Revolutionizing Voting: Blockchain for Secure and Transparent Elections

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***Abstract*—This study examines a blockchain-based election system and presents both theoretical and experimental evidence. It emphasizes the ability of blockchain technology to ensure secure, transparent, and tamper-evident elections with voter anonymity protection. Through decentralized ledger technology, the system minimizes the risk of fraud, unauthorized access, and data manipulation, enhancing electoral process trust. The initiative was a success in producing an operational prototype where blockchain has been integrated into current voting processes to make them more accessible and more reliable. Ease of admin panel, voter authentication and enrollment, live vote analysis, are a few of the system features. Support elements include a PRN-based login feature for users, add/remove facility for candidates, voting time period management and a comprehensive FAQ page to promote security and usage. The system also offers an "Add PRN" option for smooth voter verification and authentication to ensure only authentic users get a voice. All these options combined improve the integrity, efficiency, and usability of blockchain voting.**

***Index Terms*—Blockchain, voting system, voter authentication, decentralized ledger, election security, PRN-based login, real-time vote analysis, fraud prevention, transparency, tamper-evident elections.**

I. INTRODUCTION

Voting is a crucial aspect of any democratic country, allowing citizens to participate in decision-making by selecting their representatives from a pool of candidates. There are two primary methods for casting votes: the traditional paper ballot method and electronic voting machines (EVMs). Each method has its own drawbacks. Traditional paper ballots face challenges such as high costs, accessibility issues, integrity concerns, and inefficiency. EVMs, while offering some advantages, also have their own set of issues, including security concerns, accessibility problems, and the fact that they often operate as a ”black box”, making it difficult to verify their processes. Blockchain technology offers a promising solution to some of these challenges by leveraging its advantages. Blockchain employs a series of ledgers where data can only be appended and not deleted or tampered with, ensuring a secure and immutable voting process. [2]

Estonia has been utilizing electronic voting (I-voting system) since 2005, relying on a national ID card issued to all citizens. These ID cards contain encrypted files that uniquely identify the holder and serve various purposes that include document signing and banking transactions. To cast a vote, the voter will insert their ID card into a card reader and gain access to the voting website. The system will then verify the voter's eligibility by redirecting them to the website to enter their credentials. Once authenticated, the voter can cast their vote and if needed, modify it until four days before the election day. [1]

However, the I-voting system has faced criticism for its vulnerability to malware attacks and centralized control. Public blockchain like Ethereum and private blockchain like Hyperledger Fabric were discussed, highlighting the trade-offs between transparency and control. Challenges such as scalability i.e. being able to conduct nation-wide elections, privacy concerns, and regulatory compliance still need to be addressed. Future research is recommended to focus on more efficient consensus mechanisms, privacy-preserving techniques like zero-knowledge proofs, and hybrid blockchain models that balance security and efficiency. Additionally studies on real-world adoption could provide valuable insights and help in further enhancement of systems. [3]

Ensuring privacy, secure authentication, and transparency is essential for any e-voting system. The use of smart contract-based elections, defining specific roles such as administrators and voters while structuring the overall election process is crucial. While public blockchains offer a high level of transparency, private blockchain solutions tend to provide better security and efficiency, making them a more practical choice for large-scale voting applications. [4]

Although blockchain technology does not replace EVMs, it rather provides an alternative by providing a framework to address these issues. To explore its potential, we have implemented a blockchain-based voting system on a smaller scale.

II. Study Area

The study was carried out in a residential housing society in Mumbai. The society has a number of residents who voted in the election. The general elections were to select five representatives from among seven candidates. To assess the efficiency and acceptance of blockchain voting, the system was tested jointly with the conventional paper ballot. The voting process was held at the housing society complex so that all the eligible voters could access it easily. A total of 20 residents cast their votes electronically during the two-hour voting window from 11:00 AM to 1:00 PM.

Thus we applied blockchain technology to small-scale community elections, and the results show that security, transparency, and voter trust are factors that are manageable.

Additionally, Figure 1 illustrates a blockchain block from our system, demonstrating how each vote is securely recorded in Ganache with its transaction hash, block hash, timestamp, gas used, and gas limit. This visual representation highlights the security and integrity of the blockchain ledger used in the voting process.

III. Methodology

This research follows an experimental approach to design, develop and validate a blockchain-based community voting system. The process follows a structured flow, ensuring security, transparency and efficiency in the election process.

A. System Workflow

1) Smart Contract Implementation: The voting system is governed by a Solidity-based smart contract, which enforces election rules and automates important processes. It includes functionalities for candidate registration, vote casting and result computation. The smart contract maintains the following components:

- **Candidate Structure:** Stores candidate details, including name, vote count and active status.
- **Admin Privileges:** Only the admin can add or remove candidates and control the voting period.
- **Voter Authentication:** A mapping ensures that each address can cast only one vote.
- **Voting Mechanism:** Votes are recorded on the blockchain, ensuring immutability and transparency.
- **Result Computation:** The contract tallied votes in real time and allows the retrieval of the candidate standings.

2) Admin Control and Candidate Registration: The admin is responsible for managing the election. They can register candidates ensuring that only eligible individuals participate. The contract enforces conditions such as preventing duplicate candidate registration and allowing the removal of inactive candidates. The admin also has control over opening and closing the voting period.

3) Voter Registration and Authentication: Voters authenticate is done using unique identifiers. We changed the student elections that used permanent registration numbers (PRN) to flat numbers as unique voter identifiers. The registered voter is then stored in the database and in blockchain.

4) Opening of Voting Lines: Once candidates are registered, the admin opens the voting lines by updating the contract state. The openVoting() and closeVoting() functions control the voting period. The contract ensures that votes can only be cast when voting is active.

5) Casting and Recording Votes: Voters interact with the system via a frontend interface that communicates with the smart contract using Web3.py and Flask. The voting process follows these steps:

- Voter will be registered and verified with their flat numbers after which they will be redirected to a login page.
- The voter selects a candidates.
- The vote is recorded on the blockchain, updating the candidate’s vote count.
- A unique transaction hash is generated that the voter can view.

6) Result Computation and Declaration: Once voting ends, the smart contract automatically tallies votes. The getVotes() function allows real-time retrieval of vote counts, ensuring transparency. Results are displayed on the frontend in the form of a graph and a tally table.

B. Data Collection and Evaluation

Data collection includes system logs, smart contract transactions, and user feedback. On-chain data such as vote counts, transaction hashes, and gas fees provide insights into system performance. Qualitative data from user interactions help assess usability and accessibility, leading to iterative refinements.

C. Limitations

- The system currently operates in a simulated blockchain environment (Ganache), limiting real-world scalability testing.
- Assumptions are made regarding voters’ access to necessary technology and internet connectivity.
- The sample size is restricted to a specific community, affecting broader generalization.

Despite these constraints, the methodology ensures a secure, transparent, and verifiable voting system, demonstrating blockchain’s potential in digital elections.

IV. RESULTS AND DISCUSSIONS

The blockchain-based voting system was implemented successfully along with the conventional paper ballot system in the general elections of the housing society. The election was contested by seven candidates, and the voters had to choose five of them. Our voting system was open for two hours, i.e., 11:00 AM to 1:00 PM, during which 20 residents voted electronically. After that time slot voting lines were closed and the system did not allow votes. PRN validation was replaced by flat numbers.

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Fig. 1: Voting Details Stored in a Block in Ganache

While most residents enjoyed the convenience, security, and transparency of the blockchain-based system, there were some who were skeptical about trusting everything to technology. Some were more comfortable with the old ballot system, expressing fears about digital security, unfamiliarity with blockchain, and the dependability of an online system. To cater to this, our solution kept both systems running in parallel.

Our system provided results that could be verified instantly, promoting transparency, whereas the ordinary ballot process took time to count manually. The blockchain ledger kept an unalterable record of the transactions, which further boosted voter confidence in the security of the process.

Result Grid | Filter Rows:

id	name	unique_id
1	A	CAND001
3	B	CAND002
4	C	CAND003
5	D	CAND004
7	F	CAND006
8	G	CAND007
10	E	CAND005
NULL	NULL	NULL

Fig. 2: Candidates with their unique ID stored in MySQL

To provide security and distinctiveness to the vote, each contestant was assigned a unique ID as shown in our MySQL database Fig.2.

A visual depiction of election outcomes as a bar graph Fig.3 explicitly defines voter preferences

In addition, the candidate registration page Fig.4a has a friendly interface showing all registered candidates, and this makes the registration process transparent. Also, the final count of the votes is displayed in Fig.4b, identifying the number of votes garnered by each candidate.

A comparative study of the two approaches brought to light the effectiveness of blockchain voting, minimizing human

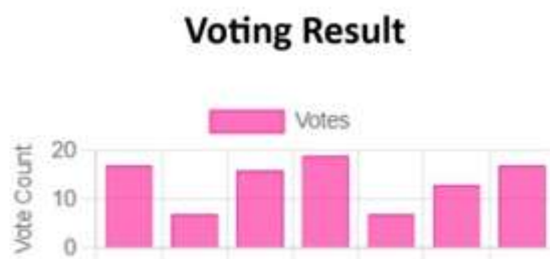


Fig. 3: Voting Graph Showing Final Results

interference, eliminating errors, and allowing faster computation of results. The success of this application is proof of the viability of blockchain-based voting in community-level elections, with future enhancements targeting scalability, higher voter turnout, and mitigating concerns of critics through education and trust-building programs.

A. Gas Consumption Analysis

To evaluate the efficiency of our blockchain-based voting system, we had a total of 280 voting transactions on the Ganache local Ethereum test network. The initial account balance was 100 ETH, and after all voting operations were completed, the remaining balance was 99.56 ETH. This indicates the total amount of Ether consumed during testing was:

$$\text{ETH Consumed} = 100 - 99.56 = 0.44 \text{ ETH}$$

Average ETH Spent per Vote

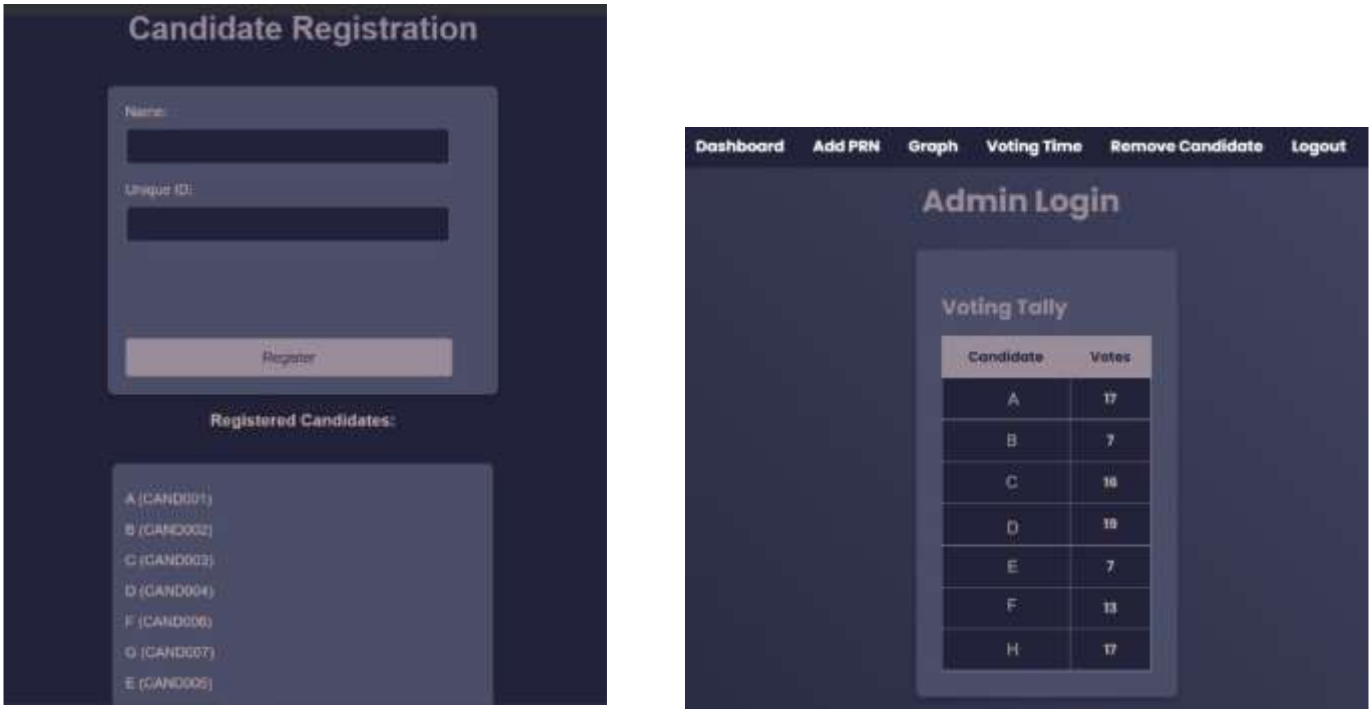
The average cost per voting transaction in ETH is calculated as:

$$\text{Average ETH per Vote} = \frac{0.44 \text{ ETH}}{280 \text{ votes}} \approx 0.001571 \text{ ETH/vote}$$

Estimated Gas Usage per Vote

Assuming a standard gas price of 50 gwei (1 gwei = 10^9 wei), and knowing that 1 ETH = 10^{18} wei, we estimate the gas consumed per vote as:

$$\text{Gas Used per Vote} = \frac{0.001571 \times 10^{18} \text{ wei}}{50 \times 10^{9} \text{ wei/gas}} \approx 31{,}420$$



(a) Candidates with their unique ID shown in Front-end

(b) Voting Tally Showing Final Results

Fig. 4: User Interface of the Voting System: Frontend for Candidate Registration and Voting Tally

Based on our analysis, each vote on the blockchain consumes approximately 0.001571 ETH, which corresponds to around 31,420 gas units at a gas price of 50 gwei. This demonstrates that the system maintains cost transparency and measurable efficiency. Future optimizations, such as gas-efficient smart contract design and bundling transactions, can further enhance performance.

V. CONCLUSIONS

Through the housing society's general election, the blockchain voting system has been successfully implemented to improve transparency, security and efficiency in the voting process. Using Solidity for smart contract development and Web3.py for blockchain interaction the system enforces strict voting rules, ensuring that a flat number cannot vote again after they have voted. This made the election process more reliable and some residents were showing confidence in its integrity. The society's letter of acknowledgment highlights the significant impact of our software in providing a trustworthy and unique voting experience.

The system was implemented and tested in a simulated blockchain environment i.e. Ganache to ensure working of candidate registration, vote casting and result computation. Despite limitations such as the reliance on a simulated environment and restricted scalability testing the study highlights the potential of blockchain in digital elections by reducing human errors, faster display of results etc. This research contributes to the growing adoption of blockchain for secure and transparent voting, paving the way for future advancements in decentralized election systems.

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