Blockchain Technology in Electronic Voting Systems: A Systematic Review of Prospects, Challenges, and Future Directions

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ABSTRACT

Blockchain technology, a decentralized, distributed, and consensus-driven ledger operating within peer-to-peer networks, has emerged as a transformative innovation across various digital ecosystems. Its integration into electronic voting (e-voting) systems offers promising advantages over traditional manual voting processes, including enhanced transparency, improved accuracy in vote counting, tamper resistance, and increased voter participation through remote accessibility. Despite these potential benefits, large-scale adoption of blockchain-based e-voting remains constrained by critical challenges related to security, privacy, scalability, transaction throughput, and voter trust.

In parallel, cloud computing has evolved as a scalable and cost-effective infrastructure for hosting and managing complex applications, including those supporting democratic processes. Leveraging cloud architecture in conjunction with blockchain presents new possibilities for improving the efficiency, transparency, and resilience of e-voting platforms.

This paper presents a systematic review of existing blockchain-based e-voting systems, focusing on recent research contributions addressing security, privacy, and performance concerns. The review identifies existing gaps in privacy protection, scalability, and transaction speed, and evaluates emerging hybrid approaches combining blockchain and cloud computing to overcome these limitations. Furthermore, the paper discusses the prospects of blockchain technology in securing digital elections and outlines future research directions aimed at developing robust, transparent, and trustworthy blockchain-based e-voting frameworks.

Keywords: *Blockchain, Electronic Voting, Cloud Computing, Security, Privacy, Voter Trust, Ethereum*

I. Introduction

Authors in [1] Argues that electronic voting in polling stations is in place in some of the world's largest democracies. Internet voting is used in some, initially mainly small and historically conflict-free countries as illustrated in [2]. Many countries are currently considering introducing e-voting systems with the aim of improving various aspects of the electoral process as pointed out in [3].The main goal of e-voting is to cast or count the votes using electronic means and connect the various participating individuals through a secure mechanism so that there is no any alteration with data or votes at any level is quickly detected and resolved [4] [5] .The E-voting is often seen as a tool for advancing democracy, building trust in electoral management, adding credibility to election results and increasing the overall efficiency

of the electoral process. The technology is evolving fast and election managers, observers, international organizations, vendors and standardization bodies are continuously updating their methodologies and approaches.

According to [6] ,proper implementation , e-voting solutions can eliminate certain common avenues of fraud, speed up the processing of results, increase accessibility and make voting more convenient for citizens—in some cases, when used over a series of electoral events, possibly even reducing the cost of elections or referendums in the long term. Unfortunately, not all e-voting projects succeed in delivering on such high promises as pointed in [7]. The current e-voting technology is not problem-free. Legislative and technical challenges have arisen in some cases; in others, there has been skepticism about or opposition to the introduction of new voting technologies. The inherent challenges of e-voting are considerable and linked to the complexities of electronic systems and procedures. Many e-voting solutions lack transparency for voters and even for election administrators [7]. Most e-voting solutions are only fully understood by a small number of experts and the integrity of the electoral process relies largely on a small group of system operators instead of thousands of poll workers. If not carefully planned and designed, the introduction of e-voting can undermine confidence in the whole electoral process. It is therefore necessary to deploy the application of blockchain technology to make sure that e voting appears to be the most appropriate prospect to meet these challenges like repudiation that are essential for voting processes [8].

E-voting alone has been faced with many challenges as pointed out in [9] in recent elections conducted by various countries has portrayed some security issues with the system.According to [9], e-voting systems have been compromised by intruders through spoofing fake websites to the voters ,changing the domain name server(DNS) and untrusted client devices can be affected thus no transparency,fair and confidentialaity in vote casted .This then leads to have a blockchain technology embedded in smart contarcts to resolves the threats associated with manipulation of data . Blockchain is a new technology that is emerging whose full potential has not been realized and where a lot of applications are being built [2].Due to its core features of allowing decentralized,irreversible,anonymous and having bestsecurity features [10] ,it has attracted many reserachers,innovators in many domains like health [11] [12],industry [13], [14], [15],agriculture [16] as well as the academic field [17], [18] that requires a technology that can store and ensure secured exchange of information without involving thrid party.

Blockchain has been widely used in cryptocurrency and also applied in other areas [3].Blockchain technology can be used in terms of tracking,organizing and supporting communications by ensuring data is stored from many devices and facilitating the formation of identities without any centralized cloud [19] .

Many approaches have been suggested by researchers on use of blockchain in electronic voting ,some faces challegs with security issues like identity theft,device trojan horse,spyware,visues and worms affecting their paersonal gadgets hence election being compromised. The contribution of this paper include the following :

1. We introduce a systematic review of the current e-voting systems based on blockchain technology
2. We elaborate extensice discussion on some of the challenges of e-voting systems based on blockchain technology that impede their applicability.
3. We reveal research gaps basing on the limititations of each e-voting systems and hence decisive solutions are provided

This paper is structured as follows: Section 1 covers the introduction .In section 2 , we present a related works .in section 3 we elaborate an architecture of e-voting system based on blockchain.in section 4 we discuss the key findings .on the other hand requirements for the proposed system is discussed in section 5.In section 6 we describe the results .Finally section 6 presents the conclusions and future work.

II. Related Work

Blockchain technology with use of smart contract was recently proposed as a new technical infrastructure for development and deployment of various types of IT applications including e-voting applications .The authors of paper [20] wrote a systematic review of e-voting applications using blockchain technology.They began by establishing the challenges that electronic voting is facing ,including privacy ,inadequate evidence, fraud resistance ,speed ,scalability and cost.The authors later on did a through compariosn with other systems that they believed to have many aspects of standard features to make a robust system.However there were less criteria to compare these applications hence not having a robust system.In terms of cost effective , authors in [21] addressed the issue of cost effective resources and resolved some of issues .However the proposed e- voting system did not address the issue of scalability which was a major issue in e-voting sinsce the system must be able to handle millions of votes in a limited time.the challenge is that it is difficult to predict the maximum number of simultaneous votes that the system should be able to handle without crashing .

Authors in [22] proposed a voting platform with a remote real-time ballot box auditing capicity .The platform is based on blockchain technology and a mathematical approached is applied to test if the results are correct and if no fraud occurred during the election. The protocol did not address security issues dealing authentication of voters credentials hence unrealible .To boost voter's credentials authentication ,a protocol is established in [23] which solve the issue of authentication using hormophonic encryption technique .the technique purely uses fingerprints technique to capture details of the voters in the database.this technique is reliable incase the biometric voting devices can recognize the fingerprints of the voter.unfortunately,some voters who have issues with fingerprints are not elligible to vote due to failure of biomteric gadgets to recognize them hence making some voters not to practice their demogratic right of electing their candidate.To mitigate the issue of voters who cant be recognized in biometric , [19] proposed a new model of e-voting using Internet of Things (IoT) embedded with blockchain technology.This e-voting application is linked with IoT devices like senors and other biometric devices that can recognise the voter who has voted and also detect an arbitarry attempt in the system.the system was robust and its performace.however the system fails in its main master nodes hence causing a barrier in communication amongst the nodes and IoT devices. This now leasd to need to corporate other proactive protocol that will ensure better cooperation between parameters .

[24] have proposed a smart e-voting system where voters can cast their votes through smartphones or laptops .the e-voting mechanism using blockchain technology have used tamper proof sectret identities and also application of encryption key which ensures that the security and transpancy of the system is cstered for .However ,this sytem faces some challenges like impersonantion ,identity theft by an intruder ,injection of malwares or spywares to the targeted smartphones and laptops hence manipulating the voting process.furthermore, this system faces difficulty in checking the accuracy of the votes recorded bin the voting results

To boost the confidentiality of a voter, [25] proposed a secured e-voting system that curbs security issues like Denial of service(DoS) attacks and Distributed Denial of Service (DDoS) ,authentication delay . The system boosts several benefits thus attracting many researchers and vendors of systems. However ,the system consumes a lot of power which makes them energy intensive to an individual thus expensive to apply in large scale like a country. [26] have proposed a verified and secured e-voting mechanism with iad of cryptographic approach to ensure voter's integrity,transparency and identity .the authentication mechanism uses a two factor mechanism to prevent double voting mechnism and also verefiuability of the untrusted individuals hence only voting to trusted source.the proposed model is validated by revealing a practical and verifiable pooling mechanism .it has been the best mechnism so far .unfortunately ,double verification process with use of key management and storage overhead further leads to complex computation hence faces a challenge of high compurtational time .in order to ensure faster computation,transparency and privacy of a voter, [27] [28] [29] implememnted an e-voting

system solidity ethereum blockchain techniology .the users are allowed to cast their votes through wallet android application using consensus.also the efficieny and reliability of blockchain enabled e-voting is demonstrated via simulation this leads to reduction in fraud during voting.However this mechanism does not address the security issues of the system which renders it questionable .

1. Related Architecture of the e-voting system based on blockchain technology

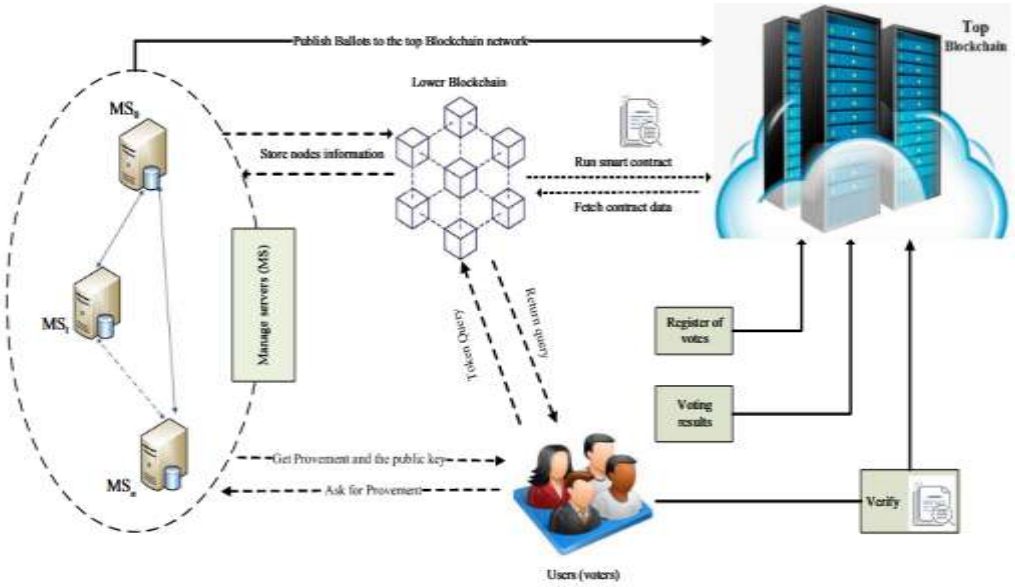

Figure 1: Architecture of the e-voting system based on a blockchain

The basic gadget that each voter requires is a smartphone. Each eligible voter as shown in figure 1 above, has a wallet containing their own user credentials.an eligible voter receives a digital coin which denotes one opportunity to cast a vote. Manage servers (MS) helps to store the node information in the lower blockchain technology and later publish it to the higher blockchain technology with provision of certificates. The voting schemes entails the following stages:

- ✓ Setup. Here the correct security parameters are entered .This leads to generation of public and private keys.
- ✓ register: Input the identifier ID or fingerprints to generate the private key as an output
- ✓ voting: An eligible voter creates a parameter and computer a cipher text and its signature
- ✓ Valid: Here the servers checks the credentials of an eligible voter. If they are valid, he/she cast the vote else the system rejects.
- ✓ Publish: This adds voting values to the polling box and later publish them as public for citizens to view
- ✓ Tallying: When all the tallies are cast and verified, the results are counted by using related private key as input and values of polling box to generate the final results.

III. Results

A multitude of security,privacy,anonymity,scalability,intergirty coercion resistance ,audit as well as performance challenges have been identified in all the current e-voting systems based on blockchain technology.Some of these challenges include identity theft,traceability,impersonation and high computation .Table 1 presents a summary of these systems and their respective challenges.

It is evident from Table 1 that most of the current e-voting systems have coercion resistance ,scalability ,audit and integrity issues that impede their deployment over internet based on blockchain technology.Furthermore ,it is clear that most of the e-voting systems based on blockchain technology utilizes ethereum framework with hashing alogorithm SHA-256.A largest percentage of e-voting system based on blockchain technology has ensured that their eligible voters remains anonymous something that should be considered so as the boost the trusts of a citizen. It has also revealed that use of blockchain technology makes the system immutable hence adversaries cannot access the system easily since data is stored in block which are encrypted [8]. Its also revealed that blockchain systems uses a lot of power hence energy intensive [30]hence need for low energy consuption mechanism.

Table 1 Summary of challenges of current systems

Authors	framework	Hashing algorithm	anony mity	audit	intergrity	scalability	Coercian resistance
Lai [31]	Ethereum	SHA-3	✓	✓	x	✓	✓
Shahzad [32]	Bitcoin	SHA-256	✓	✓	✓	x	x
Yi [33]	Bitcoin	SHA-256	✓	✓	x	x	x
Rathee [34]	Bitcoin	Not specified	✓	x	✓	✓	✓
Roopak [35]	Not specified	Not specified	✓	x	x	x	x
Krishna [36]	Not specified	AES-256	✓	✓	x	✓	✓
Singh [37]	Not specified	AES-256	✓	x	✓	x	x
Dery [38]	Not specified	SSL	✓	x	✓	✓	✓
Gao [39]	Bitcoin	SHA-256	✓	✓	✓	x	x
Mc System [40]	Ethereum	Not specified	✓	x	x	x	x
Jen [41]	Ethereum	Not specied	✓	✓	x	x	x
Rifa [42]	Ethereum	SHA-256	✓	x	x	x	✓
Freya [43]	Bitcoin	Not specified	✓	✓	x	x	x
Hamdaga [44]	Ethereum	Not specified	✓	✓	x	✓	✓

Srivastava [45]	Bitcoin	Not specified	✓	x	x	x	x
Bin Yu [46]	Ethereum	Not specified	x	x	x	x	x
Ahmed [47]	Ethereum	Not specified	✓	✓	x	x	x
Kashif [48]	Bitcoin	Not specified	✓	x	x	x	✓
Yi Liu [49]	Ethereum	SHA-256	✓	✓	x	x	x
Ganji [50]	Bitcoin	SHA-256	✓	x	✓	x	x
Fusco [51]	Ethereum	Not specified	✓	x	✓	✓	✓
Leema [52]	Not specified	Not specified	✓	✓	x	x	x
H.Yi [53]	Quantum blockchain	Not specified	✓	x	x	✓	x
Khan [54]	Ethereum	Not specified	✓	✓	x	x	x

IV. Future Research directions

A myriad of security and privacy challenges have been outlined in the current e0voting systems based on blockchain technology.Although many reserachers have tried to come with mechanisms of addressing these issues,the attainment of a perfect fully implememntation of blockchain technology is still in earlier stages hence need for more improvements .in regard,the following technologies are thought to be esseential towards boosting the perfromance ,security ,transparency and scalability of e-voting stystems based on blockchain technology.

4.1 Use of low power Raspberry Pi architecture

The Raspberry Pi is a small, affordable, and amazingly capable, credit card size computer [55].It is developed by the Raspberry Pi Foundation, and it has been the most versatile tech ever created.it was built by Eben Upton with an aim of creating a low-cost device that would improve programming skills and faster understanding of the hardware. Because of its small size and price of the device, it has become the center of a number of projects by makers and some electronics enthusiast. It utilizes less power which is the future directions to be embedded on the blockchain technology.it is inexpensive device hence cost efficient in terms of deployment. There is therefore need to come up with innovative protocols and e-voting systems for eliminating security attacks.

4.2 Artificial intelligence

Artificial intelligence deployment in e-voting systems using blockchain technology will play a critical role in ensuring that prediction and detection of any attack hence making systems secure [56]. Artificial intelligence aids in detecting the external threats hence assisting the computer security personnel to countermeasures against it instantly thus increasing security and privacy preservations .furthermore ,artificial intelligence plays a vital role in network optimization [57]- [58]- [59]. Machine learning model which is in AI will be able to detect the DOS attack on data center, which stores the citizen's record, which can compromise the availability of the data at a crucial time. In this regard, the quality of service

(QoS) of the offered remote access services will be enhanced. When this AI technology is deployed in e-voting system, it will increase security, anonymity, integrity and also transparency in voting.

4.3 Deployment of smart contract

Deployment of smart contract plays a role in simplifying business and trade between anonymous and identified party without the need of middlemen [60]- [61].smart contracts gave network automation and the ability to convert paper contracts into digital contracts .smart contracts enabled users to codify their agreements and trust relations by providing automated transactions without supervision of central authority [62] . There is therefore a need for more secured e-voting system with use of smart contracts to protect the e-voting system.

4.4 B5G and 6G Networks

The beyond 5G (B5G) and the Sixth Generation (6G) networks are the backbone of future e-voting systems based on blockchain technology deployments. Using these cellular technologies, high levels of security and performance can be attained successfully [63] [64]. For instance, fast response times in terms of large scale voting , high data rates up to 10 Gbps with low latency, high flexibility, high scalability, connectivity to heterogeneous devices, a wide range of supported applications as well as enhanced QoS are some of the goals pursued by these technologies [65]- [66]- [67].

V. Conclusion

This paper has presented and compared recent researcher's contributions to security and Privacy issues for the existing e-voting mechanisms based on blockchain technology.
First, the information on e-voting systems, concepts of blockchain technology is reviewed systematically. Further, a myriad of gaps are identified in e-voting system including privacy protection, transaction speed in large scale and scalability. Thirdly, prospects of blockchain technology have been discussed, current solutions of blockchain based e-voting systems and potential research directions are proposed .Most researchers agree that blockchain technology plays a vital role in e-voting systems to ensure anonymity of an eligible voter, integrity and transparency in voting. A number of blockchain based e-voting issues have been addressed and taken for future research for a secured e-voting system. Since blockchain e-voting systems are still in earlier stages, we did not exhaust all the risks with blockchain hence requires further research for a robust e- voting system. This research revealed that blockchain systems brought many issues that needed more attention and there are still many technical problems to be addressed. That is why it is important to understand that blockchain-based technology is still at an early stage in an e-voting solution. Hence the developing need for security and privacy protections may be a barrier to emerging the real blockchain applications.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they do not have any conflict of interest.

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