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Ethereum Blockchain Based e-voting System for Jordan Parliament Elections

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Abstract: This paper presents an Ethereum-based E-Voting System (EBVS) applied for the parliamentary election system in the country of Jordan. The proposed EBVS system implements a uniquely structured voting process, where a voter must first vote for a menu, which represents a party or a group of candidates, and then to cast a vote for one or more members within the menu. This study addresses performance issues, including time and one of Ethereum main parameters (the gas consumption). The EBVS system provides new algorithms and methods, which enable votes to be casted within a specific period for each voter in a manner to avoid coercion and intervention in the voting process, and therefore reduce corruption, which is a notable problem in many countries around the world. This study presents a parallel blockchain architecture, which is used to improve the performance of the system and enable fast voting process, avoiding long queuing time.

Keywords: Blockchain, E-voting, Ethereum blockchain, Gas , Jordan Parliament Election.

1 Introduction

Elections have always carried significant role in the political process of many countries worldwide. Quite often, elections become subject to corruption and fraud, leading to increasing distrust in the political process and causing unrest and turbulence. During the infamous 2020 presidential elections in the USA, many doubts were raised regarding the count of the votes, their authenticity, and applicability to the voting regulations in various states [1]. Electronic elections are and adopted and used by many countries as a means to improve the electoral process in terms of reliability, trustworthiness and performance [2][3]. Traditional electronic elections [4] offers benefits such as facilitating the voting process and speeding it up with less effort and cost than the traditional ones, it still has significant security flaws that compromise the integrity of the election [5]. The innovation of blockchain technology improves the electronic voting systems due to its characteristics of high security, integrity, trust, and transparency, and also overcomes the significant problems of other voting systems [6].

Blockchain is a distributed decentralized digital ledger among peers of nodes, where the ledger consists of a chain of blocks, each block points backward to the block before it by a hash value [75]. If the content of one of the blocks in the chain changed, the hash value of that block until the end of the chain will change for each block, and as a result, that change will lead to re-mine that block and all the blocks in the chain, which is a hard work making the chain immutable. Also, because Blockchain is decentralized, each peer node on the network has the exact copy of the Blockchain, so if the content of a block has changed in a specified node this change will be revealed by comparing it with the other nodes on the Blockchain making it more secure [6]. Blockchain was first introduced in 2008, by Satoshi Nakamoto who introduced the Bitcoin white paper [8].

Vitalik Buterin [9] later introduced Ethereum Blockchain where he envisioned using the simple nature of Bitcoin Blockchain in complex applications. Vitalik included the most important part of the Ethereum network, which is the smart contract. Smart contract is the core of the Ethereum network, which is a piece of code that lives in the Ethereum blockchain; a smart contract can be instructed to perform certain transactions by a human or by another contract, thus creating a hierarchy of contracts. Ethereum network and smart contracts went online in 2015 [10][11].

Ethereum networks consist of several computers/nodes responsible for transferring the money and storing the data between the different parties [9]. Ethereum includes a main network for real transactions and other networks for testing purposes. Ethereum testing networks include Ropsten (PoW), Kovan (PoA), Gorli (PoA), and Rinkeby (PoA) [12] . The purpose of using test networks is

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for testing the transactions and ensuring the smart contracts work correctly before deploying them to the main network where the ethers are worth real money [13][14]. Ethereum is a public network, where anyone can join this network [9] and consumers can connect to the network using their Ethereum wallets which is a meta-transaction implementation used to facilitate the interaction of users with that Ethereum network [15].

The most significant feature for the transactions in the Ethereum network is gas. Gas has multiple properties associated with it, one of these properties is the gas price and the gas limit. The gas price is the amount of money the sender of the transaction is willing to pay per unit of gas to get this transaction successfully processed, while the gas limit is the total units of gas a transaction can consume. In Ethereum, each transaction modifying or adding data on the blockchain must pay an amount of money for the gas. To decrease the cost of gas-consumption, developers always try to optimize the smart contracts by using simple data structures and logic; the more complex the smart contract, the more gas will be consumed[16].

Ethereum smart contract technology turns out to be effective in constructing e-voting systems due to its properties specially the decentralization that fulfills the issues of security and transparency [17][19]. In this paper, we provide a model for an electronic voting system using the Ethereum blockchain network. The Ethereum Based E-Voting System (EBVS) is created and tested using the Parliament elections model in the country of Jordan. This model has unique features that add complexity to the e-voting process. In order to accommodate the uniqueness of the electoral system in Jordan, a unique smart contract is created and utilized in this work; this model can be adapted to other electoral systems. Also, due to the importance of the Ethereum gas property when writing the smart contract as it reflects the response time and performance of the voting systems, this research has addressed the performance issues in such a way that the voting system responds quickly with minimal effort and cost.

2 Literature Review

Since the early decades, humans have invented the method of voting to choose one particular thing from multiple options. Greek civilization was considered the first to conduct the electoral process using pottery flakes called "ostraca" [19]. Over the years, the electoral process and its forms have evolved, from the traditional paper and pen to electronic voting after the invention of computers and the internet. As a result, many electronic voting systems have been proposed [6][120][21].

Many countries adopted the electronic voting system in their elections whether in the political election or other types of elections. Estonia represented the first country to use e-voting systems fully in its elections, and despite the security risks in its e-voting system, the turnout of people using the internet to vote increased remarkably [22]. In the year 2000 Brazil passed a law to implement elections using e-voting systems. In 2010, 135 million Brazilians voted in the presidential election using the e-voting system. Brazil considered its e-voting elections done successfully [23]. In 2003, India introduced its first recognized electronic election [24]. However, different countries have unsuccessful experiments with electronic voting elections due to security like Germany, the Netherlands, the United Kingdom, and others. One of these unsuccessful scenarios happened in 2016 in the USA, where 70% of American citizens voted using the conventional voting method rather than electronic voting [5].

After the advent of blockchain technology and the generation of Ethereum networks and smart contracts [6, 9], several applications in different aspects adopted the blockchain, where one of the most important applications built on blockchain was the electronic voting system [43]. In order to improve the voting process, several studies and models were presented in recent years to achieve an integrated voting system. The presented applications and studies use different types of blockchains such as public, private, and permissioned [26,27]. Voatz [28] is the first voting application to be used in real blockchain-based elections. It was used in 2018 in the state of Virginia in the USA. In 2020, the voting process with Votaz in Washington State was terminated because it suffered from significant gaps in voter privacy and security [43]. However, many voting systems that used blockchain were successfully applied like TIVI [29], Polyas [31], and Luxoft [32].

BBVS voting system [6] built an electronic voting system for the Jordanian parliamentary elections on a simulated private blockchain**,** the tallying process for BBVS is carried out by a centralized server, which threatens the security of the system and its integrity. The voting system presented in this study adopted the same voting environment as BBVS which is the parliament Jordan election[32]. The EBVS model is tested in a real Ethereum application (DAP) to take advantage of blockchain features, specifically decentralization on the Ethereum public blockchain. Several structures and methods will be introduced in this study to optimize the performance of the blockchain voting system. We conducted the experiments with Ethereum application on top of the Rinkeby test network [33] and Metamask wallet [34]. the authors conducted experiments to select the implementation which consumes less gas, taking into account that fewer transactions are required to keep the cost as low as possible, and also the time it takes to mine the transactions, is reasonable.

3 Research Methodology

Figure 1 shows the architecture of the proposed Ethereum blockchain e-voting system The elections is distributed among districts, and each district is represented by multiple menus, and each group contains at least 2 members.

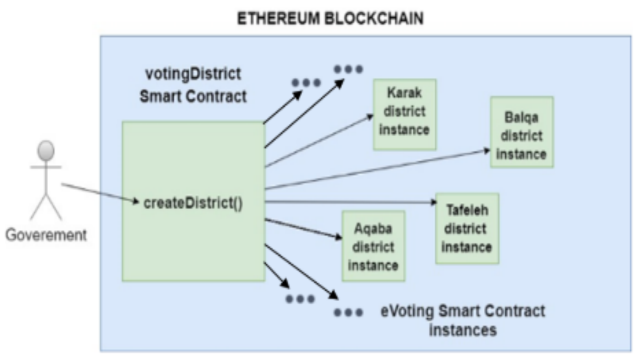

Fig.1: Structure of the parliament elections in Jordan.

To facilitate the e-voting process, two smart contracts are created, with the first being responsible for deploying the second smart contract. The first contract is directly associated with the district and responsible for creating the district structure (votingDistrict), while the second contract is the actual eVoting contract. When the government intends to add a new district, it triggers the createDistrict function from the first contract, and then this transaction creates a fresh copy of the second contract on the Ethereum blockchain.

The e-voting system Smart Contracts are created using the programming language Solidity [35]. The e-voting Ethereum application utilizes the Web3 library [36], React library [37], Infura –API [38], and Metamask Ethereum wallet [32]. The electronic Ethereum based voting system (EBVS) follows the following steps to achieve a voting process; see Figure 2.

a. Adding voting districts

There are two smart contracts in the EBVS voting system: the votingDistrict smart contract and the eVoting smart contract. The votingDistrict contract is responsible for deploying the eVoting smart contract and keeps track of all deployed eVoting smart contract instances, knowing where they are in the Ethereum blockchain by saving the addresses of the deployed instances in an array. The manager/government will add all the districts they want, using the createDistrict operation in the votingDistrict smart contract, and will generate a new district as an instance of the eVoting smart contract.

b. Adding voters

All citizens eligible for voting in a specific district are added to that district using the smart contract votingDistrict. Each citizen must generate a Metamask wallet account, an Ethereum wallet, and he/she must determine which public address he/she will use during the voting process in the preparation phase. Adding voter is handled in two ways: The first is when the voter comes to the identity verification office and verifies the blockchain address. In this case, a voter is added directly to the blockchain in a single transaction. The second option is to add a list of pre-registered voters in a given district in one transaction. Each Ethereum address represents a voter. When the voting process begins each voter casts a vote using his/her address; The identity of the voter remains unanimous; this is necessary to protect the privacy of the voter [43]. When the government adds the voters, the eVoting smart contract first checks whether the voter already added and checks if the voter's ID or address has never been used before. It also checks if the wallet balance associated with the voter address is equal to zero. This step is required as proof that the system is accurate (the number of tokens in each balance must exactly match the maximum number of candidates). From the government wallet, the government sends to each voter when he/she is added to the system multiple tokens that exactly match the maximum number of candidates in their district. Each token corresponds to exactly one vote and only one candidate. The operation of adding voters is strictly managed by the government smart contract; no one else has the authority to process this transaction. After adding a voter and sending tokens to his/her wallet, a token count variable adds the number of tokens sent to the voter to the total number of tokens sent to voters in that district count: Token = countToken + Number Of Ethers Sent. Count token variables reflect the integrity of the voting process, the number of tokens sent must match the number of votes.

c. Adding districts menus

The government allows one or more menus/lists to be used for each district. Each menu contains multiple candidates greater than one and less than the maximum number; the maximum number varies from district to district and is set by the government. In the preparation phase, the government adds the menu according to the number of candidates in the district. When the government adds the menu, it sends a transaction to the Ethereum blockchain, and the information assigned to it includes the menu number, the number of candidates, the candidate's addresses, and a counter that is incremented by one for each vote recorded during the voting process for the menu. When the transaction is triggered, smart contract eVoting checks whether the requested number of candidates included in the menu is greater than zero and less than or equal to the maximum number of candidates.

d. Candidates permission

Anyone eligible to vote can stand as a candidate. Before a citizen takes part in the election as a candidate, he/she must first obtain consent via the eVoting Smart Contract. The smart contract checks if the candidate is on the list of eligible voters, then several conditions and requirements must apply to the candidate to give them consent to participate in the election. The government through the smart contract sets the requirements and conditions.

e. Candidates participation

After the citizen takes the permission to participate in the election, he/she must send a transaction to the eVoting contract containing the desired menu number to be included in it. All other information about the candidate is collected using the address of the transaction initiator. This information was linked to the voter address by the smart contract in the Add Voter step. When the transaction is accepted, the citizen will be added to the electoral candidate list and assigned a counter for each vote he/she scores during the voting process.

f. Picking voters

We implement a method for randomly selecting a set of voters to cast their votes in a randomly generated time interval; this method is sought to increase the security and privacy of the voting system; this is primarily needed to obstruct the intervention of what is known as "political dirty money". Joran Parliamentary elections (2020) was marred by rumors regarding the use of dirty money as reported by the Arab Weekly Magazine in Nov 2020 [41].

The voter picking works as follows. The eVoting contract divides the voting time during a given voting day into randomly selected time intervals. During each voting interval, the eVoting contract selects a number of randomly selected voters to cast their votes during the given time interval. The eVoting contract sends a message to the selected voters to inform them that it is their time to cast their vote within the given time period. The idea behind this operation is to disguise the voting process for each voter by obfuscating his or her own voting time by sending a message to his or her phone number.

We generate a pseudo-random number in the smart contract using the keccak256 algorithm [36]. We pass several parameters to the algorithm, namely block difficulty, and block time, the array of voters, and a counter. The pick voter process is limited to the government smart contract only. A transaction triggers each period to create a new list of eligible voters who can vote during that period. Only the addresses generated by the picking voter operation can vote. In terms of security, this operation will increase and improve security.

This implementation makes difficult for those who would use dirty money buy the voting decision of a voter; a dirty money user would not know the time at which a voter casts his/her vote, and thus may not be able to observe the voting decision of a voter. The assumption is that dirty money user would pay a given sum of money to a voter only if there is a physical proof that the voter actually casts his/her vote in favor of the paying candidate. More logistical constraints need to be deployed with the mobile application used for the vote cast; however, this part of the system is beyond the scope of this research.

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g. Voting

In the voting process, a voter by default can access only his/her voting district. The voter must first select one of the menus in the district and cast the vote to the menu; then they can vote for one or more from the list of candidates in the menu.

- Voting to menu: The voter uses Ethereum tokens (Ethers), which have been allocated by the government smart contract for voters based on the number of menus and the number of candidates within each menu. The voter may cast his/her vote to one and only one menu. Then he/she can vote to one or more candidates within the selected menu.
- Voting to candidates: After voting for a particular menu, the voter can only vote for the candidates within the same menu he/she selected. The process of voting for candidates is carried out using tokens as well. The voter has the choice to vote for all candidates or to vote for specific candidates in the menu. If the voter has not voted for all candidates, the remaining tokens in the voter wallet are sent back to the government wallet via the smart contract; this is necessary to guarantee the integrity of the election. As we explained earlier, each token sent from the voter transaction to a specific candidate represents one vote, and the candidate's vote counter is incremented by one. In the candidate voting transaction, the voter sends the candidate IDs and if they do not want to vote for a specific candidate, they must pass a null number as an alternative to the candidate ID.

h. Publishing the results

The results are tallied with the eVoting Smart Contract. The contract reveals the results for each menu and each candidate publicly finalized on the election portal. Each candidate can check their wallet during or after the election process to know the number of votes they received. The candidate receive tokens equal to the number of votes he/she received; the system must verify this case as a proof of the correctness of the election process.

As we mentioned previously, our proposed system uses a meta-transaction wallet called Metamask [34]. Metamask is a Chrome/browser extension that allows people to interact with the Ethereum network. We use the accounts/addresses provided by the Metamask wallet to interact with our smart contract, e.g. for sending tokens and other types of transactions. In order to connect to the Rinkeby test network, we use the Infura [36] service. Infura is registered public API that allows developers to easily access Ethereum network nodes.

4 Results and Discussions

The experiments created for this research rely on the data from the latest 2021 parliamentary elections in Jordan. There is a total of 4,640,643 voters distributed over 23 districts. The total number of electoral menus is 294 with a total of 1674 candidates. In the experiments, we tested the function used for adding voters from a file and found the optimal number of voters to include in a file such that a transaction can successfully add them to the blockchain in a reasonable time. Also, we tested the pick voters' method and found the optimal number of voters that the manager can pick using one transaction every 5 minutes. The pick

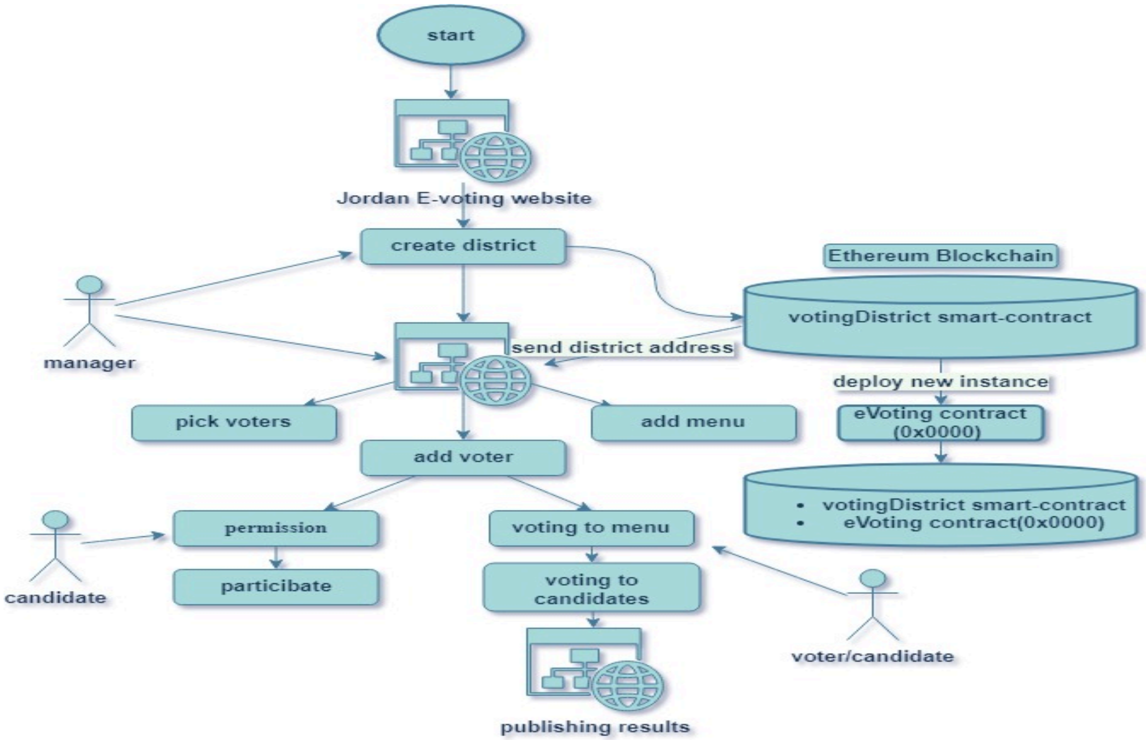

Fig. 2: The main voting steps in the Ethereum Blockchain E-Voting System (EBVS).

voter method is an algorithm designed to minimize or eliminate the political-dirty money/ coercion voting, where candidates try to buy voters' vote. Candidates quite often, when trying to buy the vote of a voter, monitor (physically) the voter while casting his/her vote. To eliminate this fraudulent case, we implement "Pick Voter Algorithm", which randomly selects voters to vote at a randomly selected time. In this case, it becomes difficult for a candidate or his assistants to know the exact time, when a voter is able to cast a vote, thus making the physical monitoring of the voter action difficult.

In this paper, we take into account the gas consumed and the time it takes for each transaction, in addition to the overhead associated with the implementation of the EBVS system. Due to the fluctuations in the Ethereum gas price, we set it to 1.00000001 Gwei in our experiments (Gwei is a subunit of ether equals to 0000000001 ETH "10^{-9} ETH"). We also estimated the transaction costs depending on the Ether price as of April 2022, which is around 3,000 USD for an Ether [39].

4.1. Adding voters

Adding voters to the voting system can be done either by adding voters one by one at the time of registering a voter, or by adding the voters directly from a file (JSON file), after finalizing the voters registration.

a. Gas consumed

We compare the gas consumed using both methods of voter adding (one by one or uploading the voters file). The transaction of adding the voters one by one consumed 181,905 gas units in 19.3 seconds. For the case of adding voter files, we split voters into several files, while trying to add as many voters as possible per file. taking into consideration that the transaction does not exceed the gas limit. We use a JSON file consisting of the voters' names, addresses, and IDs. The Ethereum blockchain has set the gas limit at around 30,000,000 gas units since 2021 [16]. We used files size, which contain 10, 50, 100, 150, 200, 230, 238, 239, and 240 voters. Each file can be uploaded using one transaction.

The transaction failed to complete for the file with 240 voters, because it exceeded the available gas limit. We fond that the maximum number of voters, which can be uploaded in one transaction is 239 voters, but it also takes a lot of time to be mined (several hours). The experiments show that when the number of voters exceeds 200 voters, the transactions begin to take a longer time to be mined. Our finding shows that it takes a relatively large time to successfully mine the transaction as it approaches the gas limit. In the meantime, adding all the voters by file(s) uses less gas than adding voters one-by-one. Figure 3 illustrates the gas consumed by adding voters' transaction in Gwei, Figure 4 illustrates a gas comparison between adding the voter one by one transaction and adding the voters by file transaction. From figure 4, adding voters by single transaction consumes ay least 30% more gas than adding voters by file(s).

b. The cost

To find the best number of voters to include in a single file, we first excluded the smaller files (10 and 50 voters) because the number of transactions will increase without any benefit. We also excluded the files with 238 and

239 voters because the transactions approach the gas limit and consume lots of time. We only included in the final experiments the files with 100, 150, and 200 and 230 voters. Therefore, in order to get the best number of voters in the file in addition to the best cost and reasonable mining time, we choose the file with 230 voters.

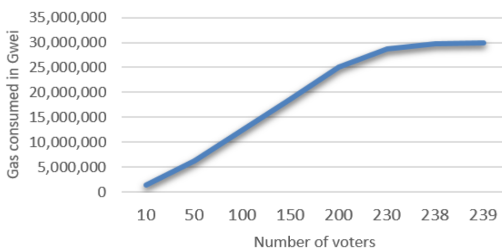

Fig. 3: The amount of gas used in the add file experiments.

Ethereum Blockchain performs around 1 million and 100 thousand transactions per day worldwide [37]. To apply the add-voters-file containing 230 voters to all 4,640,643 Jordanian eligible voters, we need 20,177 transactions , which need to be completed in one day. To be able to complete all 20,177 transactions in one day. we use parallelism in blockchain by increasing the number of mangers related to each district.

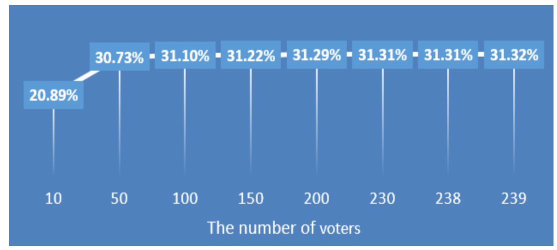

Fig. 4: Gas consumed comparison between adding single voter and add voters by file transactions.

4.2 The Pick Voters Transaction

As mentioned earlier, the EBVS system uses the pick voters' method as a way to protect the privacy of voters and to prevent coercion voting. In order to increase the efficiency of the pick-voters method and make it applicable, the method is configured to select a large number of voters per transaction in order to optimize the cost of picking voter transaction.

b. Gas consumed

Figure 5 shows the cost of "picking voters" in number of ethers using multiple transactions versus one transaction, where it shows that using single transactions costs less than the multiple transactions method. It should be noted, however that when the number of voters picked in a single transaction exceeds 220, the cost begins to increase significantly. Figure 6 illustrates the amount of gas consumed when multiple voters are picked in a single transaction.

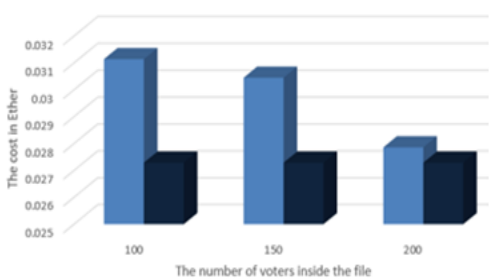

Fig. 5: Cost comparison between picking voters using multiple transactions and a single one.

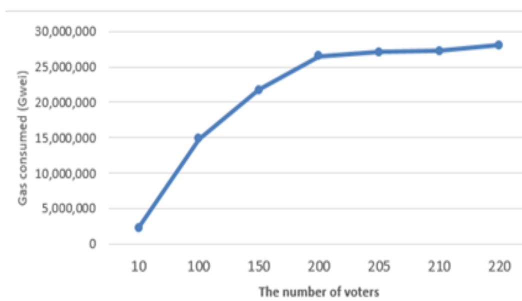

Fig. 6: The amount of gas consumed in the pick voters.

a. The cost of running election in Jordan Parliament

The traditional parliament election in Jordan lasts about 12 hours with 4,640,643 million eligible voters. Picking 210 voters at each (X) time interval (5 minutes for example), the voting process using sequential blockchain mining methods, given the current gas limit in Ethereum network, the election process may require several days to complete, which is unreasonable. In order to improve the performance of the EBVS using Ethereum blockchain technology, we tested the system using a novel structure, which exploits parallelism in blockchain mining. Figure 7 shows that with 7 parallel managers, 4.5 million voters (Jordan electoral size) can finish the voting process in 12 hours.

Fig. 7: The number of voters picked by different number of managers.

4.3. The Cost of EBVS Compared to Traditional Election

Conducting the elections with the Ethereum blockchain can be cheaper than traditional elections. We estimated the cost of EBVS voting system using the Rinkeby Ethereum test network and the Metamask wallet.We calculate the gas consumption of each transaction in EBVS voting system for both preparation and voting phases. The cost is further estimated in US dollars, at the current (April 2022) price. Figure 8 illustrates the cost of the preparation stage transactions and Figure 9 illustrates the cost of the voting stage transactions.

The total cost of the EBVS system is approximately $4 million, which is less than 13% of the current manual election process in Jordan, estimated at $32 million [38].

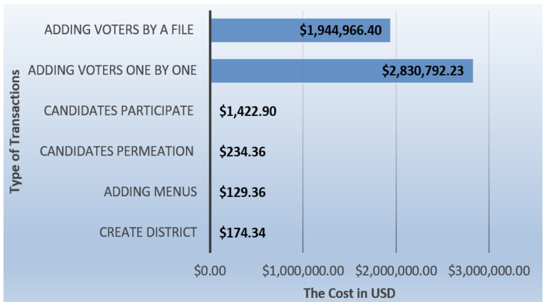

Fig. 8: The Cost in USD of preparation stage transactions.

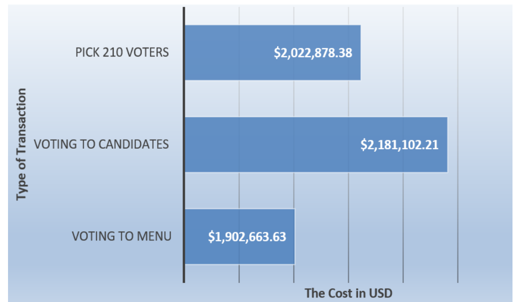

Fig. 9: The Cost in USD of voting stage transactions.

5 Conclusions and Future Work

This paper presented an electronic voting system built upon the Ethereum blockchain technology (EBVS) to take advantage of blockchain features, specifically decentralization on the Ethereum public blockchain. The EBVS was designed to meet the requirements of the Jordanian parliament election, overcome challenges and close loopholes in the traditional and electronic voting systems and also some other voting systems based on blockchain networks.

The EBVS system was conducted and validated with a set of experiments implemented with Ethereum application on top of the Rinkeby test network and Metamask wallet. We tested several implementations including adding voters one by one and adding voters in bulk files with different sizes. We also tested the pick voter method with different numbers of voters picked every 5 minutes. To evaluate othe EBVS model, we used several performance indexes such as the consumed gas, the cost of Ethers at current Ethereum prices, and the time required to complete the voting process. At current maximum gas limit, the results showed that using EBVS technology may require several days to complete in a small country like Jordan. This research provided a new parallel method aimed at improving the overall performance of the system, where we used multiple parallel managers to perform the election process. The number of parallel managers depends on the election time limit set by a certain country. In the case of Jordan's election, 7 parallel managers are sufficient to complete the elections in 12 hours.

The researchers propose to conduct more research in order to fully exploit parallelism in Ethereum blockchain technology

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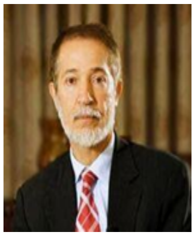

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