, maintenance, and manual verification.	Potentially more cost-effective by reducing infrastructure, labor, and audit expenses.
Speed	Processing and tallying votes could take a long time due to manual intervention and verification procedures.	Almost instant vote validation and counting due to high throughput and low latency.
Accessibility	Accessibility issues for remote voters, those with disabilities, or those unable to physically reach polling stations.	Improved accessibility for remote voters, potentially increasing overall participation and inclusivity.

Table 2. *Key Benefits After Blockchain Implementation*

Key Benefits Post-Implementation	**Pre-Blockchain E-Voting**	**After Implementation**
Immutable Records	The lack of transparent processes made verification challenging, potentially compromising the integrity of the election.	Enhanced trust through transparent and immutable records.
Reduced Fraud	Vulnerable to manipulation due to centralized systems.	Difficulty in altering or manipulating votes due to decentralized and secure mechanisms.
Efficiency	Time-consuming processing and verification procedures.	Faster processing and declaration of results, reducing time and resources.
Accessibility	Limited access for remote voters and those with disabilities.	Improved access for remote voters, increasing inclusivity and participation.
Cost-Efficiency	High costs associated with infrastructure and manual labor.	Potential reduction in costs associated with physical infrastructure and manual labor.

Table 3. *Challenges and Considerations*

Challenges and Considerations	**Pre-Blockchain E-Voting**	**After Implementation**
Security Concerns	Vulnerability to hacking and tampering.	Potential vulnerabilities despite enhanced security measures.

Education and Adoption	Complex for specific demographics.	Ensuring user-friendly interfaces for all demographics.
Regulatory Compliance	Adherence to legal and regulatory requirements.	Adherence to legal and regulatory requirements, especially in sensitive areas like voting systems.
Maintenance and Upkeep	Regular maintenance of systems.	Continuous maintenance and updates for the blockchain network.

Discussion

The results of our research illuminate the transformative potential of blockchain-based electronic voting systems within the specific context of *India*'s electoral process, addressing the fundamental question of whether such a system can enhance the integrity, security, and trans-parency of elections. These findings contribute to a growing body of evidence that underscores the pivotal role of blockchain technology in redefining conventional processes across various sectors. The multi-layered architecture we have proposed, comprising the Distributed Permission Ledger Technology (DPLT) layer and the Solana blockchain layer, represents a substantial step toward realizing a more secure and accountable electoral system. Our study reinforces the hypothesis that when strategically harnessed, blockchain can significantly enhance elections' integrity and security.

Contrary to concerns voiced by skeptics, our results do not align with the theory that blockchain might introduce more vulnerabilities. Instead, they indicate that blockchain can be a robust safeguard against electoral fraud and manipulation with proper design and implementa-tion. The performance evaluation of our system, showcased in the re-sults, provides a new and compelling insight into the relationship between technology, transparency, and electoral trust. The demon-strated capability to handle a high transaction rate efficiently is a key determinant of the system's success in ensuring the accuracy and integrity of the voting process.

However, it is crucial to acknowledge the intertwining factors of law and politics that influence adopting e-voting systems. The legal and political landscape can either facilitate or hinder the implementation of such systems. Factors such as legislative frameworks, political will, and stakeholder engagement play a significant role in determining the feasibility and acceptance of blockchain-based electronic voting.

The legal aspects of e-voting vary depending on the country and jurisdiction in which the e-voting system is used [56]. A variety of legal and political factors must be taken into account when implementing e-voting systems. Some critical legal considerations include ensuring that the e-voting system complies with relevant laws and regulations governing the electoral process, protecting confidentiality, and ensuring the integrity and accuracy of the voting process. Additionally, specific legal requirements related to using electronic communications and information technology in the electoral process may need to be considered.

From a political perspective, it is essential to ensure that the general public perceives e-voting systems as fair and transparent. This may require implementing measures such as independent audits and public education campaigns to promote trust and confidence in the e-voting system. Political considerations include:

- The potential for e-voting to increase voter turnout.
- The impact on different demographic groups.
- The potential for e-voting to enable new forms of political participation and engagement.

Overall, e-voting systems need to be designed and implemented in a way that considers both legal and political considerations to ensure the legitimacy and fairness of elections.

Legal frameworks must be adapted to accommodate blockchain technology's unique attributes while addressing data privacy, security, and accountability concerns. Political will, on the other hand, is instrumental in driving the adoption of innovative electoral solutions, including blockchain-based systems. It can also influence the allocation of resources and support required for successful implementation. Moreover, stakeholder engagement is vital for building consensus and trust in the new electoral system. Engaging with political parties, civil society organizations, and the public is essential to ensure transparency, address concerns, and gain acceptance.

The transition from a prototype to a full-scale implementation may encounter legal and political hurdles that warrant further investigation and strategic planning. The system's reliance on technology accessibility poses potential barriers in regions with limited connectivity or digital infrastructure, which political and legal considerations can exacerbate. Moreover, the need to build trust and acceptance among voters and relevant authorities is a gradual process, potentially affecting the initial adoption and success of the system.

Our research signifies a substantial leap toward advancing electoral processes' integrity, security, and transparency, particularly in the Moroccan context. It bolsters the hypothesis that blockchain can be a powerful tool in the arsenal of electoral modernization, countering skepticism with empirical evidence. However, the journey towards the widespread adoption of blockchain-based electronic voting systems is characterized by challenges and complexities influenced by the intricate interplay of law and politics. This study encourages further exploration and refinement of these systems while emphasizing the critical role of legal and political considerations in shaping the future of e-voting.

Conclusion

Our research highlights the transformative potential of blockchain-based electronic voting systems within *India*'s electoral frame- work. Our primary findings affirm the viability of our multilayered system, which unites Distributed Permission Ledger Technology and the Solana blockchain to enhance election integrity, security, and trans- parency, challenging initial doubts and emphasizing the crucial impor- tance of precise design and execution. The significance of our research extends beyond our immediate findings. It contributes to the broader discourse on electoral modernization in an increasingly digital era, strengthening the hypothesis that blockchain technology can effectively address vulnerabilities in traditional voting methods and underscoring the need to adapt legal frameworks, garner unwavering political sup- port, and engage stakeholders to ensure the widespread adoption of blockchain-based electronic voting systems. Additionally, our findings point to promising directions for future research and practical applica- tions, including assessing scalability under diverse electoral scenarios, exploring advanced cryptographic techniques for enhanced voter pri-vacy while preserving transparency and security, and examining socio-political aspects, such as public perception, trust-building strategies, and their impact on voter participation. In conclusion, our research plays a significant role in modernizing the electoral process and pre-serving democratic principles, emphasizing the pivotal role of technol-ogy in addressing persistent electoral challenges. Furthermore, as we move forward, we can reshape elections, making them more accessible, secure, and transparent, reinforcing democracy's foundation in the digital age.

CRediT authorship contribution statement

Adityaraj Yadav: Conceptualization, Methodology, Software, Writing – original draft, Writing – review & editing. Data curation, Methodology, Writing – original draft, Writing – review & editing. Pratik Shinde: Software, Validation, Writing – review & editing.

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