High-Confidence Computing 1 (2021) 100001

Contents lists available at ScienceDirect

High-Confidence Computing

homepage: www.elsevier.com/locate/hcc

# A trusted architecture for EV shared charging based on blockchain technology☆

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ARTICLE INFO

*Keywords:*
Blockchain architecture
Smart contract
Shared charging

ABSTRACT

With the development of the Energy Internet and the support of the subsidy policies of various countries, Electric Vehicles(EVs) have ushered in a golden development period. However, the development of EVs needs to solve the problems of insufficient charging piles(CPs) and difficulty in finding CPs. In order to solve the problem of difficult charging of EVs, the concept of shared charging came into being, in which idle CPs or private CPs are shared to meet the charging needs of more people and improve the utilization rate of CPs. However, the shared charging scheme implemented by third-party platforms faces the issue of trust lacking. This paper proposes a blockchain architecture for shared charging, which can use the blockchain to build a trust environment involving private pile owners, charging pile(CP) operators, Electric Vehicle(EV) users, etc.. The blockchain architecture also contains the block structure where pointer was added for quick search, contract content that can automatically execute multi-party contracts to achieve secure computing and reputation-based incentive mechanism to provide high-quality charging services in detail. This architecture establishes the multi-party trust environment for shared charging from three aspects: secure storage, secure computing, and secure incentives.

## 1. Introduction

With the declining oil reserves and the increasing air pollution, Electric Vehicles(EVs) usher in a golden development period. In 2019, global Electric Vehicle(EV) sales were approximately 2.2 million units, a year-on-year increase of 10%. GlobalData predicts that the number EVs on the road will climb to 300 million by 2040. EVs are powered by on-board power supplies and use motors to drive wheels. EVs have the characteristics of being clean and pollution-free, low driving noise, high energy efficiency, low use cost, and small maintenance work. European countries have introduced national incentives and benefits for EVs, and France provides benefits of up to 12,000 euros for EV users. The U.S. government has established 25 billion US dollars of funds to support manufacturers in the field of new energy vehicle research and production. China has included charging piles(CPs) for EVs in new infrastructure development, and 10 billion RMB will be invested in EV charging infrastructure.

With the rapid development of EVs, they are also facing the problems of insufficient CPs and difficulty in finding CPs. At the end of 2019, the gap in the demand for CPs from EV users is still large, the vehicle-to-pile ratio in US is about 18:1, the vehicle-to-pile ratio in China is about 7:1. In addition, EV users have the problem of finding CPs. Some user APPs for finding piles cannot obtain the dynamic information of CPs, and cannot search for CPs belonging to other charging operators. Private CPs cannot be installed at will due to safety considerations, and have a very high vacancy rate during the day.

To solve the above problems, the concept of shared charging came into being. In shared charging, CPs that are idle or in service are shared to meet the charging demand of more people, increase the income of pile owners and improve the utilization rate of CPs [1]. At present, all shared charging systems rely on a third-party platform (i.e., a shared CP operator): charging users and private charging pile(CP) owners need to register on the third-party platform, and the information sharing and charging pricing also rely on the third-party platform. Although these shared charging systems are efficient, there are deficiencies:

1) Important data is centrally stored in the third-party platform, which is vulnerable to attacks by hackers, and once a failure occurs, the shared charging systems may be paralyzed completely;

☆ Fully documented templates are available in the elsarticle package on CTAN. This work was supported by Natural Science Foundation of China (61802005), and Beijing Municipal Natural Science Foundation (M21029).

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https://doi.org/10.1016/j.hcc.2021.100001
Received 15 December 2020; Accepted 31 January 2021

2) The pricing method is not transparent for the private CP's owners, so the third-party platform may tamper with charging data, pricing rules, and profit sharing methods for its own benefit [2–4];
3) Charging transaction data, charging location and other information are all stored in the third-party platform, which is easy to leak the users' private information.

The emergence of blockchain technology is expected to solve the above problems[5–8]. As a distributed trusted ledger, the blockchain involves the interaction between different stakeholders and is suitable for solving the trust problem between different stakeholders, or is used as a third-party trusted platform to solve the problem of user trust in the platform [9–11]. In shared charging applications, the blockchain conducts open and transparent real-time accounting of charging situations, which is immutable and maintained by multiple parties, so that the trust friction between multiple parties can be solved, and a multi-party participation trust environment for CP operators, private CP owners and platform users is formed [12–14].

However, traditional blockchain architecture is not suitable for applying to shared charging directly due to issues such as the computing power of the charging network and the differences between private pile owners and CP operators. Therefore, it is necessary to design a blockchain architecture for shared charging. The architecture needs to consider the following issues: who should be the bookkeeper of the blockchain ledger, what information needs to be recorded in the ledger, and what functions need to be implemented by smart contracts.

This paper proposes a blockchain architecture for shared charging, including architecture composition, block structure, contract content and incentive design. The system architecture contains various CPs, energy internet, shared charging service platform, and cloud, and a trust environment is built between them. The design of the block structure facilitates the storage and query of multiple types of information in shared charging. Smart contracts automatically execute multi-party agreements to achieve secure computing, such as the fairness of charging pricing and the security of charging transactions. The incentive mechanism promotes the formation of a healthy development of shared charging ecosystem by encouraging participants to make efforts, such as providing high-quality charging services.

The remainder of this paper is organized as follows. Section 2 introduces the related work. Section 3 elaborates the architecture of the shared charging based on the blockchain in detail. Section 4 evaluates the performance of incentive mechanism and pricing contract. In section 5, the advantages of this architecture are analyzed. Section 6 summarizes and prospects future research directions.

## 2. Related work

There are different studies on the energy Internet architecture based on blockchain. Li et al [15] pointed out a consortium blockchain which is used for energy trading in the industrial IoT by using the Stackelberg game to ensure safe, fast and reliable energy trading. Christidis et al. [16] stated a new idea that the distributed and heavy workflows in the energy IoT industry are executed through smart contracts automatically.

Besides, more researchers have focused on the shared charging system based on blockchain. Dubois et al. [17] presented an blockchain system which can provides charging service between EVs and charging stations without a trusted third party via using smart contracts. Kang et al. [18] used the consortium blockchain to design the charging and discharging transactions between EVs, and set up a local aggregator to act as a service node, but not involving user transactions' situation in different aggregators.

Numerous works apply smart contracts to shared charging. Huang et al. [19] proposed a decentralized security model to improve the security of transactions between EVs and CPs by applying the lightning network and smart contract technology. Alam et al. [20] argued that each charging station installs a smart meter that can run a blockchain node and detect the power of the charging station, and interacts data with the smart contract on the blockchain through the built-in communication module. Finally, the data is packaged and written to the blockchain by the miners. The paper [9] written by Su et al. adopt blockchain and smart contracts to implement secure charging services for EVs.

Several previous studies pay attention to incentive mechanisms to improve the quality and efficiency of charging services. Zhang et al. [21] summaried typical incentive approaches in the smart grid and apply contract theoretical approach to energy trading process. Zou et al. [22] designed a scheme based on a progressive two-price auction game to solve the large-scale EV charging cooperation while keeping incentive compatibility within a limited range. Zacharia et al. [23] proposed an evaluation mechanism to calculate the charging service evaluation of charging stations, which is based on the different credibility ratings given by users and the endorsement experience value of charging station nodes.

## 3. Blockchain architecture for shared charging

### 3.1. System architecture

The blockchain-based trust system architecture of shared charging is shown in Fig. 1. The system architecture is used to build a trust environment by multiple parties such as private CP owners, public CPs, CP operators, and EV users. On this basis, it also considers the energy Internet connected by CPs, shared charging service platform that meets the shared charging needs of all participants, and cloud that stores increasing blockchain data as time goes on.

When EV users need to charge, users can search for private CPs, public CPs, and various operators CPs by shared charging service platform. Meanwhile, the billing rules of each CP are also disclosed on the service platform. So as to guarantee that the privacy of the private pile owners or operators are not leaked, the service platform does not display the CP owner information. The pile owners personal information is encrypted and stored in the blockchain. When an EV user charges at a certain CP, it can request the pile owner ID information from the blockchain. Then, according to the position and number of the pile, the blockchain can find corresponding pile owner's ID from the encrypted data on the blockchain. After obtaining the pile owner ID, the EV user contacts the pile owner and triggers a smart contract. Both EV users and pile owners are verified via the smart contract. Afterwards, a charging deposit is paid, and then the pile owner authorizes charging. In addition, the CP records the charging amount from the authorization, and sends the total charging amount to the smart contract to generate transactions after the charging. Finally, the generated transactions are collected and confirmed by the charging transaction's bookkeepers, then are packaged and stored on the blockchain.

### 3.2. Bookkeeper and block structure

The blockchain-based trust system architecture of shared charging proposed in this paper includes three types of CPs, namely, private CPs, public CPs, and CPs for various operators. The operating modes and privacy requirements of these three CPs are different, so no matter what block type it is, the type of CP needs to be marked on the blockchain. Futhermore, in addition to the protection of transaction information, the blockchain needs to record the identity and contact information of the participants, charging authorization records, the service quality of private pile owners or the power supply operator, and other useful information.

(1) Bookkeeper

Because the blockchain needs to record a variety of information in this architecture, and each participant in the shared charging network has different computing power and demand, the selected bookkeepers are also different. For charging transactions initiated by EVs, although

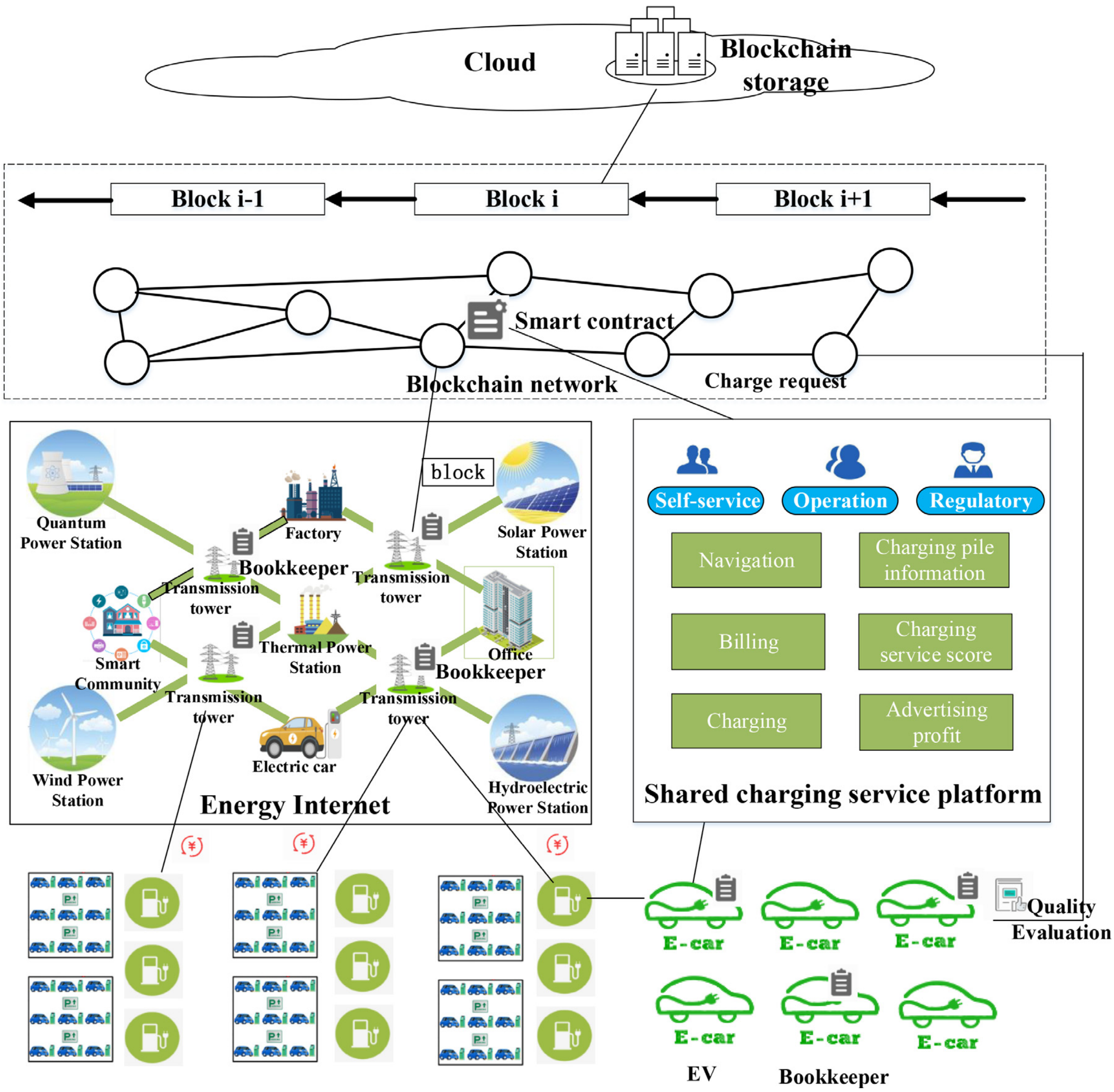


**Fig. 1.** Blockchain trust system architecture for shared charging.

the CPs can record the charging situation directly, the transmission tower serves as the bookkeeper, because it can be used to detect the electricity consumption in its jurisdiction. For the quality evaluation service initiated by the system, most of the evaluation subjects are EV users, who have limited computing power and may be malicious. Therefore, evaluation service bookkeepers are screened out through a reputation-based consensus mechanism [24]. For the user identity certificate block that contains the participant personal information and can authenticate the participant, it is kept by the authoritative prestige center, the operator, and some users jointly because of involving multiple participants.

(2) Block structure

The blocks in this architecture need to store information, including EV charging transactions, quality assessment service information and user identity certificates, and use different bookkeepers to record them on the blockchain. In order to implement information sharing and avoid information islands, multiple different bookkeepers need to publish the blocks on the same blockchain. All blocks published by different bookkeepers are sorted in order. In each block header, besides “block number”, there is an extra item named “Branch block number” to distinguish what type of block it is. And the same type blocks are linked in the order of “Branch block number” so that operators or management agencies can quickly access a certain type of information. In order to discover all the transaction and evaluation information of the corresponding CP more quickly, and avoid traversing all blocks while searching, indexes are added to different types of blocks. In the evaluation transactions, there are two pointers whether it is information about CP or EV. Taking the evaluation transaction of the CP as an example, these two pointers are “Corresponding CP transaction” and “CP Last evaluation height” point to the corresponding charging transaction and the last evaluation transaction of the CP respectively. In this way, when the shared charging service platform queries CP or EV service evaluation information, all information about CPs and EVs can be finded via index rather than traverse the entire blockchain. The specific block structure which is used to query is shown in Fig. 2. Query algorithm pseudo code is shown in Algorithm 1.

### 3.3. *Smart contracts*

A smart contract is a set of digital agreements composed of codes, made by multiple users in the blockchain together, where the rights and obligations of both parties are clearly defined. Once the trigger conditions are achieved, they will automatically be executed and cannot be changed. The blockchain system for shared charging involves compli-

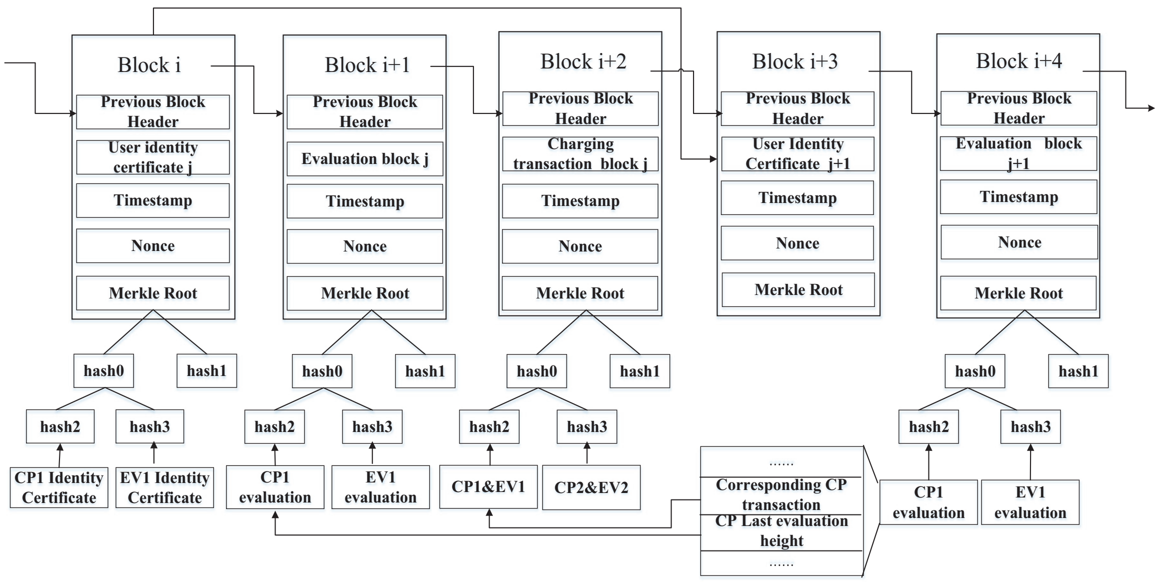


**Fig. 2.** The block structure used to query.

**Algorithm 1** Query algorithm

**Input:** $CP\ ID = p$
**Output:** All evaluations of $CP\ ID = p$
**for** $i = Block\ number$; $i < 0$; $i--$ **do**
  **while** Branch block type = Evaluation block **do**
    Access this block;
    **if** $CP\ ID = p$ **then**
      Set variable $CP\ evaluation = CP\ p\ evaluation$;
      Set variable $CP\ transaction$;
      **repeat**
        $CP\ transaction =*(CP\ evaluation \rightarrow$Corresponding CP transaction);
        Record CP evaluations to a array A[transaction];
        $CP\ evaluation =*(CP\ evaluation \rightarrow$CP Last evaluation height);
      **until** $CP\ evaluation \rightarrow CP Last\ evaluation\ height = \phi$
    **end if**
    **goto** *end*
  **end while**
  **continue**
**end for**
*end*

cated and vulnerable operations such as pricing, deposits, authorization, transactions and ect.. Smart contracts automatically execute complex operations to achieve secure computing, such as the fairness of charging pricing and the security of charging transactions [25–28].

(1) Pricing smart contract

A reliable and fair pricing contract based on user requirements is designded in this paper. EVs use the shared charging platform to query idle CPs within a certain distance, and use smart contract to implement screening algorithm. Combined with charging speed, charging price, service quality, and CP location and other user needs, the best CPs that can provide services is selected.

Fig. 3 shows the pricing smart contract. The EV sends a bid invitation to all free CP in the area through the shared charging platform. If the owners of the private pile and the CP operators are willing to provide charging, they will bid with deposit and record the bidding commitment on the blockchain. Next, the pricing contract will take out the EV user's request and the bidding of private pile owners or CP operators, execute the auction game algorithm, and find the balance between the service quality and the charging price. Then the optimal CP that meets the needs of the EV user is selected. Finally, the smart contract returns the deposit to unsuccessful bidders and the optimal pricing is determined. Fair pricing algorithm pseudo code is shown in Algorithm 2.

**Algorithm 2** Fair pricing algorithm

**Input:** Charge request
**Output:** Optimal CP
**if** User status is normal and CP is in the specified area R **then**
  // Phase 1: Pricing auction game:
  $A\ bid\ invitation \rightarrow idle\ CPs$;
  **repeat**
    $Bidding\ b = (V_b, B) \rightarrow blockchain$;
    $Bidding\ commitment \rightarrow blockchain$;
  **until** Price convergence
  // Phase 2: Calculating the optimal strategy:
  Select an optimal CP by the screening algorithm;
  $Optimal\ CP \rightarrow user$;
  $Deposit \rightarrow unsuccessful\ bidder$;
  // Phase 3: Generating decision commitments:
  The optimal decision commitments $c = H(EVID, CPID, r) \rightarrow blockchain$;
**end if**

A. Multi-party charging pricing auction game

Within the specified area, the CPs send the lowest price bid on the basis of the request. According to the user's request, whether its own location is in the area R needs to be checked firstly. In this case, the CP creates its own bid $b = (V_b, B)$, where $V_b$ is the charging speed guaranteed by the CP, and $B$ is the bidding for this charging service. All nearby CPs that eager to provide services send bids with deposit and commitments to the blockchain, so the bidding information written into the blockchain is public and immutable. The openness of bidding encourages other CPs to provide cheaper prices and make the bidding stage more transparent and reliable. Within a certain period of time, the CP can submit one or more bids and commitments to the quotation, and send updated quotations based on competitors' bids. The blockchain will store the repeated bidding process until the price converges. We design

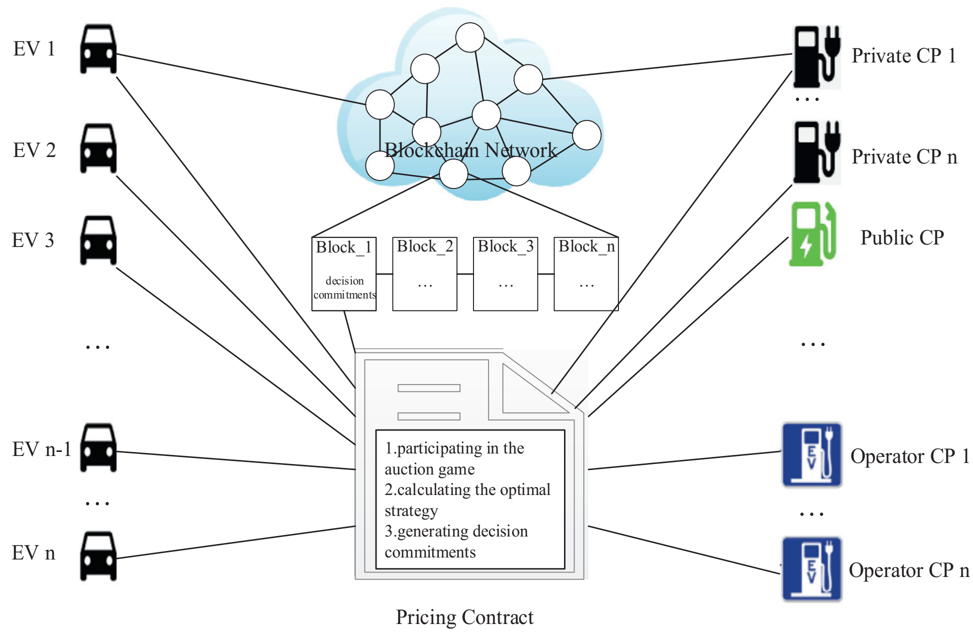


**Fig. 3.** Pricing smart contract.

the corresponding screening contract to implement the corresponding heuristic screening algorithm which select an optimal CP from private, public or various operators' CPs for recommendation. It is assumed that the designed heuristic screening algorithm can reach a balance between charging price, charging speed, and distance between CPs.

B. Pricing smart contract implementation

According to the Nash equilibrium of the multi-party charging pricing auction game, the optimal decision strategy of each participant is given. The designed pricing smart contract includes three parts, namely, participating in the auction game [29,30], calculating the optimal strategy, and generating decision commitments. The part of participating in the auction game is used to collect relevant information of participants who participate in the pricing game; the part of calculating the optimal strategy is used to calculate the optimal decision strategy of participant by the collected participant information; the part of generating decision commitments writes the optimal decision commitments to the promise $c = H(EVID, CPID, r)$,where r is a random and then take it into the blockchain.

(2) Transaction smart contract

The smart contract stored in the blockchain is formulated by the bookkeeper of the charging transaction, and is spread via the P2P network in this architecture. When the EV needs to be charged, the smart contract is triggered. Paying deposits, authorizing charging, and the processes of generating transactions are all realized by smart contracts. The CP starts to record the charging amount from the pile owner's authorization. After the charging, the total charging amount is sent to the smart contract for transaction generation. The smart contract sends the generated transaction to the bookkeeper, and then the transaction bookkeeper publishes it to the blockchain. The transaction smart contract is shown in Fig. 4.

A. Installation

Smart contracts are jointly formulated by multiple users in the blockchain. By analogy, transaction smart contract is formulated by the power transmission towers. The contract which determines the rights and obligations of the parties in the transaction is programmed. Once the contract is triggered, it is automatically executed and cannot be changed. The EV sends a charging request to the blockchain to trigger a smart contract after identifying a specific charging user and a CP for it.

B. Execution

The transaction smart contract will be executed after reaching the trigger conditions. First, the smart contract verifies the identity of the EV. After that, the owner of the EV obtains the information of the pile owner, then contacts the pile owner and places the sufficient deposit to the smart contract. When the pile owner receives the message that the deposit is successfully delivered, he will authorize the EV to charge. Here, the EV can use the CP to charge. During the charging process, the charging amount is recorded by the smart meter on the CP, and the total charging amount used is sent to the smart contract to form a transaction at the end of the charging. Finally, the smart contract evaluates the behavior of the EV during the charging process, and gives a reputation-based score for selecting the accounting EV. At the same time, the EV behavior score is also the basis for evaluating the CP.

C. Aggregation

When the charging is completed, the execution of the smart contract ends and a transaction is formed. The newly generated charging transaction is gathered to the transaction bookkeeper transmission tower. After confirmation, it is packaged and sent to the blockchain.

### *3.4. Incentive mechanism*

After the EV is charged, in order to enable users to have a better charging experience and encourage CPs to serve users better, this framework designs an evaluation mechanism to establish service quality evaluation values for pile owners, and then this service evaluation value is recorded on the blockchain. If other users choose the CP again, they will refer to this service evaluation value. Most of the bookkeepers that record the service evaluation value are EV users with limited computing power and possible malice [31,32]. Therefore, the EVs used for accounting are selected by a reputation-based consensus mechanism, and package the quality evaluation and send it to the blockchain.

When the EV is fully charged, the smart contract will evaluate the behavior of the EV, with three evaluation levels of "excellent", "fair" and "failed". After rating, the credibility evaluation is performed according

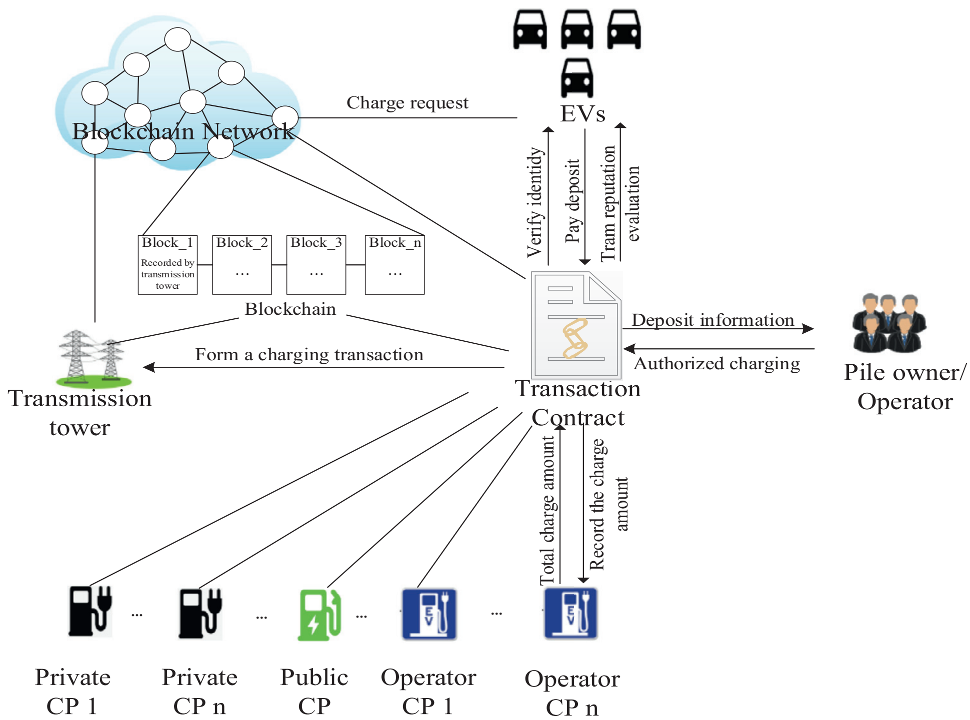


**Fig. 4.** Transaction smart contract.

to

$$R_v = \sum_{i=0}^{I} B_{vi} \tag{1}$$

Let $B_{vi} \in \{-1, 0, +1\}$ denote the reward points obtained or deducted by EVs $v$ after the $i-th$ charging transaction is completed. Under the correct payment, $B_{vi} = 1$ means that the obtained evaluation is "excellent", that is, the EV's operation is standard. $B_{vi} = 0$ means that the obtained evaluation is "fair", that is, there is no malicious operation. $B_{vi} = -1$ means that the obtained evaluation is "failed", that is, the EV operates maliciously. If the credibility is lower than the threshold set by the system, that is, $R_v < R_{v,min}$, or if the fee is not paid after charging, the user will not be able to use the charging service normally. The initial value and threshold of the credibility are set to 0.

The system recommends suitable CPs to users with normal credibility based on comprehensive factors such as the quality evaluation of CPs, price, and location. The charging service evaluation $R_{cp,n}$ is continuously updated with the increase of the number of transactions $n$, and the formula (2) is based on the evaluation mechanism of literature [20] where the charging service evaluation of the CP is calculated according to the ratings given by users with different credibility.

$$\begin{cases} E_n = R_{cp,n-1}/D \\ \Phi(R_{cp,n-1}) = 1 - \frac{1}{1+e^{\frac{-(R_{cp,n-1}-D)}{\sigma}}} \\ R_{cp,n} = R_{cp,n-1} + \frac{1}{\mu}\Phi(R_{cp,n-1})R_v(W_n - E_n) \end{cases} \tag{2}$$

In (2), $R_{cp,n-1}$represents the $n-1th$ transaction service evaluation of the CP. $\mu > 1$ is the adjustment coefficient which can determine the speed of service evaluation changement after transaction evaluation. The value of can be adjusted so that the evaluation of CPs with low evaluations will not always be affected by bad evaluations in the past after the service capacity is improved. $W_n\{1,2,3\}$ is the score made by users with a reputation of $R_v$; $E_n$ is the score expected by the CP; $D$ is the highest level in the service evaluation, and $D = 3$ in this paper; $\Phi(R_{cp,n-1})$ is the damping function [20] that makes the change of the charging service evaluation value tend to be gentle; $\sigma$ is the acceleration factor in the damping function. Algorithm pseudo code is shown in Algorithm 3.

**Algorithm 3** Incentive mechanism for evaluation

**Input:** $\sigma$, $I$, $R_{cp,n-1}$, $\mu > 1$, $D = 3$, $R_{v,min} = 0$
**Output:** $R_v$, $R_{cp,n}$

```
if R_v < R_v,min then
    Charging operation
    // Phase 1: Evaluate the EV behavior:
        Get B_vi ∈ {−1, 0, +1} ;
        Update R_v by the following formula
```

$$R_v = \sum_{i=0}^{I} B_{vi};$$

```
    // Phase 2: Evaluate the CPs service:
        Vehicles v give the W_n ∈ {1, 2, 3};
        Adjust parameters μ;
        Calculate E_n = R_cp,n−1 / D;
        And Φ(R_cp,n−1) = 1 − 1/(1+e^(−(R_cp,n−1 − D)/σ));
        Obtain R_v by the following formula;
```

$$R_{cp,n} = R_{cp,n-1} + \frac{1}{\mu}\Phi(R_{cp,n-1})R_v(W_n - E_n)$$

;

**end if**

To prevent EVs evaluating maliciously, the reputation of EV users is considered while calculating the service quality of CPs. In this way, the incentive mechanism can not only motivate CPs to improve their own charging service level, but also solve the selection problem of EV's bookkeeper. Within a certain time T, the system selects the EV with the highest reputation score in this area as the bookkeeper, which can have the right to free bills or obtain coupons.

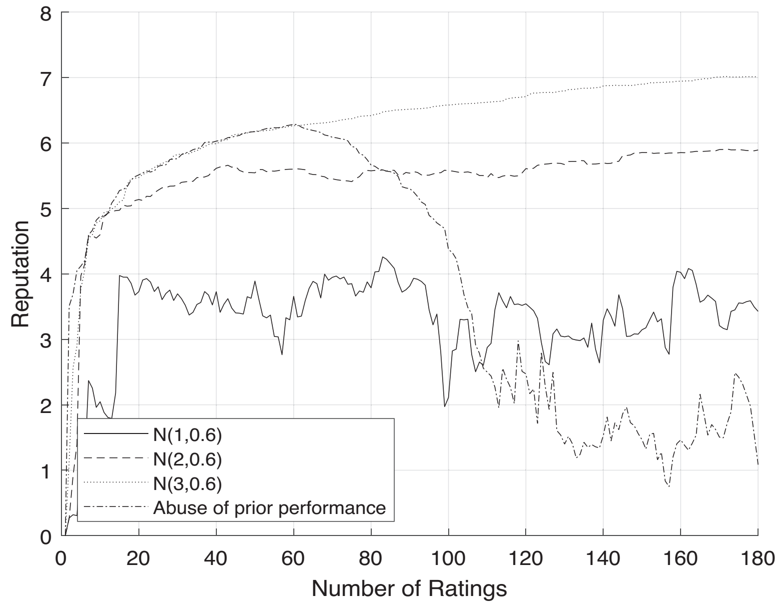


**Fig. 5.** Incentive mechanism simulation results.

## 4. Experiment

### 4.1. Evaluating incentive mechanism

In this section, we firstly verify the effect of the incentive mechanism and select CPs with excellent, good, and poor service quality to simulate users' reputation scores. Then, in another experiment, market factors are introduced into CPs with excellent service quality, that is, after reaching a certain reputation value, the service quality of CPs starts to decline and deceive users. In addition, we test the cost of the pricing smart contract by verifying the gas consumption. In order to evaluate the reputation-based incentive mechanism, we apply the algorithm to different situations. The evaluation result is shown in Fig. 5. We select 4 CPs with 180 evaluations for testing. The user ratings of the first, the second, and the third CPs obey $N(1, 0.6)$, $N(2, 0.6)$, $N(3, 0.6)$ respectively. The fourth CP introduces market factor that at the beginning, its behavior is reliable until it reaches a high reputation, and then it starts to abuse its reputation for fraud. This phenomenon is shown in the experiment as: the first 60 user ratings obey $N(3, 0.6)$, the last 120 user ratings obey $N(0.3, 0.6)$. From the performance of the first three CPs, generally speaking, the better the service quality of the CP is, the higher its reputation value is. In addition, the better the service quality of the CP is, the easier its reputation value will converge. When the service quality of the CP is low, its reputation value changes greatly without convergence. Judging from the performance of the fourth CP, when a user with a high reputation value starts to cheat, the users' score will drop, and fluctuate around the quality level of the CP finally.

### 4.2. Overheads of pricing smart contract

The pricing smart contract proposed in this paper is programmed through solidity. The execution of the smart contract is triggered by the state transition of the interface, so it is necessary to deploy the pricing smart contract on Remix to measure its consumption. The main gas consumption of pricing smart contract is shown in Fig. 6. Since the process of auction game involves much interact and states transition, these processes consume much gas, which takes up the main consumption of smart contract.

## 5. Advantage analysis

The architecture proposed in this paper has the following advantages.

(1) System security

As we all know, traditional third-party charging platforms centrally store all important information, including transaction information, user information, etc. Therefore, third-party platforms are vulnerable to single-point failures, data tampering, and other attacks, being hackers' targets. So we propose a shared charging architecture based on blockchain. Compared with traditional platforms, this architecture uses blockchain, which has the characteristics of decentralization, anonymity, and immutability, as the underlying technology to solve the problems of traditional platforms and ensure data security and privacy. In addition, compared with other blockchain-based shared charging architectures, this architecture uses different consensus mechanisms to select different bookkeepers to ensure safety and save resources, according to the different information that each participant needs to store on the blockchain and accounting characteristics. Pricing, deposit, authorizations, transactions, and other operations that are complex and vulnerable to attacks are executed by smart contracts to ensure their safety. The incentive mechanism is designed to encourage EVs to compete for the right to keep accounts, regulate their own behavior, and encourage CPs to improve their charging services. This architecture, which is jointly participated by EV time-sharing leasing operators, CP operators, private pile owners, EV users, etc., establishes a trusted environment of shared charging multi-party participation from three aspects: safe storage, safe computing, and safe incentive.

(2) Service quality improvement

The existing third-party shared charging platform only displays the operator's CPs and does not display the shared information of private piles, leading that the utilization rate of CPs is low. EV owners always need to download multiple APPs when they go out. Besides, they also face the difficulty in payment after charging, so the efficiency is very low. In the blockchain architecture proposed in this paper, private CPs, public CPs, and operator CPs are all placed on the same shared charging platform, which improves the efficiency of CPs. During the charging process, the important information that needs to be recorded is placed on the blockchain to ensure the safety of charging and the privacy of user

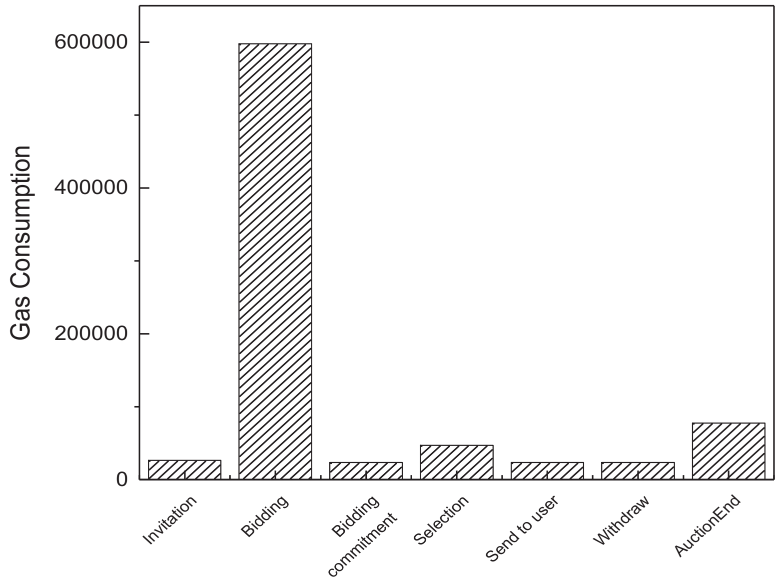


**Fig. 6.** The main gas consumption of pricing smart contract.

information. What's more, two different types of blocks are generated. In order to share information, this architecture puts all blocks on the same blockchain and adds pointers for quick query in the block. So as to encourage CPs to better serve users, a reputation-based evaluation mechanism is used to incentivize EVs to compete for accounting rights, and the service evaluation of CPs is calculated based on the EV's own reputation and its scoring for CPs.

(3) Pricing fairness

Since the existing CP sharing platform is opaque for the pricing of CPs, it is extremely easy for third parties to tamper with data on CPs of other operators or private piles for their own benefit. This architecture improves the fairness of pricing via blockchain and smart contract technology, and negotiates the charging price via multi-party fair pricing technology to reduce the cost of third-party platforms, and improve the utilization of CPs. The pricing contract proposed in this framework determines the optimal pricing response strategy through multi-party pricing auction game model analysis, realizing multi-party safe and fair pricing. The pricing contract makes all idle CPs to take part in the bidding, and the process of bidding is in public. All CPs participating in the bidding can adjust their prices according to the prices given by others until the price converges. The system recommends the most suitable CP to the user based on the pricing, location, and rating given by the CP to improve the service quality of the CP.

(4) Multi-information storage and query

In other researches on blockchain architecture for shared charging, the blockchain usually only stores information about charging transactions. However, in this architecture, in order to ensure transaction security and user privacy, user information and CP information and others are all recorded on the blockchain. When CPs and EVs need to verify identity verification, user identity certificate information can be obtained from the blockchain for verification. When the EV is charged, the generated charging transaction block and service evaluation block are recorded by the transmission tower and the accounting EV as the bookkeeper respectively to solve the problem of multi-information storage. When charging is required, in order to search the required information in all information quickly, we add pointers in the transaction: the pointer of the charging transaction points to the last charging transaction of the corresponding CP; the evaluation information transaction pointer of the CP points to the CP evaluated; the evaluation information transaction pointer of the EV points to the last charging transaction that the EV participated in the last time.

## 6. Conclusions and Future Work

Firstly, this paper analyzes the current status and problems of shared charging. Then the state-of-the-art literature to the field of shared charging based on blockchain is investigated. Afterwards, we proposed an blockchain-based architecture for shared charging to record different types of blocks. What's more, it is smart contracts that solve complex and vulnerable operations such as pricing, deposit, authorization and transactions, and make sure the simplicity and safety of shared charging operations. In addition, the reputation-based incentive mechanism whose function encourages that EVs are to be a bookkeeper and that CPs provide better services for EVs is employed to evaluate EVs and CPs. Finally, this paper analyzes the advantages of the proposed architecture.

In addition, moving forward, the key technology of shared charging based on blockchain can also be studied in the following aspects:

(1) Consensus mechanism:

The shared charging blockchain needs to record charging transactions, identity information, charging authorization records, charging service quality and other information to achieve a trust environment built by multiple parties. There are differences in the confirmation and consensus of different types of information. Therefore, in order to publish different types of information to the blockchain, designing a consensus mechanism between bookkeepers and achieving consensus across the network will be an important research.

(2) Multi-party fair pricing:

Shared charging involves private CPs, public CPs, and CPs of various charging operators. Different EV users have different requirements for charging speed, charging price and service quality. Therefore, how to realize the transparent pricing of various CPs and design a multi-party fair pricing strategy that meets the individual requirements of all parties is a problem that needs to be further resolved.

(3) Two-way privacy authentication:

If the shared charging blockchain wants to realize the interconnection of information among operators, private pile owners, public CPs, and EV users, it is necessary to realize two-way authentication between each operator and EV users, or private pile owner and EV users. However, the authentication process will cause the leakage of identity privacy, location privacy or data privacy of each participant. Therefore, how to protect the privacy of each participant in the process of implementing two-way authentication is a challenging issue.

## Declaration of Competing Interest

The authors declared that they have no conflicts of interest to this work.

Authors declare that they do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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