Scheduling Charging of Electric Vehicles in a Secured Manner using Blockchain Technology

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***Abstract*—In the proposed work, a Mobile charging Vehicle-to-Vehicle (M2V) charging strategy is introduced for an efficient charging of Electric Vehicles (EVs). It also covers the conventional Vehicle-to-Vehicle (V2V) and Grid-to-Vehicle (G2V) charging strategies. The charging of vehicles is done in a Peer-to-Peer (P2P) manner; vehicles charging from Charging Stations (CSs) or Mobile Vehicles (MVs) in the absence of a central entity. Blockchain technology is used to overcome the privacy issues. Further, it promotes transparency, trustworthiness, data immutability and security. The main objectives of the proposed work are the charging cost reduction and scheduling the EVs' charging. Two algorithms are proposed which deal with the charging schedule and waiting time at CSs, respectively. Mathematical formulation is done and the total charging cost is calculated. Simulation results prove that the proposed work outperforms the conventional techniques in minimizing the EVs' charging cost.**

***Index Terms*—Mobile Vehicles, Vehicle-to-Vehicle Communication, Scheduling, Blockchain, Security**

I. Introduction

With the huge increase in the population and urbanization, issues such as drastic climate changes, increased gas emissions and depletion of fossil fuels arise. Rapid progress has been made in the vehicle industry over the past few years. Road congestion has increased drastically owing to the large number of vehicles. It created huge amount of environmental pollution, which includes noise pollution, air pollution, land pollution, etc. These factors disturb the global economy and community to a great extent, which leads to the need of new revolutions for mitigating the previously mentioned problems [1].

To reduce the huge amount of energy required by the vehicles, scientific and research community have joined hands and started focusing on the Electric Vehicles (EVs) as a source of clean energy. EVs have the ability of reducing the fuel demands as well as the gas emissions. EVs can be powered either from Charging Stations (CSs) or the batteries installed within [2]. The EVs emerging drastically in the local market aim to make the grid a beneficial entity by introducing the concept of Grid-to-Vehicle (G2V) charging strategy [3].

With an immense development being made in the Information and Communication Technologies (ICT) sector, bi-directional communication and trading is becoming a reality. In Smart Grids (SGs), Plug-in Hybrid Electric Vehicles (PHEVs) are developed, which play major roles in transportation management [4]. The increasing number of EVs also poses some problems like the range anxiety problem, lack of charging spots and privacy and security issues [5]. To overcome the issues of conventional energy trading system such as single point failure and privacy leakage, a Peer-to-Peer (P2P) system is the only solution. Though it still has some problems, such as privacy, security and trust issues [6].

To overcome the above mentioned problems, a decentralized system is required which ensures security, privacy and data immutability. For this, blockchain technology is used in the vehicular sector. Blockchain technology promotes trust, security, data immutability, etc. The transactions are saved in a distributed ledger; copies are available with every node ensuring transparency which means that the transactions' data being stored can not be altered. For data verification, consensus algorithms like Proof of Work (PoW), Proof of Authority (PoA) and Proof of Stake (PoS) are used. In PoW, nodes compete against each other to solve the puzzle and the winner gets to mine the blocks. In PoA, the nodes which prove their identities get to mine the blocks. Whereas, in PoS, the node with the highest stake gets the upper hand to mine the blocks. 51% agreement between nodes is required for any action to take place [7]. A number of problems are associated with the charging of EVs like limited battery capacities, less number of CSs, trust issues, etc. The cost of charging also plays a vital role. The vehicle users are reluctant to have their vehicles charged at higher costs. Primary focus of the current research is the scheduling strategies of the EVs. The problem of less number of CSs can be resolved using the blockchain technology. It ensures trust between users which further promotes users' willingness to trade energy among themselves. By using Global Positioning System (GPS), the location information of the EVs can be traced and sent to the other vehicles of the network. Then, the shortest distance between EVs is calculated from the information obtained through GPS [8].

After reviewing the work done by several authors in [4], [7] and [9], the motivations for the proposed work are summarized as follows:

- there is a need of a charging scenario other than conventional scenarios, i.e., G2V and Vehicle-to-Vehicle (V2V), where vehicles are charged from Mobile Vehicles (MVs),
- a charging schedule should be devised to charge the vehicles efficiently and to reduce the charging load on the CSs,
- blockchain technology should be implemented to promote transparency, data immutability, traceability and security in a P2P trading scenario and
- such algorithms are required which will reduce both the

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charging cost and charging time of the EVs.

The major contributions made in this paper are as follows:

- scheduling algorithms are introduced to deal with the charging cost and charging time of EVs,
- M2V communication between vehicles is done and compared with existing V2V and G2V communications,
- cost reduction is achieved using the proposed scheduling algorithm,
- both the number of hashes generated and the mining time required are calculated using different difficulty levels and
- mathematical formulation is done to calculate the total charging cost.

II. Related Work

At present, the Vehicular Network (VN) is getting smarter with every coming day and research is aiming towards making it an integral part of the smart city infrastructure. PHEVs play a vital role in distributed transportation and management in SG. PHEVs are able to get energy both from the CSs as well as from other PHEVs using V2V trading. In the near future, the traffic sector will be comprised of a huge number of intelligent EVs. To ensure the security and cost reduction, blockchain will surely play a major role. Several research organizations are currently working on integration of blockchain in the vehicle sector. Authors in [10] described methods of making the EV communication secure using cryptographic keys and establishing a public key infrastructure. The proposed model used visible light and acoustic side-channel techniques for minimizing the throughput requirement and providing device independency. Authors in [11] presented a decentralized security model. The scheduling of vehicles' charging is also presented. Authors in [12] developed and implemented a game based mechanism which involves auction mechanism. It helped to resolve the large scale EVs' charging coordination problem.

In [13], authors gave the concept of a distributed coalition charging scheme for Plug-in EVs (PEVs) which cut down the charging cost for PEV fleets. The computations were performed locally. Authors of [14] proposed a coordinated EVs' charging technique in a RES powered Micro Grid (MG) using a Markov Decision Process (MDP) approach. The MG dealing with buildings was under study in this work. The EV energy demands of buildings were claimed to be efficiently fulfilled using RES in the vicinity of MG. By implementing various stochastic dynamic programming methods, authors in [15] investigated the energy management in a Smart Home (SH) equipped with PEVs to address the issue of volatility of RES supply while considering the electricity cost.

Authors discussed about the effects of EVs on energy demand and supply, stability and reliability in [16]. Two different scenarios were discussed: Vehicle-to-Grid (V2G) and G2V. Authors in [17] proposed a double-layered model and tried to properly allocate the charging lots to EVs. In the first stage, lots were properly allocated; whereas, in the second stage, integration of RES in the charging lots was studied. Similarly, authors in [18] proposed the MG scheduling for EVs' charging and also discussed about the algorithms which could make the EV charging and discharging an easy and efficient task. Ways to reduce the operational costs and environmental pollution were also discussed. Integrating RES in EVs can prove to be a beneficial task and can overcome the hazards of the environmental pollution. Authors in [19] proposed a MG architecture running on RES. It is equipped with a charging lot and aggregated EVs. The main objective is the cost reduction and also to provide incentives to those EV users, who took part in DR strategies.

III. Problem Statement

For ensuring the establishment of a smart city, it is necessary that Vehicular Network (VN) is made smart, intelligent and is powered using green energy, i.e., RES. The inclusion of RES makes the ecosystem user-friendly and ecological. In modern era, vehicles are getting smarter, throttling is getting faster and infrastructure is becoming more complex. This is due to the huge number of diversified electronic equipments and Electronic Control Units (ECUs) being installed in the vehicles. The interconnection between devices and ECU is opening doors to new communication streams [20].

To ensure maximum EVs participation and to exploit the social welfare, the energy transactions between EVs and CSs are being monitored and audited [4]. However, the proposed system lacks in cost reduction. Due to the dynamic nature of EVs charging, discharging and the mobility of the EVs, an efficient load transmission and dispatch to the EVs is quite challenging [7]. The EV users are being incentivized to encourage collective charging. However, it created burden on CSs leading to frequent energy shortages. Hence, either the user comfort or the energy transaction at reduced cost is compromised. An optimized algorithm for EV charging and discharging in different scenarios, e.g., V2V, G2V and Mobile charging Vehicle-to-Vehicle (M2V) needs consideration, which also reduces the cost.

IV. Proposed System Model

In the proposed system model, four different entities exist, i.e., charging EVs, discharging EVs, MVs and the CSs. These entities send the status details to the nearest agents. A blockchain based EV charging scenario: M2V, is established. The transaction details are being stored in a distributed ledger. The Discharging Vehicles (DVs) can be charged either from the CSs or from the MVs. Whenever a vehicle needs energy, it sends its request to the agent. The agent then forwards this request to the charging entities. Meanwhile, the agents collect and save the incoming demands and the vehicles' data, keeping a check on the total number of demands being made. All entities, i.e., vehicles and the CSs have their own accounts and wallets. Whenever the transactions are being made, the digital currency is used. When buying from the CS, cost is usually high, so the EVs tend to buy energy from the nearest MVs which reduces the cost. Figure 1 shows the vehicles arrangement for three different charging scenarios, each having EVs, MVs and the CSs, motivated from [21]. The charging data is stored in blockchain where contracts are deployed. After a blockchain is established, it is stored in a distributed

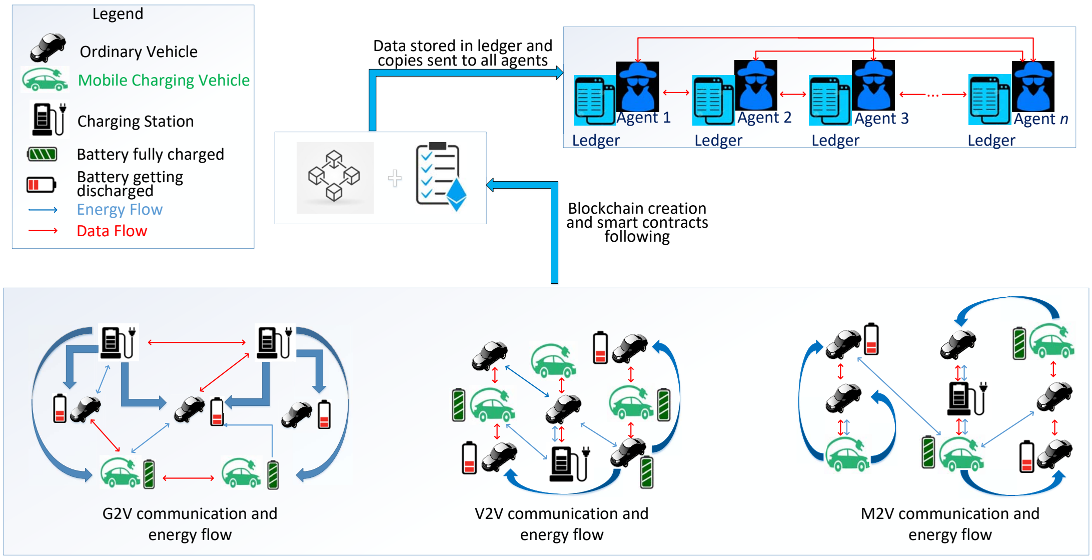

Fig. 1: Proposed system model

ledger. The copies of this ledger are provided to all the agents, who are the part of the network.

V. EV Charging Schedule

In this section, the charging schedule of the EVs is discussed. It is important to ensure that the EVs added in the proposed blockchain-based network should have proper scheduling scenario. There are four entities in the proposed charging scenario: agents, CSs, EVs and MVs. Algorithm 1 gives the charging schedule of the vehicles: calculation of distance between vehicles, CSs and MVs, calculation of different costs, etc. Whereas, algorithm 2 gives details about the waiting procedure which the vehicles have to adopt when they are at the CSs. Figure 2 shows the charging of an EV from three different sources, i.e., from a MV, from another EV and from a CS. The charging source of the EV is decided by the EV according to the distance and price relationship. If the distance between the EV and the charging source is large, then the price will be automatically high. So, the EV will discard that source and travel towards another nearest charging source.

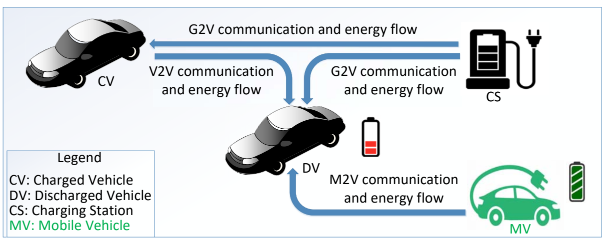

Fig. 2: Charging process of an EV from different sources

Algorithm 1 Algorithm of charging schedule

```
Initialization
Inputs: EV, MV, CS, dis_G2V, dis_M2V, dis_V2V
Outputs: EV charging schedule
Find the number of registered vehicles
for (Each vehicle EV, EV = 1, ..., n) do
    Find distance between EV and MV, dis_M2V
    Find distance between EV and CS, dis_G2V
    Find distance between EV and other EV, dis_V2V
end for
for (Each vehicle EV, EV = 1...n) do
    Find state of charging, SoC
    if (Vehicle is discharging) then
        SoC = 1
    else if (Vehicle is not discharging) then
        SoC = 0
    end if
end for
for (Each vehicle and charging station) do
    Calculate charging cost using equation 3
    Calculate distance cost using equation 4
    Calculate waiting cost using equation 5
    Calculate reward and penalty cost using equation 6
end for
Calculate total cost using equation 7
End
```

VI. Results and Discussion

This section covers the simulation results and discussion. The simulations are performed in two different environments. In the first step, smart contracts are written in Solidity and then they are verified in RemixIDE. The smart contracts cover the registration of the vehicles and the nature of the requests

Algorithm 2 Algorithm of waiting at charging station

Initialization
Inputs: V, v, τ, dis_{G2V}, δ, diff(V,v)
Outputs: Waiting time
Find distance between vehicle and charging station, dis_{G2V}
Find the number of vehicles at a charging station, V
Find the number of incoming vehicle at the charging station, v
Find the difference between V and v, diff(V,v)
if ($dis_{G2V} \leq \tau$) **then**
    Let the vehicle come for charging
else if ($dis_{V2S} > \tau$) **then**
    Ask the vehicle to look for some other source for charging
end if
if (diff(V,v) $\leq \delta$) **then**
    Vehicle is eligible to be charged
else if (diff(V,v) $> \delta$) **then**
    Deny the vehicle to be added to the charging queue
end if
for ($dis_{V2S} \leq \tau$ §§ diff(V,v) $\leq \delta$) **do**
    Calculate waiting time

$$T_{waiting} = v * 300 \tag{1}$$

end for
End

being made: requests accepted and requests denied. In the later stage, the charging scheduling is done in Spyder (Python 3.6 package) provided by Anaconda. These simulations are performed on HP 450G ProBook, having 1 TB Hard Drive and 8 GB RAM. Figure 3 shows the transaction and execution costs in terms of gas for five different functions. These functions are used in the smart contract deployed in Solidity. Figure 4 shows the probabilities of requests being entertained by different charging entities in 4 different time slots. Each time slot consists of 6 hours. In time slot 1, when no request is made, all entities have same probability of requests, i.e., 0.33. In time slot 2, requests are being entertained by the CS. Therefore, its probability is increased to 0.50 while probability of EV and MV is decreased to 0.25 each. In time slots 3 and 4, requests are being entertained by EVs and MVs, respectively. The respective probability values are increased to 0.50 while the other two values are reduced to 0.25. Different probability values show the active status of different charging entities in different time slots. Figure 5 shows the charging price and the travelling price of G2V, V2V and M2V. It is observed that both the charging price and the travelling price are less for M2V. This is because when charging through the CSs, waiting cost and distance cost are also incurred by the vehicles. On the other hand, charging through the EVs incurs the distance cost along with the charging cost of the EVs through CSs. Whereas, MVs have less charging costs because they are equipped with batteries and are self charged. So the major cost which exists in M2V is the distance cost. Figure 5 shows the increasing

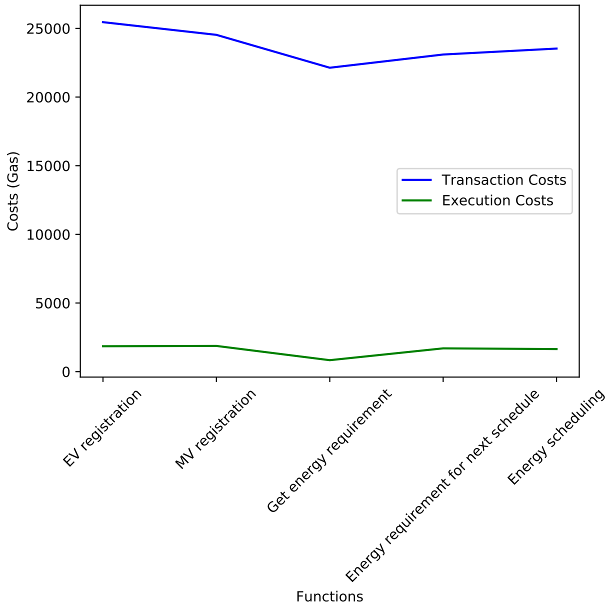

Fig. 3: Costs comparison

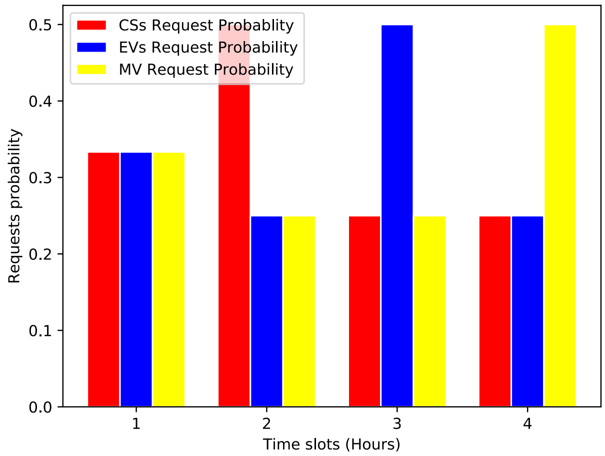

Fig. 4: Request probabilities

trend with the increasing number of vehicles. The travelling cost primarily consists of fuel costs and maintenance costs. Figures 6 and 7 show the number of hashes generated and the mining time for the transactions performed against different difficulty levels. It is observed that both the number of hashes generated and the mining time increase with the increase in difficulty level. Difficulty is defined as the measure of the complexity for miners to find a hash or a signature for a block in the network. The hash is generated using random numbers. The amount of zeroes a signature requires initially determines the difficulty level. The formula for calculating difficulty is given in equation 2, taken from [22].

$$difficulty = \frac{Hash\ target_{(genesisblock)}}{Hash\ target_{(currentblock)}} \tag{2}$$

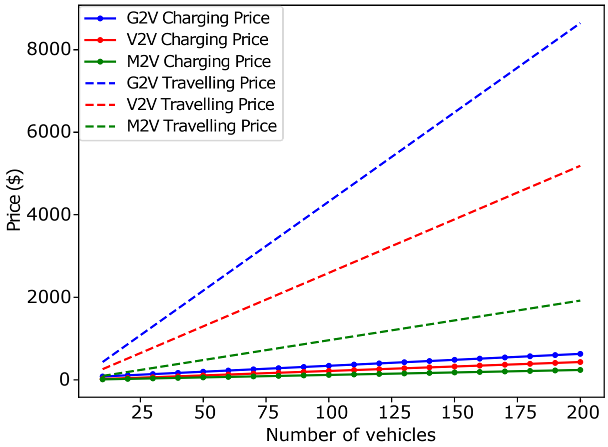

Fig. 5: Cost comparison of different scenarios

Where, target is a 256 bit number. Table I gives all the important details related to the contract creation phase. Similar tables can be drawn for different functions involved in smart contract.

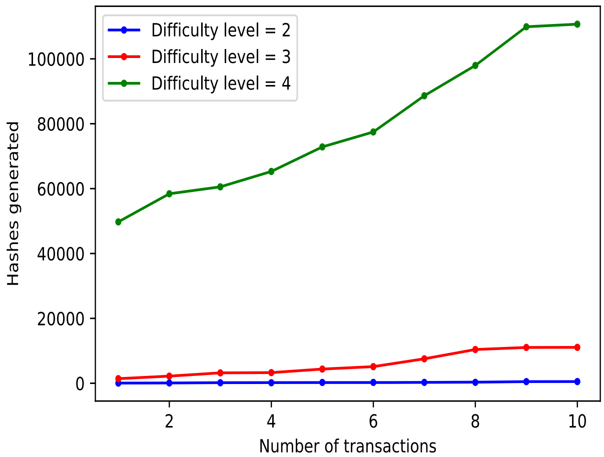

Fig. 6: Hashes generated for different transactions

TABLE I: Contract creation

Parameter	**Value**
transaction hash	0x2e104...a93a6
contract address	0x35ef0...450cf
from	0xca35b...a733c
to	EV.(constructor)
transaction cost	998685 gas
execution cost	713861 gas
hash	0x2e104...a93a6
input	0x608...a0029
decoded input	{}
decoded output	-
logs	[]

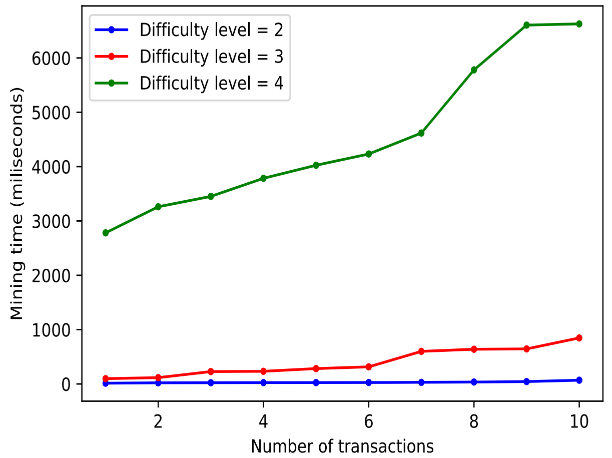

Fig. 7: Mining time for different transactions

VII. Mathematical Formulation

This section provides the mathematical calculation of the total cost, which is the sum of four different costs, i.e., charging cost, waiting cost, distance cost and reward or penalty cost. These costs are denoted as C_{1T}, C_{2T}, C_{3T} and C_{4T}, respectively. These costs are mathematically given below in equations 3 - 6.

The first cost is the total charging cost for CSs, EVs and MVs. P_{CS}, P_{MV} and P_{EV} are the generation costs per unit for CSs, EVs and MVs, respectively. Whereas, C_{CS}, C_{MV} and C_{EV} are the energy selling costs for CSs, EVs and MVs, respectively.

$$C_{1T} = (P_{CS} * \sum_{i=1}^{I} C_{CS}) + (P_{MV} * \sum_{j=1}^{J} C_{MV}) + (P_{EV} * \sum_{k=1}^{K} C_{EV}) \tag{3}$$

After calculating the charging cost, the next cost which needs to be calculated is the distance cost. This cost is related to the distance between the charging and discharging entities. The main objective of the vehicles is that they should be charged from their closest entities, either from the CSs, MVs or from other EVs. Equation 4 calculates the total distance cost, where dis_{S2V}, dis_{M2V} and dis_{V2V} give the distance between vehicle to CS, vehicle to MV and vehicle to EV, respectively.

$$C_{2T} = (P_{CS} * dis_{G2V}) + (P_{MV} * dis_{M2V}) + (P_{EV} * dis_{V2V}) \tag{4}$$

The third cost, i.e., the waiting cost also needs consideration. This cost is incurred when the vehicle needs to wait at the time of charging. For instance, a vehicle goes to the CS for charging. At that CS, a number of vehicles are already present for charging purpose. Therefore, this new incoming vehicle is added to the waiting queue. This also implies even when the vehicle intends to get charged from the MV or the EV. So for calculating this cost, the distance is calculated, which is then multiplied with the number of the vehicle in the queue. This cost calculation is given in equation 5.

$$C_{3T} = \left((dis_{G2V} * diff(V, v)) * \left(\sum_{y=1}^{Y} V_e + \sum_{z=1}^{Z} V_m \right) \right) \quad (5)$$

The fourth cost is the reward/penalty cost. If a certain vehicle saves some units of charge or if it generates some extra units, which it can sale to other vehicles, then the particular vehicle is given some reward and vice versa. Equations 6a and 6b show the reward and penalty calculation. In the given equations, Q is the price per unit, T_s are the total units saved and T_w are the units wasted. Whereas, *ev* and *mv* are the number of EVs and MVs, respectively.

$$C_{4Tr} = (Q * T_s) * \left(\sum_{l=1}^{L} ev + \sum_{m=1}^{M} mv \right) \quad (6a)$$

or

$$C_{4Tp} = -(Q * T_w) * \left(\sum_{l=1}^{L} ev + \sum_{m=1}^{M} mv \right) \quad (6b)$$

Equations 3 to 6 are all summed up to give up the total cost, given in equation 7.

$$C_{Total} = C_{1T} \ + \ C_{2T} \ + \ C_{3T} \ + \ C_{4Tr/4Tp} \quad (7)$$

A. Objective Function

The total charging cost is minimized using equation 8, which is the objective function [21].

$$min \ (C_{Total}) = C_{1T} \ + \ C_{2T} \ + \ C_{3T} \ + \ C_{4T} \quad (8)$$

Subject to following constraints:

- Minimizing the EV and MV charging costs, as given in equations 9a and 9b.

$$0 \leq C_{MV} \leq C_{MV}^{max} \quad (9a)$$

$$0 \leq C_{EV} \leq C_{EV}^{max} \quad (9b)$$

- The other is maximizing the units saved or minimizing the units being wasted, as given in equation 9c.

$$max \ (T_s) \ or \ min \ (T_w) \quad (9c)$$

VIII. Conclusion

In this paper, an improved vehicle charging scenario, i.e., M2V is proposed and compared with the existing scenarios, i.e., G2V and V2V. The vehicles communicate with each other in a P2P manner for data transfer and energy trading purpose. For an efficient charging schedule of the vehicles, new algorithms are proposed. A vivid charging cost reduction is observed when using the scheduling algorithms. The proposed work uses blockchain technology for vehicles' registration and also for ensuring data immutability, security and tamper proof nature. The blockchain data is then stored in a distributed ledger; copies of which are placed at every agent's end. PoW makes the entire system trustworthy and attracts more users to be added to the network. The mathematical formulation guarantees that all possible costs are calculated and the total cost is reduced.

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