A Smart Contract and IPFS-based Framework for Secure Electric Vehicles Synchronization at Charging Station

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Abstract

The growth of electric vehicles (EVs) at a significant pace is a promising solution for reducing harmful greenhouse gas emissions compared to conventional vehicles. Nevertheless, optimal and efficient EV charging management is a serious concern that needs to be solved for the benefit of both charging stations (CSs) and EVs. In this regard, we proposed a smart contract and Interplanetary File System (IPFS)-based secure EVs synchronization framework at the CS utilizing a 5G wireless network. Blockchain technology strengthens the security of the EV charging at the CS in a synchronized and coordinated manner. The IPFS and 5G wireless network ensure efficient and reliable EVs synchronization to charge vehicles from the available number of charging points (CPs) at a CS. Furthermore, we have coordinated and synchronized the EV charging, considering various scenarios based on the waiting queue time, energy demand, and EVs (they can arrive in an emergency). We have shown the implementation interface of the proposed model based on the execution of a smart contract using the Remix Integrated Development Environment (IDE). Moreover, we have performed the security analysis of the smart contract using Echidna fuzzing-based tool to ensure the secure EVs allocation to the corresponding CS. Finally, the performance analysis of the IPFS and smart-based proposed model is evaluated and simulated considering various metrics such as transaction storage cost analysis,

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computational overhead analysis, utilized cost based on the smart contract functions, and the number of EVs.

Keywords: Electric Vehicles, Charging Stations, Charging Synchronization, IPFS, Blockchain

1. Introduction

Over the past decade, the proliferation of electric vehicles (EVs) has replaced fossil-fuel or gasoline vehicles on the road. The surge in EVs is due to the depreciation of various non-renewable energy resources such as solar, wind, and thermal energy. Moreover, EVs have surpassed gasoline vehicles due to various benefits, such as high efficiency, usage of a clean form of energy, low energy consumption, and low charging cost. But, with EV penetration in the energy market, it is critical to allocate EVs optimally to the charging stations (CSs) as they are challenging to deploy and install due to the high operational and maintenance costs. To solve the issue of EV charging having enormous energy demand arriving at the CS, many researchers across the globe have presented various works to allocate CSs to EVs effectively. For instance, Zhang *et al.* [1] presented a CS planning model while considering the EV charging queue. They have mainly focused on facilitating the waiting queue time of EVs to utilize the CS effectively. However, they did not consider the scenario of the arrival of a huge number of EVs, which can cause congestion at the CS.

Thus, to resolve the congestion issues of CS, Son *et al.* [2] discussed game theory-based EVs allocation at the CS considering the case in which many EVs want to charge at a particular time. Next, Zhang *et al.* [3] proposed a non-cooperative game theory-enabled charging system with power grid-equipped CSs for EV charging. The system proposed by the aforementioned researchers focuses on assigning energy demand to all the vehicles, even in the case of limited energy available at the CS. Later, Qarebagh *et al.* [4] presented a meta-heuristic algorithm for optimally scheduling EVs and solving the position-assigning problem arising at the CSs. The aforementioned solutions provided by the researchers can allocate charging efficiently for EVs. Still, they can be exposed to various security attacks due to the involvement of centralized authority during the communication between EVs and CS. To deal with the security and privacy issues arising during the data communication between EV and CS at a cloud server, many researchers have proposed blockchain-based solutions to allocate the EV at the CS to accomplish the security in the system [5] [6] [7]. For example, Khaki *et al.* [8] presented a hierarchical distributed scheduling algorithm for EVs. They have formulated a consensus-based iterative procedure embedded with battery energy storage to reduce the electricity cost for charging. Then, the authors of [9] have focused on reducing the risk of data loss and manipulation to maintain the efficient working of the energy sector by designing a Proof-of-Stake-based consensus algorithm. Then, Wang *et al.* [10] presented a smart contract-based EV charging system to schedule EVs to fulfill their charging demand optimally, further optimizing the charging operator's utility. They have designed a delegated Byzantine fault tolerance consensus algorithm to achieve the consensus between entities in the permissioned blockchain. Despite achieving the consensus during EV charging at the CS, the authors did not consider real-time coordination for EV charging. Towards this goal, Liu *et al.* [11] designed a real-time scheduling algorithm for energy storage systems and EVs to safely operate the distribution network. For that, a Grey Wolf Optimizer algorithm is utilized for the charging and discharging of EV and energy storage system.

As per the literature, the researchers have incorporated blockchain technology in their research work to secure the coordination between EVs and CS. However, they did not consider all the possible scenarios based on Ev's huge energy demand and waiting queue time which can delay the EV charging at the CS. Thus, using blockchain technology, we proposed an Interplanetary File System (IPFS) and smart contract-based framework for secure EVs synchronization at CS. We have formulated various synchronization scenarios to allocate the EV from the available number of charging points (CPs) at a CS based on various parameters such as EVs, type of EVs, waiting queue time, and energy demand. Additionally, IPFS and blockchain-enabled framework provides secure and cost-efficient coordination between EV and CS using a 5G wireless network of high availability, reliability, and data rate.

1.1. Motivation

The existing EV coordination schemes mainly emphasized securing the communication between EV and CS for efficient charging using blockchain technology. But, they did not discuss various aspects of reliable EV charging, such as data storage cost, computational overhead, transaction, and execution cost, which can occur due to the consideration of a high-cost data storage platform. For example, the authors of [12] proposed a blockchain-based mechanism to perform secure and transparent data transactions for

EV charging while ignoring the scalability, high storage cost, and efficiency issues associated with the blockchain. Some of the authors [13] [14] have considered the system's high storage cost and scalability issues by discussing the blockchain-based smart and trustable EV charging architecture. Still, none of the mechanisms can handle the coordination of the arrival of more EVs for charging at the CS, further increasing the waiting time for EVs, making it inefficient for them. Thus, motivated by the aforementioned issues, we have proposed a smart contract and IPFS-based cost-efficient framework for EVs synchronization at the CS considering various scenarios based on the arrival of EVs (emergency or not). Integrating IPFS with the blockchain yields cost-efficient and reliable data communication between EV and CS.

1.2. Research Contributions

Following are the research contributions of this paper.

- This paper proposes a smart contract and IPFS-based framework for secure EVs synchronization at the CS. The employed blockchain technology ensures the secure synchronization of approaching EVs for charging due to its immutable and transparent characteristics

- We have formulated various synchronization scenarios for efficient and coordinated EV charging based on the parameters such as waiting queue time, EVs, and energy demand considering the case of the arrival of emergency EV or not for charging.

- The blockchain and IPFS-enabled secure and cost-efficient framework is proposed to facilitate the secure and reliable energy data storage associated with the EV and CS.

- The security analysis of the smart contract of the proposed model is performed and evaluated using the Echidna security tool to enable the confidential EV allocation to the CS considering the functionalities of the smart contract.

- The performance evaluation of the smart contract and IPFS-based proposed model is analyzed by deploying the smart contract in Remix Integrated Development Environment (IDE) considering the metrics such as transaction storage cost analysis, computational overhead analysis, utilized cost based on the smart contract functions and number of EVs.

1.3. Organization of the Paper

The rest of the paper is organized as follows. Section II represents the related works and Section III presents the system model and problem formulation of the proposed model. Section IV highlights the detailed proposed model. Then, Section V discusses the performance evaluation and simulation of the proposed model. Finally, the paper is concluded with future work in Section VI.

2. Related Works

Many researchers have extensively discussed the secure and efficient EV charging coordination schemes at the CS. For instance, Miyahara *et al.* [15] discussed an EV charging prioritization framework for the commercial area to enable controlled and efficient charging. Still, they did not focus on the computational overhead issues along with the CS constraint. To improve the computational capability of EV charging, authors of [16] investigated a contract and fog computing-based protocol for secure EV charging, but they have not considered the issues of high transaction and computational cost due to the data processing at the fog networking. Nevertheless, the aforementioned EV charging schemes are susceptible to various security and privacy issues due to the usage of a centralized data storage platform. In this context, Lin *et al.* [17] presented a consensus-based framework for an EV charging system so that EVs can achieve the optimal charging scheduling at the CS. Next, Wang *et al.* [18] proposed a decentralized energy demand allocation mechanism for EVs in the charging network. Further, they have implemented the consensus mechanism to provide robust power allocation without any delays and loss of packets for EV charging. But, there is no focus on improving security, cost-efficiency, high communication, and computation overhead, which can occur due to the applied consensus mechanism.

Considering the security aspect during EV charging, Xue *et al.* [19] presented an energy trading architecture for EVs charging through the smart grid with blockchain. The proposed system helps to maintain system stability during the transmission and energy distribution between EVs and the smart grid. Moreover, Their proposed system efficiently achieves non-tampered transactions for the benefit of users. However, they did not consider the reliability and network scalability issues that can deteriorate the system's performance. To resolve the aforementioned issues, Abishu *et al.* [20] proposed a Practical Byzantine Fault Tolerance-enabled Vehicle-to-Vehicle (V2V) energy trading system using Proof of Reputation (PoR) algorithm. The main focus of the proposed system is to reduce the transaction delay, which further yields the improved throughput of the system. Still, they need to improve the security and privacy of the V2V energy trading system to prevent leakage of EV's confidential information. To improve the security of EV energy trading, the authors in [21] investigated a blockchain-based EV energy trading automatic payment system to accomplish secure, preserve, and transparent data transactions during charging.

Similarly, Guo *et al.* discussed a blockchain-based EV charging transaction model for multi-charging operators. They have focused on achieving high transparency, efficiency, and stabilized operations during EV charging. The authors have incorporated a blockchain-based secure and immutable data storage platform for confidential EV charging and coordination at the CS. Still, most have not considered the data storage cost, computational overhead, and transaction cost required to allocate EVs at a CS. Moreover, none of the authors have considered multiple scenarios in which EVs can be coordinated at the CS for efficient charging. Thus, we have proposed a smart contract and IPFS-based framework for secure EVs synchronization at the CS considering the aspect of cost-efficiency, utilized cost (in terms of gas consumption, transaction cost, and execution cost), and security. Towards this goal, Table 1 shows the comparative analysis of various state-of-the-art EV charging schemes with the proposed model for allocating EVs at the CS efficiently.

3. System Model and Problem Formulation

This section focuses on the system model and problem formulation of the proposed model for EVs charging synchronization, which is mentioned as follows:

3.1. System Model

We have proposed a smart contract η and IPFS-based public ledger framework to secure the EVs synchronization at CS. The proposed model comprises EVs ψ along with their energy demand (based on the available energy) approaching the CS Ω, which consists of the number of charging points (CPs) ω to get the charging based on their traveling destination. The energy demand

Table 1: Comparative analysis of various state-of-the-art EV charging schemes with the proposed model.

Author	**Year**	**Purpose**	**Pros**	**Cons**
Chanthong *et al.* [22]	2020	Blockchain and smart contract-enabled electronic payment system for EV charging	Controlled and secure charging	Need to perform real-time implementation, high transaction time and data storage cost
Okwuibe *et al.* [13]	2020	Blockchain-based smart and flexible EV charging infrastructure	Cost-effective and high acceptance rate	Real-time implementation for more EVs is not discussed
Miyahara *et al.* [15]	2020	EV charging prioritization framework in the commercial area	Controlled charging and improved SoC	No consideration of CS constraint, security, and computational overhead issues
He *et al.* [14]	2021	EV trusted architecture for shared charging using blockchain	Secure data storage and incentives	No discussion on coordinated, preserve, and transparent pricing
Khan *et al.* [21]	2021	Blockchain-based EV energy trading and automatic payment system	Improved latency, privacy, throughput, and transparency	Optimal routes and cryptocurrency should be discussed
Khoumsi *et al.* [12]	2021	Blockchain and cryptocurrency-based mechanism for EV charging architecture	Secure, immutable, and transparent transactions	Scalability, storage cost, and efficiency is not achieved
Xu *et al.* [23]	2021	Anonymous system for secure connected EVs charging	Strengthened anonymity, authenticity, and security	Real-time implementation with dynamic scenarios is not considered
Guo *et al.* [24]	2022	Blockchain-based EV charging transaction model for multi charging operators	High transparency, efficient, and stable operations	Computational and communication overhead is not discussed
Wei *et al.* [16]	2022	Contract and fog computing-based protocol for EV charging	Reduced computation capability, feasibility, improved service latency, and convergent	No analysis on the transaction and computational cost
The proposed model	2023	A smart contract and IPFS-based framework for secure EVs synchronization at CS	Secure, reliable, and cost-efficient	-

is determined with the available energy of the EVs measured by the smart meter, which is assigned to each EV involved in the synchronization procedure between entities, i.e., EVs ψ and CS Ω. Moreover, we need to synchronize the Evs at the CS based on the energy demand, EVs (in an emergency), and waiting queue time τ_w^{ψ}, for which we have considered a waiting queue that can be assigned to the EVs based on their type. For example, if an emergency EV arrives at the CS, priority is assigned to that particular vehicle for charging, and EV(already at the CS) has to return to the waiting queue. In another scenario of EVs entering the CS with the τ_w^{ψ} ($> threshold$), they can get their vehicle charged first when there is no emergency vehicle.

Moreover, the main focus of the proposed model is to secure the EVs synchronization at the CS, which can be achieved by utilizing blockchain as a public ledger technology and IPFS. Before getting insights into the blockchain introduced for secure data communication, the data associated with the entities should be verified by the charging admin for storing it efficiently and securely in the blockchain using IPFS. Once the charging admin verifies the data, the smart contract can check if the received data contains authorized information about the entities. Then, based on the authorization performed by the smart contract, the data can be stored in the blockchain through a cost-efficient IPFS content-addressing protocol.

3.2. Problem Formulation

The smart contract and IPFS-based public ledger proposed model encompasses e EVs $\{\psi_1, \psi_2, \ldots, \psi_e\} \in \psi_E$ approaching the CS to charge their vehicle from the available p number of CPs $\{\omega_1, \omega_2, \ldots, \omega_p\} \in \omega_P \in \Omega$ in a secure and reliable environment. Now, Evs associated with the available energy (which can be used to define energy demand) detected by the smart meter χ embedded within the EVs arrive at the CS to get the charging services. Further, we need to perform the synchronization between EV ψ and CS Ω based on the EVs, emergency EV ψ^{ϵ}), energy demand κ^{ψ}, and waiting queue time τ_w^{ψ}. The communication between EV ψ and CS Ω based on their associated data is mentioned as follows:

$$\psi_{\epsilon} \rightarrow \{\psi_1, \psi_2, \ldots, \psi_e\} \tag{1}$$

$$\sum_{E=1}^{e'} \psi_E^{e, \psi^{\epsilon}, \kappa^{\psi}, \tau_w^{\psi}} \xrightarrow{k} \sum_{P=1}^{p'} \Omega^{\omega^P} \tag{2}$$

$$\sum_{P=1}^{p'} \Omega^{\omega^P} \xrightarrow{l} \sum_{E=1}^{e'} \psi_E^{e,\psi^\epsilon,\kappa^\psi,\tau_w^\psi} \tag{3}$$

where k and l signify the communication between EV ψ and CS Ω for secure synchronization between them. Now, we can discuss the energy demand of EVs, which can vary based on the day (weekday ζ or weekend ζ') and time (morning υ, afternoon Υ, evening ι, and night α). The energy demand tends to be high in the case of weekdays during the morning ($\upsilon \in$ [8 AM, 11 AM]) and evening time ($\iota \in$ [5 PM, 8 PM]). Next, if we consider the weekend scenario, then energy demand is high during the afternoon ($\Upsilon \in$ [1 PM, 5 PM]) and night ($\alpha \in$ [9 PM, 11 PM]. So, we can express the above-mentioned associations of the high energy demand of EVs based on the day and time, which is mentioned as follows:

$$\kappa^{\psi_E^{e,\psi^\epsilon,\kappa^\psi,\tau_w^\psi}} = \begin{cases} \zeta^{\upsilon,\iota} & \text{if weekday} \\ \zeta'^{\Upsilon,\alpha} & \text{if weekend} \end{cases} \tag{4}$$

Next, the EV ψ and CS Ω energy data can be authorized and confirmed by the charging admin Θ based on the issued request of the entities. So, we can explain the communication of charging admin Θ with EV ψ and CS Ω for authenticating the data, which is represented as follows:

$$\sum_{E=1}^{e'} \psi_E^{e,\psi^\epsilon,\kappa^\psi,\tau_w^\psi} \rightarrow \Theta \tag{5}$$

$$\sum_{P=1}^{p'} \Omega^{\omega^P} \rightarrow \Theta \tag{6}$$

Furthermore, energy data associated with the EV ψ and CS Ω can be securely stored in the IPFS so that synchronization between the entities can be performed reliably and securely through a blockchain network. To ensure secure data transactions between entities, smart contracts, as a self-executing program, run based on the fulfillment of the predetermined conditions to check and verify the authenticity of energy data that needs to be stored in the IPFS. Suppose energy data is found to be authenticated by the smart contract to maintain anonymity in the system. In that case, it can be stored in cost-efficient and reliable IPFS. Now, energy data get the authority from

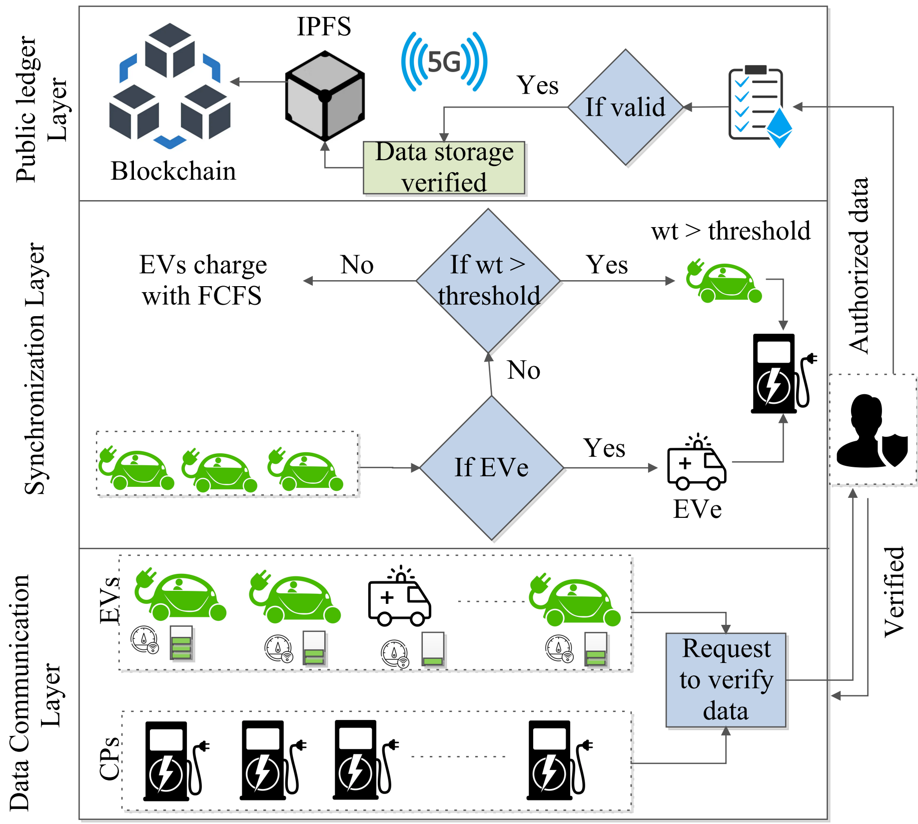


Figure 1: The proposed model.

smart contract to get their data stored in the IPFS, and it returns the favor to the entities by facilitating them with the hash keys $(\delta^{\psi_E}, \Delta^{\Omega^{\omega^P}})$ for EV ψ and CS Ω. The aforementioned association is represented as follows:

$$\{\sum_{E=1}^{e'} \psi_E, \sum_{P=1}^{p'} \Omega^{\omega^P}\} = \{\delta^{\psi_E}, \Delta^{\Omega^{\omega^P}}\} \tag{7}$$

Finally, the energy data stored securely in the IPFS can be considered to perform the data transactions required for synchronization procedure between entities with the help of a public ledger, i.e., a blockchain network using a 5G wireless network of high availability and reliability.

4. Proposed Model

Figure 1 shows the smart contract and IPFS-based model for secure EVs synchronization, which is bifurcated into three layers, i.e., Data Communication Layer, Synchronization Layer, and Public Ledger Layer.

4.1. Data Communication Layer

The foremost layer in the proposed model is the data communication layer which consists of all the data corresponding to the EV ψ and CS Ω. The EV users contain information such as EVs, type of EVs (emergency ψ^{ϵ}), energy demand κ^{ψ}, and waiting queue time τ_w^{ψ}. Moreover, CS is also associated with data, i.e., the number of charging points CPs at the station, delivery rate d_r of the station β, per unit price for charging P_u, total vehicles registered p_{ψ}, total emergency vehicles registered $p_{\psi_{\epsilon}}$, and the threshold demand considered for bifurcation of less energy demand vehicles and high energy demand vehicles. It means we have considered less energy queue $\kappa^{\psi_q^{'}}$ and high energy demand queue $\kappa^{\psi_q^{''}}$ to bifurcate EVs based on the energy demand less than or greater than the threshold. The data entered by the EV ψ and CS Ω is checked and verified by the charging admin in this layer itself. The charging admin authorizes the data, which is further used in the subsequent layer to facilitate the EV ψ and CS Ω with effective and synchronized charging using IPFS and blockchain. The aforementioned associations is represented as follows:

$$\psi = \{\psi^{\epsilon}, \kappa^{\psi}, \tau_w^{\psi}\} \tag{8}$$

$$\Omega = \{\omega, p, \beta, P_u, p_{\psi}, p_{\psi_{\epsilon}}\} \tag{9}$$

$$\kappa^{\psi_q} = \begin{cases} \kappa^{\psi_q^{'}} & \text{if less than threshold} \\ \kappa^{\psi_q^{''}} & \text{if greater than threshold} \end{cases} \tag{10}$$

Further, the energy data of EV ψ and CS Ω can be considered to synchronize the charging efficiently which is discussed in the synchronization layer.

4.2. Synchronization Layer

The second layer is the essential layer to execute the proposed model efficiently to synchronize EV ψ and CS Ω. The main focus of the synchronization layer is to optimally schedule the EVs approaching the CS to complete their energy demands. Firstly, EV ψ and CS Ω are registered by the charging

Algorithm 1 Secure and optimal EV synchronization algorithm.

Input: $d_r, \kappa^{\psi_{Td}}, \tau_w^{\psi_{Td}}$
Initialization: e=0, k,j,count
procedure $Synchronization\_EV\_CS(\psi, \omega, \Omega)$
  if $(e <= p)$ **then**
    Directly assign to CP
  else if $(\kappa^{\psi} >= \kappa^{\psi_{Td}})$ **then**
    $\kappa^{\psi_q''}.push(\kappa^{\psi})$
    $\tau_c^{\psi}.push(\kappa^{\psi}\ d_r)$
    $\tau_w^{\psi}.push(\tau_c^{\psi}[prior_e v] + \tau_e^{\psi})$
    for $j = 0, 1, \ldots, \kappa^{\psi_q''}.length$ **do**
      if $(is_{emrgncy}[j] == true)$ **then**
        assign CP to emergency vehicles first
      else if $(\tau_w^{\psi}[j] >= \tau_{w_{Td}}^{\psi})$ **then**
        assign CP first
      end if
    end for
    if $(\tau_{w_{Td}}^{\psi} >= \kappa^{\psi}/d_r)$ **then**
      assign CP to EVs on the basis of FCFS
    else
      count = κ^{ψ}/d_r
      while $count > \tau_{w_{Td}}^{\psi}$ **do**
        count–
        $\kappa^{\psi_q''}[j] = \kappa^{\psi_q''}[j] - d_r$
      end while
    end if
  else
    $\kappa^{\psi_q'}.push(\kappa^{\psi})$
    for $k = 0, 1, \ldots, \kappa^{\psi_q'}.length$ **do**
      if $(\tau_w^{\psi}[k] >= \tau_{w_{Td}}^{\psi} || is_{emrgncy} == true)$ **then**
        CP assign first to emergency and high waiting queue time EV
      else
        assign CP to less demand EVs in FCFS order
      end if
    end for
  end if
end procedure

admin so that effective and efficient transactions can be performed to synchronize the charging procedure securely. Now, EVs can be bifurcated based on their type, i.e., a normal or an emergency EV. The charging admin can check whether the registered EV falls under the category of emergency or not. Furthermore, we have synchronized the EV charging at the CS based on various parameters such as the EVs, energy demand of EVs, and waiting queue time τ_w^{ψ}. Algorithm 1 shows the optimal EV synchronization procedure to coordinate and allocate them to the CPs at a CS in terms of time complexity, i.e., O(e). In scenario 1, if the EVs are found to be less than the number of CPs, they are allocated directly to the charging points. But, considering scenario 2, if the EVs approaching the CS are greater than the CPs, then the EVs are assigned to the normal energy demand queue or less energy demand queue based on their energy demands. The bifurcation is done by comparing the energy demand of EVs with the threshold demand. If the demand associated with the EV is less than the threshold, then they are added to the less energy demand queue (case 1); otherwise, EVs with energy demand greater than the threshold can be added to the normal energy demand queue (case 2).

Considering case 1 of scenario 2 in which EVs are allocated to the less energy demand queue, they are directly allocated to the CP at a CS based on the First Come First Serve (FCFS) algorithm considering the timestamp of EVs $(\lambda_{\psi_1}, \lambda_{\psi_2}, \ldots, \ldots, \lambda_{\psi_e})$. Next, case 2 of scenario 2 allocates EVs of energy demand greater than the threshold in the normal energy demand queue in which we have calculated their waiting queue time τ_w^{ψ} with the help of entry time τ_e^{ψ} and the prior EVs charging time τ_c^{ψ} (which is calculated using prior EVs energy demand and the delivery rate offered by the CS). Therefore, case 1 and case 2 of scenario 2 to synchronize the charging for EVs at the CS are represented as follows:

$$\sum_{E=1}^{e'} \psi_E^{\{\lambda_{\psi_1}, \lambda_{\psi_2}, \ldots, \ldots, \lambda_{\psi_e}\}} \xrightarrow{\lambda_{\psi_e}, \kappa^{\psi_q'}} \sum_{P=1}^{p'} \Omega^{\omega^P} \tag{11}$$

$$\tau_w^{\psi} = \tau_e^{\psi_E} + \tau_c^{\psi_{E-1}} \tag{12}$$

where $\lambda_{\psi_e}, \kappa^{\psi_q'}$ signify the allocation of EVs of energy demand (less than the threshold value) present in the less energy queue $\kappa^{\psi_q'}$ according to the timestamp. After calculating the waiting queue time τ_w^{ψ} of EVs present in the normal energy demand queue, there can be various possibilities in case 2 of scenario 2; for example, if an EV approaching the CS is an emergency vehicle, then that vehicle needs to be allocated to the CP by preempting the prior EVs in the normal energy demand queue. But, if there is no emergency vehicle in the normal energy demand queue, EVs can be assigned to the CP considering the timestamp (FCFS algorithm). However, this case should be considered until the waiting queue time of all the EVs in the normal energy demand queue is less than the threshold waiting queue time.

$$\sum_{E=1}^{e'} \psi_\epsilon(\tau_w^\psi, \kappa^{\psi_q''}) \xrightarrow{\text{preempt prior EV}} \sum_{P=1}^{p'} \Omega^{\omega^P} \tag{13}$$

So, another possibility for case 2 of scenario 2 is if the waiting queue time of the EV exceeds the threshold waiting queue time, then that vehicle needs to be charged first, followed by the other vehicles in the queue (when there is no emergency vehicle). The vehicle that has a higher waiting queue time can preempt the other EVs and get the opportunity to charge first. So, in this case, that EV can be charged to the extent where the next EV's waiting queue time exceeds the threshold value. Then, the EV whose waiting queue time has exceeded gets the chance to charge completely. Lastly, when both the emergency vehicle and the EV with a waiting queue time greater than the threshold are encountered in the normal energy demand queue. In this case, the emergency vehicle is assigned priority for charging, preempting other vehicles in the normal energy demand queue. Next, the EV with a higher waiting queue time can apply for charging, followed by the other EVs in the FCFS order. Thus, synchronization layers coordinate the charging between entities, i.e., EV ψ and CS Ω, based on various parameters such as EV type, waiting queue time, and energy demand. But, we need to ensure data security corresponding to the entities that can be performed with the help of the public ledger layer by using blockchain and IPFS-based framework for the proposed model.

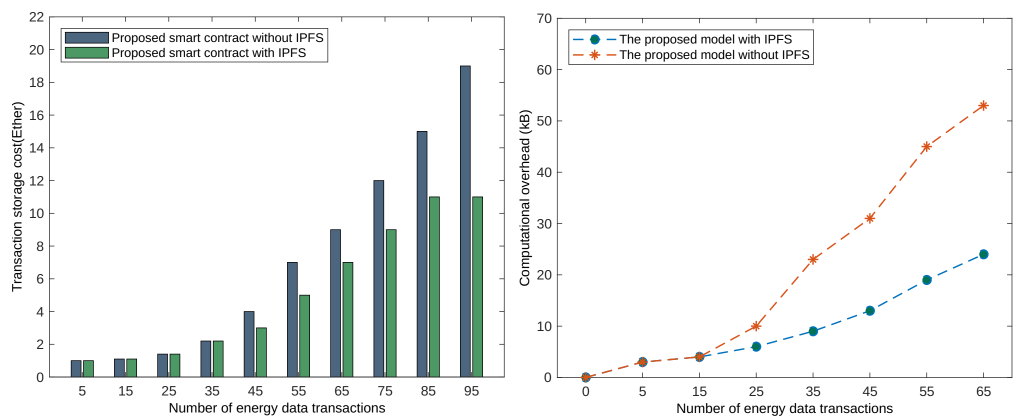
4.3. Public Ledger Layer

The public ledger layer is the final layer of the proposed model which comprises data transactions performed between EV ψ and CS Ω. Once the data transactions are authorized by the charging admin as discussed in the data communication layer, the authorized data can be stored in the blockchain with the help of the IPFS protocol. The information stored on the blockchain contains the energy demand of EVs, the price per unit for charging, waiting queue time, entry time, and charging time. Despite storing energy data directly in the blockchain as a public ledger network, IPFS is considered for data storage based on the verification performed by the execution of the self-executing program, i.e., a smart contract that ensures the data availability and reliability in the network by overcoming the high data storage cost issues of the blockchain. Then, blockchain as a secure and transparent platform can perform synchronized data transactions between EV ψ and CS Ω. Moreover, the employed 5G network reduces the latency issues, increases the bandwidth to a great extent and also possesses a higher capacity to upload data efficiently through the blockchain network.

5. Performance Evaluation

This section highlights the performance evaluation and experimental results of the proposed smart contract and IPFS-based public ledger model for secure EVs synchronization at the CS. The performance analysis of the proposed model is evaluated using Remix IDE (Integrated Development Environment), which works on an Ethereum blockchain to perform the data transactions securely and efficiently. Then, the synchronization between EV ψ and CS Ω is simulated in Python, considering scenarios formulated for EVs at the CS based on the EVs, energy demand, and waiting queue time.

5.1. Transaction storage cost analysis



(a) Transaction storage cost analysis.

(b) Computational overhead analysis.

Figure 2: Comparative analysis of transaction storage cost and computational overhead of the proposed model with IPFS and without IPFS

Figure 2a represents the comparative analysis of the proposed smart contract performed with IPFS and without IPFS to show the cost-efficient synchronization for the arriving EVs that can charge from the available number of CPs at a CS. It can be distinguished from the graph that the transaction storage cost of the implemented smart contract to accomplish the synchronization between entities yields improved and better results with IPFS than without IPFS. Moreover, it is quite clear from the figure that less energy data transactions don't make a massive difference in transaction storage cost with and without IPFS. But, the rise in the number of energy data transactions proves to provide cost-efficient results for the entities involved in the synchronization for energy data storage due to the usage of IPFS as it aims to store energy data efficiently and reliably (in the form of cryptographic hash) which makes it a cost-efficient data storage platform for EV ψ and CS Ω.

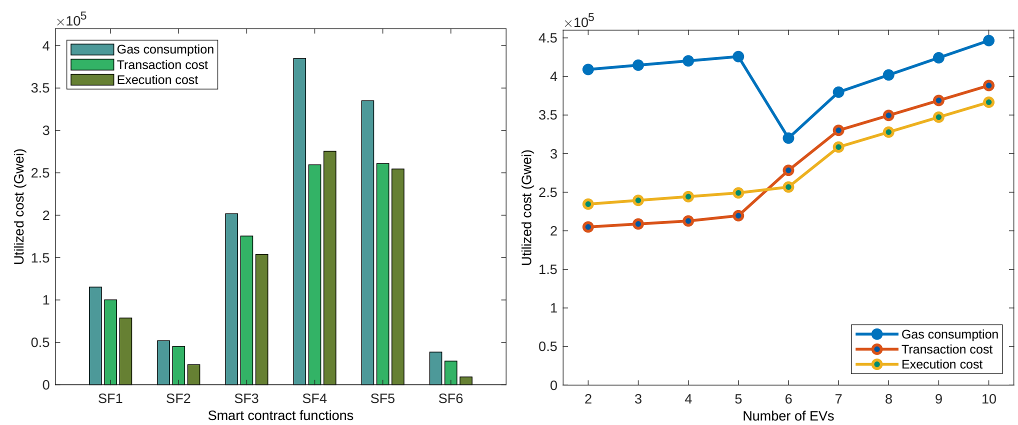
5.2. Computational overhead analysis

Figure 2b depicts the analysis of computational overhead performed for the proposed model with IPFS and without IPFS. The graph clearly shows that the proposed model can efficiently perform and process the energy data transactions with IPFS than without IPFS, yielding improved computation overhead for the proposed model with the IPFS. Moreover, less energy data transactions do not impact the computational overhead for the proposed model with IPFS and without IPFS and align at the same level for both cases. Although with the surge in the number of data transactions due to the arrival of more EVs at the CS for synchronization, usage of IPFS with blockchain proves to process data transactions more efficiently than without IPFS as blockchain with IPFS performs data transactions by generating the cryptographic hash, further improving the reliability and efficiency of the network.

5.3. Utilized Cost Analysis

We have contemplated and performed a comparative analysis of the utilized cost for implementing the smart contract of the proposed model in terms of gas consumption, transaction cost, and execution cost. Figure 3a depicts the analysis of the utilized cost of the implemented smart contract of the proposed model with the various smart contract functions acquired to allocate EVs to the CS based on the various scenarios where SF1 represents the function for registering the vehicle, SF2 denotes registration of an emergency vehicle, SF3 represents the creation of vehicle queue for arriving EVs, SF4 denotes function to complete the energy demand of EVs, SF5 signifies function to complete energy demand of emergency EVs, and SF6 function is to check whether a vehicle is in an emergency or not. Furthermore, it can be perceived from the graph that the F4 function that works to complete the energy demand of EVs yields higher gas consumption and execution cost than the other functions. On the other hand, the transaction cost of functions SF4 and SF5 does not have a substantial difference and it is also higher than the other functions due to their functionality to complete the energy demand of EVs with emergency or without emergency.

Figure 3b shows the comparison of the utilized cost, i.e., gas consumption, transaction cost, and execution cost, with the arriving number of EVs for the corresponding CP. Based on the arrival of less number of EVs, gas consumption of the smart contract is at a higher level than the transaction and execution cost. Moreover, with the arrival of more EVs, the utilized cost for gas, transaction, and execution increases exponentially due to the considered scenarios in which energy demand is completed based on the EVs type (emergency or not).



(a) Utilized cost for smart contract functions.

(b) Utilized cost for number of EVs.

Figure 3: Comparative analysis of Utilized cost for smart contract functions and number of EVs.

5.4. Proposed Model Implementation Interface

The smart contract and IPFS-based public ledger proposed model is implemented using Remix IDE considering the scenarios for secure synchronization between EV ψ and CS Ω for charging. Figure 4 depicts the functionalities considered while implementing the smart contract of the proposed model to show the synchronization between EV ψ and CS Ω in the blockchain network. The functionalities are represented along with their input parameters to show the functions used for the considered synchronization scenarios based

Figure 4: Proposed Model Implementation Interface over Remix IDE.

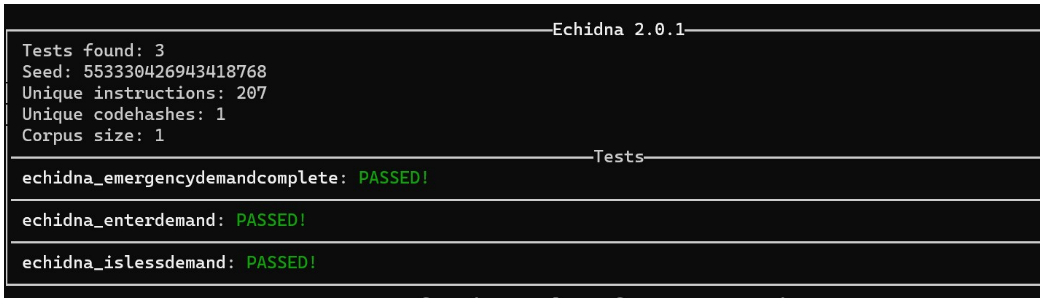


Figure 5: Echidna security analysis of the smart contract.

on the energy demand, EVs, and waiting queue time.

The *enterdemand* function is the foremost function in which EV users are required to enter their energy demand and unique identification string. Before that, normal and emergency EVs need to register and authenticate themselves with the *registerVehicle* and *registerEmergencyvehicle* function for allocation to the CP. Also, *isRegistered* and *isemergency* functions are considered to check whether the arrival EVs is registered or not based on their type. The bifurcation among less demand and high demand users is done through the above functionality and the users are promoted to the required queue based on the threshold energy demand. Further, *lessdemand* and *vehicledemandcomplete* functions are used by the less energy demand and high demand users to access the queue in order to get allocated to the CS based on synchronization. *emergencydemandcomplete* function is used by EVs registered as an emergency for availing CPs faster. Moreover, *vehicleCount* functionality provides total count of EVs approaching the CS so that they can keep track of the EVs to fulfill their energy demand in a day. The *chargingpoint* functionality is further used to enter the number of charging ports available at a particular CS. Thus, all the aforementioned functionalities of the smart contract implemented over Remix IDE synchronizes the EV charging at the CS efficiently.

5.5. Security analysis over Echidna

We have performed the security analysis of the smart contract of the proposed model using the Echidna security tool, which works on the principle of property-based fuzzing to detect the vulnerability or threat in the smart contract. Figure 5 shows the Echidna security analysis applied to the smart contract functionalities to allocate the EVs to a CS securely, which proves that it is not susceptible to any malicious attack or threat that further motivates EV x and CS Ω to involve in the allocation procedure with the improved confidentiality and transparency.

6. Conclusion

This paper proposes a smart contract and IPFS-based secure framework for EVs synchronization at the CS. The main aim of the proposed model is to secure data storage and synchronize EV charging utilizing the blockchain network. Moreover, the amalgamation of blockchain and IPFS facilitate protected and cost-efficient EV charginng to the corresponding CS. Further, we have discussed various synchronization scenarios to coordinate the EV charging based on the waiting queue time, EVs, and energy demand. Additionally, EVs in an emergency or waiting queue time greater than the threshold have assigned priority for charging their vehicles at the CS. The blockchain and IPFS-enabled secure EVs synchronization framework provides a secure, reliable, and available coordination EV charging utilizing the 5G wireless network. We have also implemented the smart contract of the proposed model to validate the functionalities involved in the EVs synchronization to show the implementation interface of the proposed model. Moreover, we have performed the security analysis of the smart contract of the proposed model over Echidna to prove the secure allocation of EVs to the corresponding CS. Finally, the performance evaluation of the smart contract and IPFS-enabled synchronization framework is simulated and evaluated against various performance metrics such as transaction storage cost analysis, computational overhead analysis, and utilized cost analysis based on the smart contract functions and number of EVs.

In the future, we will consider more real-time and dynamic scenarios to implement EVs synchronization to the corresponding CS to improve its applicability and reliability.

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