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Research Article

NOVA-Charge – A Novel and Secure Approach for Effective Electric Vehicle Charging using Blockchain

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ABSTRACT

Electric Vehicles are attaining greater popularity in the recent times due to its potential for reducing carbon emissions. However, lack of sufficient public charging stations is found to be major hindrance to the widespread adoption of electric vehicles. Though several shared charging models are in place, ascertaining the trustworthiness of the participating entities continues to be a challenging problem. This paper proposes a novel approach called NOVA-Charge that exploits the potential of blockchain technology to facilitate trusted and secure charging of electric vehicles. The approach involves deployment of decentralized blockchain network for enabling transparency and trust. The transactions of shared charging are maintained on blockchain and smart contracts are developed for authorization and pricing. The credibility of the participating entities is evaluated and appropriate incentive mechanisms are employed for ensuring best charging experience. The system model is implemented using Ganache and the results reveal that NOVA-Charge provides better throughput and efficiency when compared to the state of the art approach. Thus, the proposed model can be deployed for facilitating efficient, secure and trusted environment for shared electric vehicle charging in real time scenario.

INTRODUCTION

Owing to rapid depletion of natural oil and increase in the environment pollution, electric vehicles are gaining greater popularity among the people in the recent times [1]. Characteristics such as lower carbon emission and lower fuel cost have enabled EV to become most effective technology for cost effective commuting [2]. Though the benefits provided by the EVs are immense, limited availability of the charging infrastructure is found to be a major factor that hinders their widespread deployment. Seamless commuting experience of the EV users is often affected because of the non-availability of sufficient charging piles [3].

Shared charging emerged as a promising solution to overcome the issue of lack of adequate charging piles. The idea of shared charging is to make the private charging piles available to the public or to specific group to satisfy their energy demands. This scheme enhances the overall utilization of the private charging piles in addition to the objective of satisfying the energy demands of the EV users in rapid manner. However, with respect to the shared charging models, security and privacy is always considered to be the major cause of concern among the users. The lack of trust is another common problem among the users and pile owners [4]. Further, there exist numerous security threats due to the compromised users and malicious entities in the system [5].

Several computational techniques were employed by the researchers for facilitating trusted electric vehicle charging. Blockchain came into existence as powerful technology for providing solutions to problem of lack of trusted interaction in a shared charging environment. Blockchain contains several blocks and pointers wherein transaction details are stored in blocks and pointers are employed to link all the blocks are together. The validation of transactions is done by all participating nodes. Based on the mutual consensus, valid transactions are added to the blockchain and are always immutable as revocation of any recorded transaction is impossible.

The work in the paper proposes a novel blockchain based approach called NOVA-Charge to facilitate shared charging in a secure and trusted manner. The contribution of the paper is highlighted below

- A novel architecture for shared charging is proposed for establishing trust interaction among participating entities.
- Smart contracts are developed for authentication and pricing thereby achieving secure computing.
- Incentive mechanisms are developed to enhance the experience of shared charging by ascertaining the credibility of participating entities.
- Simulations are conducted to evaluate the performance and demonstrate the superiority of the proposed model.

The remaining portion of the paper is organized as follows. Section 2 provides the background of the work. Section 3 describes the architecture and working of the proposed model. Section 4 discusses the performance of the proposed system and compares the work with the state of the art approach. Section 5 provides the conclusion and future directions of the work.

2. BACKGROUND

In the current scenario, charging at public places is found to be very useful in satisfying the charging needs of the electric vehicle users. Such infrastructures ease the process of charging as the electric vehicle users can avail charging during the shopping time or office time without sparing an exclusive time slot for the process of charging. Shared charging is an effective technique in which the private charging piles are provided for a group of electric vehicle users to satisfy their charging needs. This enables win-win condition for both the users of electric vehicle and the pile owners in the way that it creates profit for the pile owners and provides a means of cost effective charging and easy availability to the electric vehicle users.

Fast charging is found to be most desirable amongst electric vehicle user community. In this case, a massive charging requirement can be completed rapidly, in a very small amount of time there by avoiding multiple frequent charging operations. Meeting the charging demands of the user, reduced time for charging, and meeting the required quality of service are the major aspects to be considered in the process of electric vehicle charging. Last, but most important is to deal with the security and privacy concerns associated with the untrusted charging environment.

Several experimentations have been carried out in the past on leveraging blockchain for the purpose of enhancing the trust and services pertaining to electric vehicles. A Blockchain is a collection of data blocks. Each of the data block possess a header and body, and pointers are used to facilitate the linking of all the blocks. In general, blockchain can be of the following types namely public or private or consortium blockchain.

The factors of trust, mechanisms of interoperability, deployment of smart contracts, scalability concerns in blockchain based solutions were studied in Kirpes et al [6] et al. A Novel approach for securing the transaction between untrusted entities in the electric vehicle charging scenario is proposed by Christian Gorenflo et al.[7]. Sharing of sensitive information is implemented by the novel blockchain based technique proposed by Jamil et al. [8]

A pile sharing system employing blockchain technology was put forward by Jian Wang [9]. In his work a decentralized approach providing transparency, reliability among charging station, maintenance and supervising agents was proposed. Several systems were developed in the past for ensuring the trust among pile owners, operators and vehicle users in the electric vehicle charging process using blockchain technology. Yunhua et al. [10] proposed a novel architecture for secure shared charging. In their work multiparty contracts were used for the purpose of secure storage and computations. Khan et al. [11] have developed a model employing hyperledger fabric for enabling payment for electric vehicle charging using blockchain.

Several methods for sharing charging credits were developed in the past by leveraging the potential of blockchain. Firoozjaei et al. [12] proposed a model to ensure trust and distributed privacy preservation during the process of charge credit sharing. Zhengtang et al. [13] proposed a Novel ethereum based framework for charging management in which, multiple smart contract were used for supporting the charging process. The model is also enabled to record accountability of the transactions in an untrusted context.

It was also studied that blockchain based approaches are engaged for the process of selecting the electric vehicle charging station. Danish et al. [14] proposed a blockchain model based protocol for effective selection of charging station, supporting high level of trust. Guo et al. [15] have proposed a blockchain based framework for selection process wherein the honesty of the electric vehicles are accounted for caluculation of reputation. Further Javed et al. [16] have proposed blockchain aided scheme for reliable and trusted vehicle charging.

2.1 Cryptography aided blockchain based approaches

Almuhaideb et al. [17] proposed a novel blockchain based approach for authentication by employing implicit certificates. Chen and Zhang [18] proposed a ECC based digital signature in with blockchain in the context of charging for higher level of security. Baza et al. [19] proposed a novel blockchain model for secure and privacy preserving energy trading along with an improved method for payment using blockchain. Wang et al. [20] have constructed a powerful blockchain architecture for private charging pile sharing and a protocol for the effective sharing is proposed based on the signature and score of reputation.

2.2 Hybrid blockchain based approaches

Li and Hu [21] proposed a novel and decentralized model electricity trading employing consortium blockchain Their model was implemented on hyperledger fabric and appropriate smart contracts were employed for the purpose of enhancing security and privacy. Amrit et al. [22] proposed a novel model for charging management of electric vehicles considering dual perspectives namely both the system and user. A robust consensus scheme was implemented to facilitate improved level of user satisfaction while catering to the required charging needs of the vehicles.

Consortium blockchains have alleviated the problems of lack of coordination among energy companies. Zhengtang et al. [23] have proposed a novel electric vehicle charging model to provide hassle free charging for users by employing several custom smart contracts. A robust search algorithm is used for aiding the operations to provide better performance. Erdin et al. [24] proposed a powerful bitcoin approach for enabling payment process pertaining to electric vehicle charging. The work has used main ledger in conjunction with appropriate signature verification and security schemes so as facilitated seamless trusted operations. Wang et al. [25] have proposed a novel blockchain model using sophisticated ledgers and cryptocurrencies for implementing a secure incentive mechanism. A reputation based consensus protocol is deployed by taking into account the trust and credibility of the nodes.

3.PROPOSED METHOD

The proposed model NOVA-Charge employs a blockchain based approach for enabling trust in the shared charging scenario. The architecture of the proposed model is depicted in Figure.1 The major entities in the system include electric vehicle users, charging stations, pile owners and the charging interface. The information of all entities in the system and their interactions are stored on a cloud based blockchain so as to maintain enhanced level of security.

The methodology for the carrying out shared charging through NOVA-Charge is described below:

When an electric vehicle user intends to charge the vehicle, the user need to locate the available charging pile by means of the NOVA charging interface that provides the information on the charges. If any user intends to charge at any pile, he can send a request for the information of the pile owner from the blockchain. The associated information on the pile owner can be obtained by considering the location and identity of the pile. The information is available in the encrypted format and the same can be retrieved for the blockchain. Once the identity of the pile owner is fetched the user of electric vehicle needs to connect to the pile owner by means of smart contract. The authentication process is initiated wherein the user and the pile owners get verified against each other.

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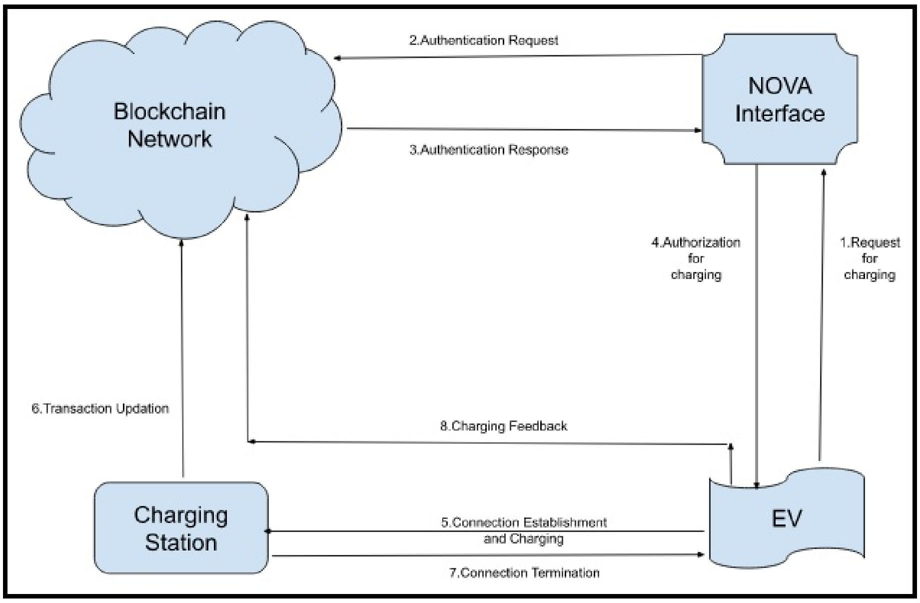

Fig.1 Architecture of the NOVA-Charge

The initial tariff for the charging is paid to the pile owner by the electric vehicle user and the owner of the pile will approve the user to get the charging service done. As per the amount of charging required, the associated transaction is initiated and the charging fare detail is sent to the user through the smart contract. The user receives the details and initiates the payment transaction and all the aforesaid operations are recorded in the blockchain.

The storage structure of the blockchain is demarcated by means of variety of blocks. Special blocks are designated for each of the information such as identity, authentication, charging, payment, quality of service detail. As all the information are maintained on the same blockchain several book keepers are implemented for the purpose of information sharing. Every block contains a basic block number and unique branch number to locate the type of the information stored. As there are large number of blocks stored, the same type of blocks are linked together so as to facilitate faster fetching of the information. Pertaining to the information associated with a charging pile, all the information associated are indexed. Pointers are employed for the purpose of quick retrieval of the information associated.

The major features of the proposed approach is mentioned below

a) Secure Access Control:

In the proposed work, we employ a strong authentication scheme wherein, only those electric vehicles and pile owners who are authenticated by means of smart contract can call critical functions. This enables the prevention of illegitimate or unauthorized access and ensures that only legitimate entities are allowed to carry out operations in the system.

b) Fair and Optimal Bidding:

The novel auction system employed in the work ensures that the electric vehicles get the best service at the optimal price. This is achieved by providing an opportunity for the electric vehicles to select the minimal bid, promoting fairness and competition.

c) Secure Payment:

Before the commencement of charging process, an initial deposit is required for participation. This ensures that funds are available for carrying out transactions, preventing issues in the intermediary stages like insufficient payments or fraudulent payment. The fund transfers are governed by means of smart contract that enables handling of fund transfers in completely secure manner. This ensures that payments are made only specific conditions in the contract are met.

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d) Enhanced Transparency and Accountability:

This is the most promising feature wherein all the bids, transactions, and feedbacks are stored on the blockchain. This enables the creation of immutable record. The feedback mechanism incorporated encourages good behavior of the participating entities and updating the ratings based on performance, ensures the evidence of trust in the blockchain network.

3.2. Smart Contracts

The major contribution of this work is the deployment of the novel smart contracts for accomplishing operations related to authentication, pricing etc. Initially when the electric vehicle intends to avail the charging facility, the authentication is performed by means of light weight authentication scheme. Then the authenticated entity can access the charging platform to locate the optimal charging pile by considering various factors such as distance, speed of charging and other quality criteria. In the initial evaluation phase, the smart contract aid in checking for the nearest charging station that satisfies the criteria of the request. The smartcontract EVChargingContract is shown in the figure 2.

```
contract EVChargingContract {
   struct Bid {
      address payable cp;
      uint256 amount;
   }

   struct ChargeRecord {
      address ev;
      address cp;
      uint256 amount;
   }

   struct Credibility {
      uint256 totalRatings;
      uint256 numberOfRatings;
   }
```

```
Bid[] public bids;
 ChargeRecord[] public chargeRecords;
 address public ev;
 bool public auctionEnded;
 mapping(address => uint256) public deposits;
 mapping(address => Credibility) public evCredibility;
 mapping(address => uint256) public cpRatings;

 modifier onlyEV() {
    require(msg.sender == ev, "Only the EV can call this function");
    _;
 }

 constructor() {
    ev = msg.sender;
    auctionEnded = false;
 }

function initiateBidInvitation() public onlyEV {
    auctionEnded = false;
    delete bids;
 }
```

Fig.2 EVCharging Contract

A bidding process is initiated wherein all the charging piles that can offer charging service can send the corresponding responses. All bid and responses will be recorded in the blockchain. Finally optimal pricing is determined and once the charging process is completed, the total charging cost is estimated and the transaction is recorded in the blockchain.

The major advantage of this approach is that once any transaction is completed, the same is appended into the distributed blockchain network, thereby making it immutable. All the parties involved in the blockchain network are updated with a copy of the transaction and it is irrevocable. Further these transactions are automatically implemented whenever the specific conditions mentioned are met thereby they cannot be changed randomly. The above ensures that the system is completely trusted. The smart contract is associated with each and every action such as verification of the identity of the electric vehicle, payment of deposit to the pile owner, receipt of deposit, authorization of charging to the electric vehicle user, recording of price for charging, disbursement of tariff to the pile owner, determining the behavior of the users, etc.

3.3. Incentive Scheme

It is indeed essential to enhance the quality of service associated with the charging process. Our system provides an exclusive mechanism for the enhancing the service quality by means of the feedback mechanism. Once the electric vehicle completes the charging process, the charging platform offers a provision to register the feedback. This is again implemented by means of smart contract and the data is recorded onto the blockchain. Our system employs four level of rating for the charging experience. The best charging experience is rated as excellent and worst experience is rated as poor. There are two intermediate levels of charging experiences namely good and fair.

In order to enhance the quality of experience to the prospective users, the system provides a list of charging piles to the new user based on the feedback obtained in the recent past. The system updates the quality of service provided by the charging stations in accordance to the feedback provided by the electric vehicle users who availed the service. In order to avoid false updation of the service quality with respect to a specific charging station, the reputation of the electric vehicle is first checked before accounting the response given by the particular entity. If the reputation of the entity is below the threshold, then the response of the electric vehicle is neglected during the consolidation of service quality. By enforcing such a scheme, the system ensures that the malicious feedbacks are neglected and only the feedback of the legitimate entities are taken into account, making the system more trusted in the process of shared electric vehicle charging with enhanced quality of service.

4.RESULTS AND DISCUSSIONS

The section elaborates on how the novel block chain based model NOVA-Charge is constructed and validated. The experimental settings, initial assumptions and charging model are discussed. Further, a detailed analysis of the results is presented.

4.1. Experiment Settings

The work developed a prototype to illustrate the mechanism of shared charging. Initially the environment for the electric vehicle network is set up. It involves configuration of parameters such as the number of vehicles, the number of charging stations, and factors such as the locations of EV and charging station, identities of charging station and vehicle users.

A variety of assumptions have been made to simulate the shared charging:

- A total of 100 electric vehicles can be placed at preferred locations as per the initial configuration.
- The vehicles were provisioned to move along the designated paths in the specific direction.
- Each of the electric vehicles can move at a specified speed.
- The level of battery charged is initially set for each of the electric vehicle.
- A total of 6 charging stations can be placed at specific locations as per the initial configuration.

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• A cloud based blockchain network was employed to store the information.

Once the network is configured, the simulation begins by depicting the movement of the vehicles in the given environment. The vehicles are programmed to navigate in fashion around the canvas, so as to represent their mobility in the charging network. The simulation is carried out in such a way that movement of vehicles is analogous to the movement of the vehicles in the real-world scenario pertaining to urban environments or highways. Further various factors such as traffic, roadblocks and route detours are also mimicked to reflect a real world vehicular movement.

This work is implemented using Python 3 through Jupyter Notebook. Ganache is used for simulation of blockchain environment. The work deployed a Core i5 processor with 16GB RAM computer and the simulations was carried out using Windows operating system.

4.2. Charging Model

As vehicles move from the source towards the destination, their batteries often deplete over the period of time. When the battery level of the vehicle falls below threshold of 0.4 then, the battery of the vehicle needs to be charged. The vehicle needs to identify the nearest charging station and the charging process needs to be initiated. This charging process involves the vehicle's navigating towards the charging station, then the vehicle getting connected to the charging infrastructure, and finally the vehicle getting its battery replenished. A typical charging scenario of the simulation is shown in the figure 3.

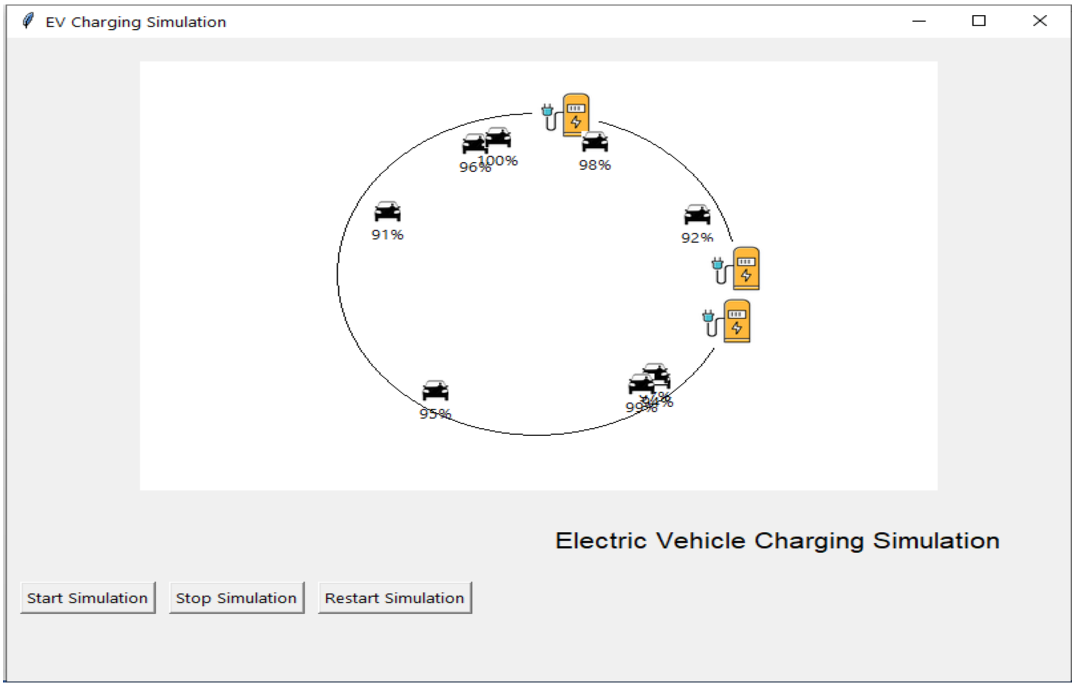

Fig 3. Typical Charging Scenario

The simulation begins the process of charging once the vehicle encounters its battery depleted below the threshold. The charging process involves several important actions such as identification of nearest charging station, connecting to the charging infrastructure, authorization, pricing, charging etc. For the purpose of locating the nearest charging station, the simulation calculates the distance between the particular vehicle and the available charging stations to find the nearest one. Further to the identification of the closest station, the vehicle then navigates towards this station. Once the vehicle arrives at the charging station the process of connecting to the charging infrastructure is initiated. The appropriate smart contract interaction is executed.

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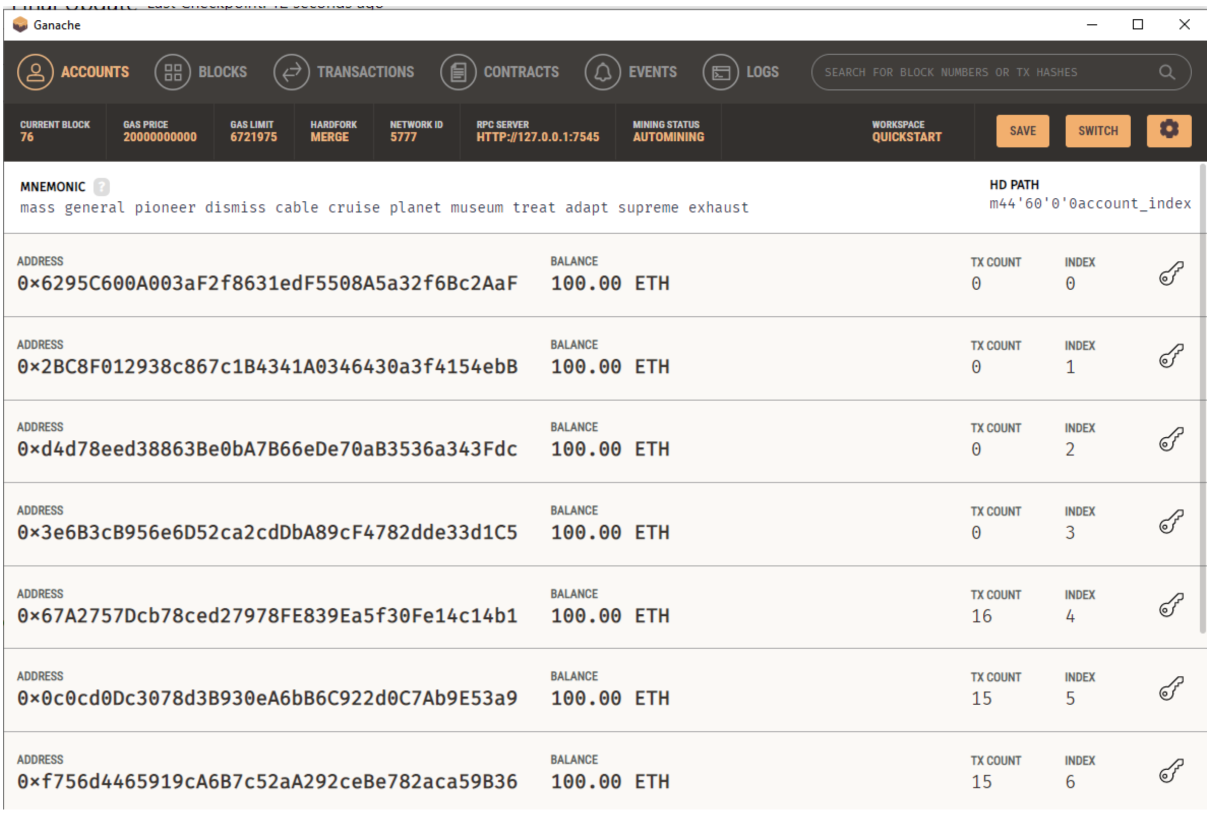

Fig.4 Records on Blockchain

The simulation leverages the Ethereum blockchain and smart contracts to manage the charging process. The first smart contract is called as EVChargingContract and it is deployed to authorize the charging transaction. This contract contains functions to handle charging authorization and payments and the same is executed first. Here the Ethereum account address of the vehicle interacts with ethereum account address of the charging station to facilitate the corresponding transaction. The smart contract ensures that the correct amount of Ether is transferred for the service pertaining to the required amount of charging. The records stored in the blockchain are shown in the figure 4.

Once the battery of the electric vehicle is charged to the required level, the simulation records the time taken for the transaction and charging process. This data is further used to analyze the performance of the blockchain network such as throughput and transaction latency.

4.3. Results and Evaluation

This performance of the proposed model is ascertained in terms of throughput. The throughput values obtained from our simulation for various send rates ranging from 175 to 1275 are considered for the purpose of evaluation. It is found that the throughput increases steadily from 209 tps to 761 tps for the send rates from 175 till 475. It is also observed that the throughput increases from 877 tps to 1242 tps for the send rates from 775 till 1075. The peak throughput of 1374 tps is obtained for the send rate of 1175. The evaluation compares the throughput of the proposed system NOVA-Charge against the existing state of the art approach discussed in Khan et al. [11], with respect to varying transaction per second (tps) send rates. The throughput of the existing system and proposed system at various send rates is provided in the table 1.

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Send rate(tps)	Existing System Throughput(tps)	Proposed System NOVA-Charge Throughput(tps)
175	412	209
275	474	371
375	546	451
475	556	761
575	573	652
675	598	1006
775	627	877
875	658	960
975	873	879
1075	819	1242
1175	780	1374
1275	751	1102

Table 1. Throughput of Existing and Proposed Model

4.4 Discussion and Findings

The graphical comparison of average transaction throughput is depicted in Figure.5. The x-axis denotes send rate in transactions per second (tps) and y-axis denotes the transaction throughput in transactions per second (tps). The average transaction throughput TPT is computed using the formula given in equation 1

$$TPT = \Sigma VT / \Sigma T \quad (1)$$

wherein, VT is the total number of valid transactions and T represents the total time period measured in seconds.

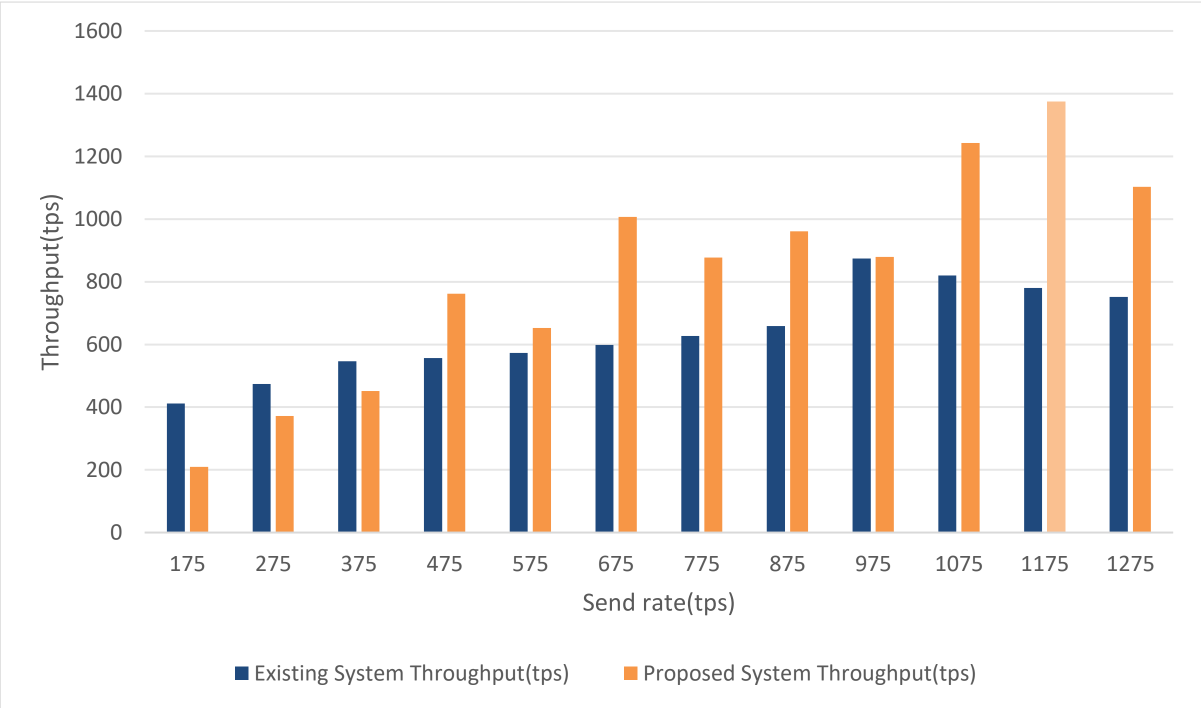

Fig.5 Performance Comparision

It is clearly evident from the results that the existing system provides higher throughput in the cases of lower send rates namely 175, 275 and 375 respectively. As the send rate increases, the existing system exhibits slow rise in throughput. This is evident for the send rates of 475, 575, 675, 775 and 875 wherein the throughput is found to be

556, 573, 598, 627 and 658 tps respectively. However, the proposed system NOVA-Charge exhibits a drastic increase in throughput say 371, 761 and 1006 tps for the send rates of 275, 475 and 675 respectively. It is also witnessed that the proposed system performs significantly well at higher send rates, accomplishing a peak throughput of 1374 tps against the existing system's peak throughput of 873 tps. The increase in throughput obtained by the proposed model when compared against the existing model for various send rates is provided in the table 2

Send rate(tps)	Increase in Proposed System Throughput (tps)
475	204
575	79
675	408
775	249
875	302
975	5
1075	422
1175	594
1275	350

Table 2. Increase in Proposed System Throughput

It is observed that the proposed system has obtained maximum increased throughput of 594 tps when compared to existing system at the send rate of 1175 and second maximum increased throughput of 422 tps at the send rate of 1075. The proposed blockchain based system NOVA- Charge demonstrates superior performance over the existing system especially at higher transaction send rates by providing exemplary increase in throughput and achieves an overall average increased throughput of 290 tps for the various send rates considered in our simulation. Careful investigation of the results reveals that the proposed system NOVA-Charge is more efficient in terms of handling higher volumes of transactions, thereby facilitating it to be a more robust solution for various real time scenarios that demand high throughput.

In general, the shared charging platforms leverage the support of centralized servers for storing all the information related to users and transactions. However our approach has alleviated this concern and provisioned fool proof security by storing all the data in the blockchain, thereby making the system robust against the single point of failures. At the time of charging the important information associated with the user and the charging is recorded on the blockchain so as to guarantee the privacy. Generally many shared charging systems that deploy blockchain store only the charging information on the blocks. However our system provides enhanced level of security by encompassing all user, charging pile owner and transaction related information in the blockchain.

As we know, blockchain technology supports immutability and anonymity, our blockchain based approach NOVA-Charge overcomes the common problems of vulnerabilities and data tampering issues thereby leading to enhanced security and privacy in EV charging scenario. The work also employs an authentication mechanism to validate the participating entities and its unique method of implementing pricing deposit and authorization related operation through smart contracts makes the system superior in terms of security.

5.CONCLUSION

Shared charging in electric vehicles is becoming very popular owing to its ability to address the major concern of sparse charging infrastructures. However, the problem of lack of trust remains a major challenge. This paper has proposed a novel blockchain based approach called NOVA- Charge for providing a trusted and secure environment for electric vehicle charging. The transactions of the shared charging are maintained in the blockchain network and smart contracts were deployed for the purpose of authorization and pricing. Simulation results reveal that the proposed approach is very efficient as it achieves high throughput when compared to the state of the art systems. Further the system is also found to be robust against the vulnerabilities when compared to the traditional system yielding enhanced security and trust in the realm of shared charging. The work can be further extended by deploying novel consensus mechanisms or by adopting enhanced techniques for authentication and privacy preservation.

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