A Peer-2-Peer Management and Secure Policy of the Energy Internet in Smart Microgrids

Shenghong Ding, Jun Zeng, Zongkang Hu, and Yang Yang

***Abstract*—A peer-to-peer (P2P) energy trading (ET) scheme has been presented in numerous scenarios within the industrial Internet of Things (IIoT), such as vehicle-to-grid network, microgrids, and energy harvesting network. These scenarios present security and privacy issues because of the lack of trust and transparency in the energy markets. In this article, a secure ET system named energy blockchain (EBC) is proposed in order to overcome the security issues. An EBC is suitable for P2P ET situations in which trusted intermediaries are not needed. Similarly, a credit-based payment method to help eliminate ET delays due to transaction confirmation delays on the EBC is proposed. In addition, an optimal pricing method according to the Stackelberg game has been suggested for credit-based loans. According to a real dataset, security analysis and numerical outcomes indicate that the suggested blockchain and payment layout based on credit are both effective and safe in IIoT.**

***Index Terms*—Blockchain (BC), energy trading (ET), industrial Internet of Things (IIoT), privacy and security, Stackelberg game.**

1. Introduction

ACADEMIC and industrial researchers are increasingly interested in the industrial Internet of Things (IIoTs) that is the key to transforming industrial systems in the coming years [1]. IIoT enables industrial systems to be connected and intelligent by sensors and actuators with ubiquitous computing and networking [2]. In contrast, the increasing energy requirements of IIoT applications present a great challenge to industrial systems, especially since the number and performance demands of IIoT' ties are soaring [3]. Peer-to-peer energy trading (P2P-ET) between IIoT ties, such as electric vehicles (EVs), has been proposed to meet this issue in prior research [4]. Ties of the IIoT could exchange surplus energy with one another via P2P trading to meet local energy demand, reduce transfer losses and increase energy performance in order to achieve green industrial systems.

The green industrial system has incorporated numerous advanced technologies, including wireless power transfer, vehicle-to-grid (V2G), and energy harvesting network (EHN) [5]. These technologies together enable industrial systems to expand ET scenarios that are effective and sustainable [4]. P2P-ET scenarios for IIoT can be divided into three categories as follows.

1) *Microgrids* (MGs): wind generators and solar panels on smart buildings take advantage of ambient energy to harvest and exchange energy amongst themselves on a P2P basis.
2) *Energy Harvesting Network:* Industrial ties with EHN capabilities are able to generate power from clean energy sources, as well as can be charged via mobile chargers that use wireless power transfer technology through P2P-ET.
3) *V2G Network:* The EV served as energy storage tools by charging at load valleys and feeding the energy into the electrical network at peaks to decrease the power grid load. Local aggregators allow charging vehicles to sell the power to neighbor ones in the P2P mode [6], [7].

Despite being a vital component of the IIoT, P2P-ET faces privacy and security issues in general.

1) IIoT ties cannot conduct large-scale energy trading (ET) in nontransparent and untrusted markets without security concerns.
2) The privacy concerns of IIoT ties with surplus energy might prevent them from participating as energy suppliers [8]. There is an imbalance between energy supply and demand among ties of the IIoT.
3) To ensure that IIoT ties' transaction records are audited and verified, there is an intermediary in P2P-ET. Among the issues faced by this intermediary are privacy leakage and single points of failure [9].

For this reason, a secure and unified system for ET needs to be designed in IIoT [9]. Furthermore, IIoT devices with surplus energy must be encouraged to act as sellers of energy through the design of appropriate incentives.

Due to its benefits in decentralization, anonymity and trust, blockchain (BC) technology is being investigated in ET in recent years. Bitcoin is built on top of BC technology, a distributed and open ledger which systematically has recorded transactions in the secure and permanent method. Renewable ET in smart grids

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has been made possible by the development of "NRGcoin" on the basis of Bitcoin protocols. As a part of decentralized smart grids, [9] used multisignature BCs to combat transaction security issues. Nevertheless, these methods might not be effective for P2P-ET between IIoT ties because establishing a general BC is really costly.

Based on [7], consortium BC is a promising technology for establishing decentralized ET systems with moderate costs. Consortium BCs are special BCs which have authorized ties in order to keep distributed shared databases. Using consortium BC technology inspired by [7], the present article develops a P2P-ET system with consortium BCs, called energy BC (EBC). Several IIoT scenarios, such as V2G described in [7], can be impacted by the EBC. Contrary to [7], here, a typical P2P-ET scenario in IIoT is observed, rather than the price of electricity trading. Next, a unified ET frame which includes aggregators, energy purchasers, and sellers is presented. The EBC is based on aggregators pre-selected for public auditing and sharing of records under general ET scenarios without requiring trusted intermediaries. In addition, the EBC has similar transaction confirmation delays to those in Bitcoin, which results in slow transactions and reduced performance [10]. As a solution to this issue, a payment based on credit layout that supports frequent and rapid ET has been suggested here. The ties of IIoT could complete fast payments by using for loans from banks according to their credit amounts. The optimum loan pricing scheme for credit bank (CB) in IIoT has been suggested for the purpose of maximizing CB utility.

The present article, compared to the existing researches, has some major contributions as follows.

1) *Unified EBC:* A typical ET scenario is observed and unified EBC with moderate costs is established for IIoT.
2) *Credit-Based Payment:* A credit-based payment layout that supports frequent ET with fast payments is designed in order to minimize the limitation transaction confirmation delay.
3) *Optimal Pricing Strategy:* To enhance the CB's utility, we present the optimum pricing method applying Stackelberg games for loan according to the credit has been suggested for the credit-based payment layout. Based on outcomes, it is concluded that this suggested EBC and payment system according to the credit are practical and useful.

II. BC Activated ET for IIoT

A. United P2P-ET Scheme

Among IIoT ties, P2P-ET occurs ubiquitously with the aim of balancing power demand and supply. The three generic P2P-ET cases for ET are shown in Fig. 1, namely V2G network, MG, and EHN. Typical ET scenarios should present a unified ET frame and a secure ET BC for establishing an EBC [11]. In summary, there are three entities of the unified ET framework.

1) *Energy Ties:* P2P-ET involves various roles from ties of IIoT (such as EVs, smart buildings, and industrial sensors): energy sellers and purchasers and unemployed ties which do not trade energy. Ties choose their own roles according to their prevalent energy status and subsequent plans.
2) *Energy Aggregators* (EAGs): The EAG manages occurrences based on trading and provides wireless communications for sensors of IIoT. Each EAG corresponds to a different type of physical entity. The enhanced metering infrastructure in MGs would be an EAG, for example. It is possible to have an advanced based station with computing and storage capabilities as an EAG in EHN. Local aggregators can serve as EAGs in V2G systems.

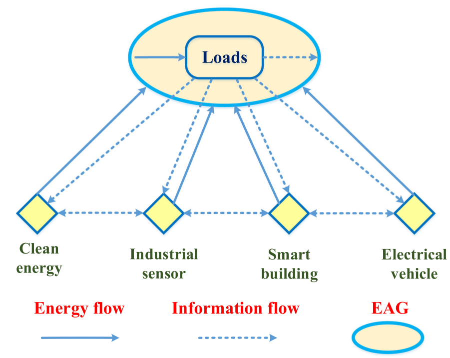

Fig. 1. Generic ET cases in IIoT.

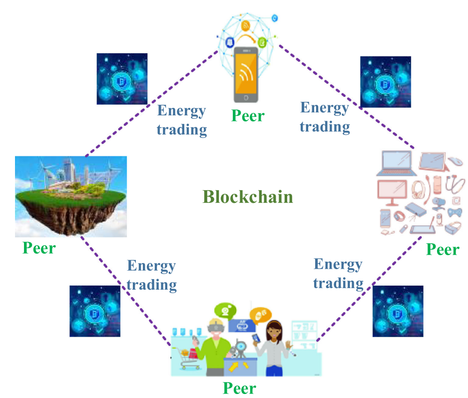

Fig. 2. Secure P2P-ET with EBC.

An EAG consists of four entities is shown in Fig. 2: memory pool (MP); account pool; CB; and transaction server. Transaction servers collect energy demands from energy ties, and match ET pairs among these ties. In order to trade energy in IIoT, a digital cryptocurrency referred to as energy coin (EC) is used as energy ties' digital assets [7]. There is an EC account for every energy tie with the aim of storing personal transaction records. Personal ECs can be managed in a corresponding wallet on this account. Energy ties use random pseudonyms for public keys of their wallet, and they are called wallet addresses, replacing the actual wallet address for privacy purposes.

In local account pools, each wallet and its corresponding wallet address are mapped to each other as well as EC accounts. Energy ties' personal wallet addresses are recorded in the account pools of EAGs. Whole transaction records of local energy ties are stored in MP.

Smart Meters: Smart meters built into IIoT ties track and calculate traded energy in real time. Based on the records of smart meters records, the energy purchaser pays the energy seller.

B. Unified EBC for Secure P2P-ET

By exploiting consortium BC, an EBC can be established on the basis of the unified P2P-ET frame to support secure P2P-ET. The consensus process, known as a transaction inspection stage, is the first step towards forming a BC from transactions for traditional BCs. Whole ties in traditional BCs carry out this process at high costs. EBCs, on the other hand, perform consensus on preselected EAGs at moderate costs. The EAGs maintain their local transaction records. Once the consensus process between the EAGs is complete, the transaction records have been structured into blocks and the MP stores them.

Details about the key operations supported by EAGs in the EBC are as follows.

1) *System Initialization:* An effective Boneh–Boyen short signature layout can be used to initialize systems in EBC. The energy ties become legitimate entities after being registered with the trusted authority like the government sector. An energy tie k with true identity ID_k has joined the system and achieved the certificate (Cert_k) and public and private keys $(\mathrm{PK}_k$ and $\mathrm{SK}_k)$. With binding registration information, the certificate Cert_k represents a unique way of identifying an energy tie. Tie k has received a set of ω wallet addresses $\{\mathrm{WID}_{k,l}\}_{l=1}^{\omega}$ from the authority. The authority has generated a mapping list $\{\mathrm{ID}_k,\ \mathrm{PK}_k,\ \mathrm{SK}_k,\ \mathrm{Cert}_k, \{\mathrm{WID}_{k,l}\}_{l=1}^{\omega}\}$, and stored the list in the account pools. Wallet addresses of tie k are uploaded to its nearest EAG account pool during system initialization. In tie k, the wallet integrity is verified, and it gets the last information concerning the wallet from the MP and the EAG-CB.

All transaction records are stored in the EBC by the MP and credit payments are recorded by the CB.

2) *Choosing Roles in ET:* Energy ties (energy purchasers and sellers) in P2P-ET select their roles according to the prevalent energy conditions and subsequent power demands. To address local energy demands from purchasers, Excess energy ties might become energy dealers.

3) *ET Among Sellers and Purchasers:* Energy demands which consists of the extent of energy from energy purchasers have been transferred to the transaction server of the close EAG. Transaction servers work as controllers in the EAG, counting the total energy requirements and transmitting them to local sellers. In addition, the EAG acts as a dealers for energy ties, setting dealt prices based on prevalent energy markets and encouraging local energy vendors to participate. The energy vendors have determined the selling power and provided replies to the controller. The controller manages the power request and supply within the energy ties. After that, wireless power/power lines transmit the energy from the power vendors to relevant purchasers.

4) *Payments Using ECs:* ECs have been transmitted from the wallet of a purchaser to the wallet address of the seller through an energy purchaser, as illustrated in Fig 2. Section III provides additional details. For the purpose of verifying this payment activity, the energy seller gathers the most current BC information from the EAG's MP. Novel transaction records are generated by the energy purchasers. Energy sellers verify and digitally sign these transaction records, so these records have been uploaded to EAGs for inspection. Then, both energy sellers and purchasers receive an increase in credit values.

The EBC provides incentives so that ties address their local energy requests out of self-interest, as a means to balance energy demand and supply. Based on the participation metering of energy flows among purchasers and sellers, the energy purchaser with the largest participation to energy providing within the EAG has been given ECs. The proof-of-flow is the special proof-of-work (PoW) for energy ties of energy participations, (like the entire amount of energy traded).

5) *Building Blocks in EBC:* Each EAG has collected total local transaction archives over the specified duration and next encrypted signed each record to ensure its authenticity. The transaction records have been structured into blocks as can be seen in Fig. 2. Every block consists of a cryptographic hash that points back to the previous blocks of the EBC in order to provide verification and traceability. EAGs attempt to discover their own PoW regarding datum survey (such as a hash amount meeting the specified hardness) like Bitcoin. The EAG computes the hash content of the block according to the random nonce amount ϑ, the prior block hash amount, time-stamp, and merkle root of transactions (known as $\mathrm{history_{data}}$) [12]. Videlicet, $\mathrm{Hash}(\vartheta +\ \mathrm{history_{data}}) <\ \mathrm{Difficulty}$. The system is able to adjust Difficulty with the aim of controlling the speed of identifying the certain ϑ. Once an authentic PoW (such as ϑ) is found, the quicker miner (EAG) has broadcasted the block and the certain ϑ to the further EAGs. The further EAGs have audited and verified the transaction archives in the block and ϑ. The datum in this block would be added to the EBC in a linear, chronological order if the other EAGs approve it, and the fastest miner will be rewarded with ECs.

6) *Carrying Out Consensus Process:* The chief that is the most rapid EAG with an authentic PoW and the authorized EAGs carry out the consensus process. The leader has broadcasted block data, times-tamp, and PoW to the further permitted EAGs provide inspection and validation. The EAGs have audited the block datum and broadcasted their verification outcomes with their signatures among themselves to provide a reciprocal verification and supervision. When the inspection outcomes are received, any EAG has compared its outcomes with the others and sent the response back to the chief. The response contains the inspection outcome of EAG, comparison outcome, signatures, and archives of gained inspection outcomes. The obtained responses from EAGs is analyzed by the leader. When whole EAGs have agreed on the block information, the chief would send a record consisting of prevalent audited block datum and the relevant signature to whole permitted EAGs. These blocks are then added to the consortium BC, and the leader has been rewarded by ECs. In case some EAGs disagree with the block information, the chief analyzes the inspection outcomes, and if needed, sends it back to the EAGs for inspection.

EBCs are very scalable and could support network scale with many IIoT ties. In contrast to public BCs, consensus of the

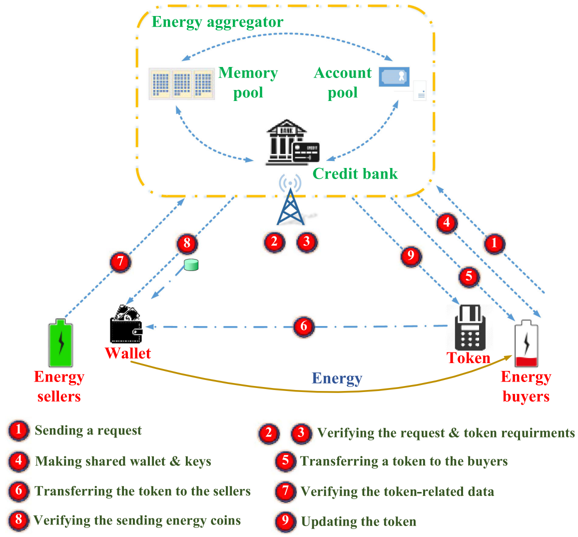

Fig. 3. Payment scheme based on credit for P2P-ET.

EBC occurs among a few authorized EAGs [13]. During the growth of the network, the predefined ties can also scale the calculating power and storage sources in response to the rise in the transaction numbers [14]. No matter what size the network is, the time taken to reach consensus of a new block is constant once the EAGs have been formed [15].

III. Payment Based on Credit for Rapid P2P_ET

Transaction records in new blocks are audited and verified by whole authorized EAGs in EBC (such as the consensus process). Consensus is completed after a certain amount of time, known as the transaction confirmation time. Therefore, ECs for the payment of transactions are sent to the relevant wallets address. IIoT ties are still unable to trade energy regularly, even though the EBC's transaction confirmation time is shorter than Bitcoin's time (about 60 min) [16], [17]. Energy purchasers might not have any ECs in order to trade energy regularly. In order to solve this issue, a credit-based payment layout is developed that makes it possible to have P2P-ET frequently by EC loans.

As shown in Fig. 3, any authorized EAG has a CB that operates as a trusted bank tie that has sufficient ECs. Energy ties can obtain EC loans from CBs based on the credit amounts, and the EC would then be transmitted through accounts of CB to the addresses of wallet which are divided among the borrowers and CBs.

Here is additional information about the credit-based payment layout.

1) *Token Requesting:* In order to complete payments, a borrower ψ_k (such as a purchaser of energy k who does not have sufficient ECs) is able to use for tokens according to the credit amount through the local CB.

a) *Stage 1:* ψ_k has sent a demand consisting of the correct identity ID_k, certificate Cert_k, whole applied wallet addresses $\{\mathrm{WID}_{k,l}\}_{l=1}^{K}$, loan quantity amount_i, and prevalent credit amount Cerdit_k to the EAG m, videlicet, $\psi_k \rightarrow \mathrm{EAG}_m : \mathrm{request}_k = \{\mathrm{ID}_k\|\{\mathrm{WID}_{k,l}\}_{l=1}^{K}\|\mathrm{Cert}_k\|\mathrm{credit}_k\|\mathrm{amount}_k\}$.

b) *Stage 2:* When $\mathrm{request}_k$ is received, the CB has verified the identity of ψ_k and checked fund-flows of the given $\{\mathrm{WID}_{k,l}\}_{l=1}^{K}$ based on the archives in account pools and CBs. So the CB computes prevalent asset of ψ_k.

c) *Stage 3:* The below conditions must be met for ψ_k to get a token: energycoin account of $\psi_k$has some wealth; there is a regular income for the account (such as selling the energy to obtain ECs); and the ψ_k's credit amount is positive. The CB computes an optimum loan content of ψ_k and the relevant penalty and interest rates, such as prices of loan. Section IV provides additional information about loan pricing.

d) *Stage 4:* The CB has created a divided wallet $(\mathrm{wallet}_{cb}^{k})$ and sent private key and public key of the wallet (i.e., PK_{cb}^{k}, and SK_{cb}^{k}) to ψ_k. The PK_{cb}^{k} indicates the divided wallet addresses for ψ_k and the CB. Two ψ_k and the CB have been permitted to apply the ECs in wallet_{cb}^{k}, and fill the wallet if needed.

e) *Stage 5:* ψ_k has received a reply consisting of a token (Token_k) and the token signature $\mathrm{Sign}_{SK_{cb}}(\mathrm{Token}_k)$ are as follows:

$$\mathrm{EAG_m} \rightarrow \psi_\mathrm{k} : \mathrm{response}$$
$$= \left\{ \begin{array}{l} \left(\mathrm{PK_{cb}^{k}},\ \mathrm{SK_{cb}^{k}}\right) \|\mathrm{Token_k}\|\mathrm{Sign_{SK_{cb}}} \\ \left(\mathrm{Token_k}\right) \|\mathrm{Timestamp} \end{array} \right\}$$
$$\text{where}\ \ \mathrm{Token_k}$$
$$= \left\{ \begin{array}{l} \mathrm{balance_k}\|\mathrm{t}\|\mathrm{Cert_{cb}^{k}}\|\mathrm{amount_k}\|\mathrm{Cert_{c|b}} \\ \|\mathrm{buffer}\|\mathrm{pre-record_k}\|Timestamp \end{array} \right\}$$
$$\text{and}\ \ \mathrm{pre-record_k}$$
$$= \{\mathrm{RP_k(s,f)}\|\mathrm{Hash(TX_k)}_{\mathrm{k}\ =12,\ldots,\mathrm{h}}\}.$$

f) n which, Token_k consists of current balance $\mathrm{balance}_k$, loan amount amount_k, an authorization certificate Cert_{cb}^{k}, validity duration t of wallet_{cb}^{k}, loan repayment buffer buffer, and prior loan archives $\mathrm{pre-record}_k$. ψ_k must pay EC loan during $buffer$ again, Aside from that, ψ_k would endure with the fee delays (i.e., penalty). $\mathrm{pre-record}_k$ includes a loan repayment record $\mathrm{RP}_k(s,f)$ and the hash amount of prior payment according on the credit archives $\mathrm{Hash}(TX_k)$. In $\mathrm{RP}_k(s,f)$, s refers to the number of loan repayments during buffer in prior archives of loan, however f shows the number of nontimely repayment of loans.

2) *ECs Payment:* Throughout ET, ψ_k applies ECs in wallet_{cb}^{k} to complete payment. Any payment according to the wallet_{cb}^{k} has been recorded and confirmed via the local CB. The CB has put the hash amount of payment relevant datum into $\mathrm{pre-record}_k$ in order to check out wealth of ψ_k If needed. Here is additional information about payment operations:.

a) *Step 1:* The borrower ψ_k has sent the following $\mathrm{Payment}$ consisting of the token $(\mathrm{Token_k})$, the token signing and license certificate $(\mathrm{Cert_{cb}^{k}})$ to the seller of energy $\mathrm{S_i}$.

S_i has verified Cert_{cb}^k and the validity duration of wallet_{cb}^k $(i.e.,\ t)$ in Token_k, and checked whole prior payment according to the credit archives in the EBC in order to verify prevalent balance in wallet_{cb}^k.

$$\psi_k \rightarrow S_i : \mathrm{Payment}$$
$$= \{\mathrm{Token}_k \| \mathrm{Cert}_k \| \mathrm{Cert}_{cb}^k \mathrm{Sign}_{SK_k}\left(\mathrm{Token}_k\right) \| \mathrm{Timestamp}.$$

b) *Step 2:* S_i has sent the Token_k, the energy bill, and the wallet address in order to receive ECs (WID_{S_i}), a digital signing of the mentioned data to the CB

$$S_i \rightarrow \mathrm{EAG}_m : \mathrm{Energy}_{\mathrm{bill}}$$
$$= \{\mathrm{Cert}_i \| \mathrm{Bill} \| \mathrm{WID}_{S_i} \| \mathrm{Payment} \|$$
$$\mathrm{Sign}_{\mathrm{SK_i}}\left(\mathrm{Payment}\right) \| \mathrm{Timestamp}\}.$$

c) *Step 3:* The CB has verified the receiving $\mathrm{Token_k}$ via comparing to the original $\mathrm{Token_k}$ recorded in the CB. The CB has checked which if the balance in $\mathrm{Token_k}$ is sufficient in order to pay for the Bill. If yes, the CB has transferred ECs in $\mathrm{wallet_{cb}^k}$ to $\mathrm{WID_{S_i}}$in order to complete payment. If no, the CB has sent a notification of inadequate equilibrium to ψ_k.

d) *Step 4:* Then, the CB has updated equilibrium information of $\mathrm{wallet_{cb}^k}$and $\mathrm{Token_k}$, and added the digital signing to the novel token $\mathrm{Token_k^{new}}$. The mentioned payment according to the credit archives has been recorded and audited in the EBC, the new token will be transfer to the purchaser simultaneously.

3) *Repayment of EC Loans:* Once credibility period of token_k, ψ_k has received the latest token $\mathrm{Token}_k^{\mathrm{newest}}$ consisting of whole hash amounts of the payment according to the credit archives applying token_k.

Here are three states of loan repayments.

a) *State One:* ψ_k is repaid the loan with the interest as the dealing fee to the CB if ψ_k can repay the EC loan during the repayment buffer. Section IV computes the benefit.

b) *State Two:* If ψ_k is not be able to refund the loan timely, f in $\mathrm{RP}_k(s, f)$ would be added one, and the credit amount of the purchaser would be reduced. The novel credit amount of the purchaser has been shown by, $\mathrm{Credit}_{n+1}^k = \mathrm{Credit}_n^k - d$
amount_i in which Credit_n^k is the credit amount of n^{th} energy transaction. d shows a stable and $d > 0$. The CB has generated an archive regarding to the occurrence, and so stored the archive in the MP and uploaded it to the EBC. ψ_k still suffered the penalty relating to the loan value after completing the EC loan repayment.

c) *State Three:* If ψ_k has rejected to repay or is not be able to refund the loan within a long-term, like one year, the CB has placed the borrower to the blacklist and broadcasted the data to whole ties in the EBC. After that, whole IIoT ties and CBs have rejected with the aim of cooperating with the borrower.

IV. Optimum Loan Pricing in Payment According to the Credit

The present part offers the description of the issue of the loan pricing value and EC loan amount (such as penalty and interest rates) for borrowers in order to enhance the economic advantages of CBs. Energy purchasers with insufficient ECs work as borrower in order to use for loan from the CB within the local EAG. Then, the borrower who acted as energy purchaser is able to purchase energy from energy seller.

In the local EAG_m, for the borrower ψ_k, the loan content given via a CB m(i.e., CB_m) has been shown as R_k. where $k \in \mathbb{I}$ and $\psi_k \in \mathbb{B}$. $\Gamma_k^{\min}$ shows the minimum energy resource demand for ψ_k and ρ_k indicates the defined price of the energy source in advance of loan demands. The CB should supply $\frac{R_k}{\rho_k}$ loan to ψ_k in order to finish energy payment. The local CB is considered to have sufficient ECs in order to support loan requests of borrowers. CBs that are near each other are able to cooperate to meet loan requests if one local CB lacks sufficient ECs for borrowers. The $\psi_k's$ satisfaction function is given by

$$u_{\mathrm{sat}} = d_k \ \ln\left(\frac{R_k}{\rho_k} - \Gamma_k^{\min} + \phi_k\right). \tag{1}$$

In which $d_k > 0$ and $\phi_k > 0$ shows predefined factors for ψ_k. The $\psi_k's$ utility is given by

$$u_k = \xi_k \ [u_{\mathrm{sat}} - \beta_k R_k t_k] - (1 - \xi_k)\,\sigma_k R_k. \tag{2}$$

where ξ_k defines the capability to repay the loan, videlicet, this is the probability which ψ_k is able to refund the loan during the refund buffer. The loan repayment record $RP_k(s, f)$ of ψ_k can be used to calculate ξ_k (as noted in in Section III). Where $0 < \xi_k = \frac{s}{s+f} \leq 1$. Interest rate of the loan is shown through ψ_k which is determined via the CB. Penalty rate of the repayment delay is donated by σ_k. $\sigma_k = \varrho_k\ t_k \beta_k$ is considered as the relationship among the interest rate and the penalty rate [18]. Where $\varrho_k > 1$ shows a predefined factor, such as 3.5, and is the time when the loan started is shown by $t_k > 0$.

The prize of the CB includes the loan interest from ψ_k, and the delayed cost (such as penalty) if ψ_k is not be able to refund the loan timely [18].$R_k t_k c_k$ shows the overhead of the CB. The unity cost of ψ_k's loan for the CB is donated by c_k. So, The CB's economic benefits can be summarized in the following way:

$$u_{bc}^k = \zeta_k \ [\beta_k R_k t_k - R_k t_k c_k] + (1 - \zeta_k)\,\sigma_k R_k. \tag{3}$$

In which ζ_k shows predetermined credit grade (CG) index relating to ψ_k's CG determined via the CB (there, $0 < \zeta_k \leq 1$). Loan histories of borrowers can be used to calculate ζ_k. In accordance with energy purchasers' credit values, energy purchasers' CGs are categorized into various levels. Higher CG starts higher ζ_k. Section V-C provides additional information about the value of ζ_k.

An uncooperative Stackelberg game is formulated in the article, in which the borrowers are followers and a CB is a chief. Ultimately, the penalty amount is specified through the CB (i.e., σ_k) for any borrower, respectively. Any borrower would reply with the best value of loan $(i.e., R_k)$ based on the penalty index determined via the CB. According to its strategic definition, $\mathbb{G}$ is

$$\mathbb{G} = \{(\mathbb{B} \cup \{CB_m\}), \{u_k\}_{k\epsilon\mathbb{I}}, \{u_{bc}^k\}_{k\epsilon\mathbb{I}}, R_k, \sigma_k. \quad (4)$$

The objective functions for the follower and chief into the local EAG have been shown in the following, way, respectively:

$$\text{Leader} : \max_{\sigma_k} \sum_{k=1}^{\mathbb{I}} u_{bc}^k(\sigma_k), \text{ s.t., } \sigma_k \geq 0$$

$$\text{Follower} : \max_{R_k} u_k(R_k), \text{ s.t., } R_k > \Gamma_k^{\min}\rho_k - \phi_k\rho_k. \quad (5)$$

In order to solve the Stackelberg equilibrium for the above-formulated game, the backward induction method is used, that has been taken from [20].

V. Analyze the Security and Numerical Outcomes

Firstly, a security analysis of the EBC is provided here. Then, the EBC 's efficiency is evaluated and a real dataset is used in order to assess the efficiency of the credit-based payment layout.

A. Security Analysis on EBC

To protect the privacy and security of ET, a consortium BC is used by the EBC in contrast to traditional communication security and privacy protection. The BC-relevant security efficiencies have been summarized below [22].

1) *Get Rid of the Reputable Intermediary:* The ties of IIoT trade energy in a P2P manner in the EBC instead of traditional centralized trading that relies on global trusted intermediaries. IIoT ties with authorized EAGs are entitled to trade energy equally. The EBCs are scalable and robust without the need for a globally trusted intermediary.
2) *Wallet Security:* An adversary is not able to open the IIoT tie's wallet and abduct ECs if it lacks corresponding certificates and keys. Since any tie of IIoT has a specific wallet associated with the EC bill, multiplex wallet addresses are used as pseudonyms of the wallet to protect the privacy.
3) *Transaction Authentication:* Other entities, such as IIoT ties and trusted EAGs, inspection and authenticate whole transaction data publicly. Because of high costs, compromising whole entities on the EBC is not possible. A transaction information with something wrong would still be detected and fixed before being structured into a block even if the EAG has been compromised.
4) *Data Unforgeability:* Consortium BC's decentralized nature along with digitally-signed transactions guarantees that adversaries cannot act as ties of IIoT in order to corrupt the network. This is due to the fact that the adversary is not be able to forge the digital signature of a tie/control most of the resources of the system [22]. Due to encryption with IIoT tie keys, an adversary who controls one or more EAGs in the EBC is able to learn nothing about the raw data. The audited and stored data are not able to be forged by the adversary in the EBC [16].
5) *No Double-Cost:* The EC uses digital signatures in order to ascertain possession and a public record of transactions in order to avoid double cost. A P2P network is used to share transaction histories, and PoW is used to verify transactions.

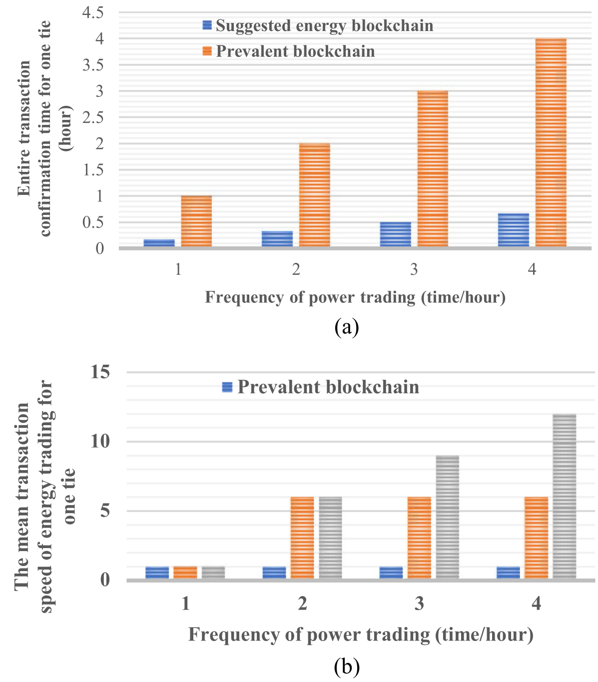

Fig. 4. Proficiency comparison concerning. (a) Dealing verification time. (b) Dealing velocity.

B. Performance Analysis on EBC

The confirmation time of transactions under various frequencies of ET in several BCs is compared in this article, and the efficiency of the mean dealing velocity of the suggested payment layout according to the credit is evaluated. Dealing velocity is defined as the number of completed ET per hour. The entire dealing verification time on the mean is equal to the mean time of completing the consensus procedure of the ET for an energy tie. For illustration purposes, the efficiency of fifty couples of IIoT ties for 4 hours is simulated. Traditional BCs confirm transactions in 60 min, such as Bitcoin, while the EBC confirms transactions in 10 min [20]. ET 'frequency can take amounts from set $\{1, 2, 3, 4, 5\}$ with equivalent probability for ties of IIoT within an hour. The wallet of any IIoT tie contains 20 ECs for P2P-ET.

According to Fig 4(a), when the ET ' frequency rises, the total confirmation time on the average for an energy tie for a traditional BC (such as Bitcoin) takes longer compared to that of the EBC. As opposed to the traditional BC, the EBC has carried out consensus just on the prechosen EAGs in lieu of whole joint ties. The average transaction speed of ET in various layouts is illustrated in Fig 4(b). Ties with insufficient ECs are not able to carry out the next ET until the last ET has completed the consensus process. Based on Fig 4(b), the EBC and the traditional BC both contain the upper limit for the mean dealing velocity within an hour. The EAG's payment layout according to the credit has a faster average dealing velocity

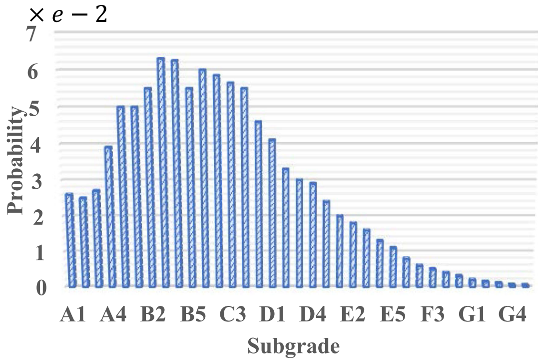

Fig. 5. Probability distribution diagram of the credit ratings in an actual dataset.

due to the assistance of CBs. IIoT ties benefit from these CBs because adequate EC is provided to enable continuous ET on the EBC without being impeded by transaction confirmation delays. According to outcomes, the suggested system facilitates fast P2P-ET, making it possible for frequent trading between ties of IIoT.

C. Proficiency Analysis on Payment According to Credit

The efficiency of suggested payment layout according to credit on the basis of an actual dataset from the loans issued by the lenders club in [23] is examined in article. Current loan status (such as fully paid), credit values, addresses, and latest payment information are included in the dataset. Based on the loan information of lenders club, Fig. 5 shows 890 000 observations with 35 incrementally rising CGs ($"A1", "A2", \ldots, "B1", "B2", \ldots, "G4", "G5"$). A total of 100 borrowers with various CGs ranging from A1 to G5 in IIoT are considered. The n^{th} CG includes a relevant CG ratio $r_n = 1 - \frac{n-1}{N}$, here $N = 35$. Based on the probability distribution histogram in Fig. 5, it is possible to determine whether a borrower belongs to a particular CG. There is a division of the borrowers into 5 groups for applying for EC loans from five CBs, respectively. Loans are provided to 20 borrowers at any CB with restricted ECs. Two heuristic distribution layouts of ECs are investigated in order to compare efficiency with the suggested layout. One heuristic layout allows borrowers to request a random extent of ECs from 5 CBs. Another layout is that borrowers may use for the mean value ECs. Based on information about borrowers (such as credit value, income, loan records), the proper pricing decisions for them is made. Table I gives further parameters about the suggested layout.

It is worth noting that peer to peer technique has some significant advantages, compared to the centralized control and tries to give some benefits for the distributed management. Therefore, it is expected that the computational burden would be distributed among all agents. Fig. 6(a) compares the efficiency of EC distribution layouts. As an instance, the loan interest price is set at 0.1 using random value layout (RVL) and mean value layout (MVL). The suggested layout is able to provide CBs with optimal economic benefits. According to the suggested layout, the mean economic advantage for 5 CBs is 226.9% higher compared

TABLE I
VARIABLES AND COEFFICIENTS ADJUSTING

Variable	Predefined factor			Unit penalty	Repayment ability	CG factor	Loan unit cost
	d_k	ϕ_k	t_k (month)	ϱ_k	ξ_k	ζ_k	c_k
Value	[2,2.04] $\times\, e4$	[2,2.5] $\times\, e3$	(0,10]	3.5	(0,1]	[0,1]	[1,2] $\times\, e - 1$

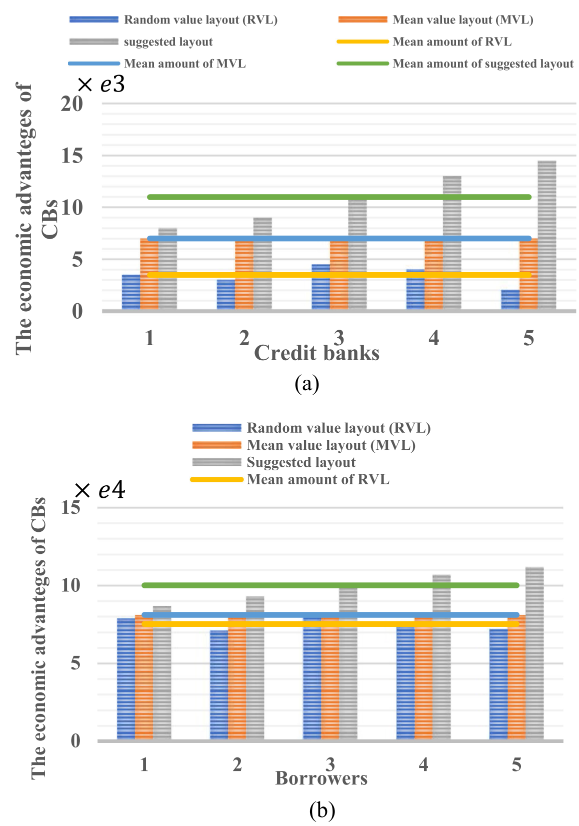

Fig. 6. Proficiency comparison concerning economic advantages of (a) CBs and (b) borrowers.

to that for RVL, and 64.8% higher compared to that for MVL. Fig 6(b) shows the same outcomes. In the suggested layout, the mean economic advantage for five borrowers randomly selected is 5.7% higher compared to that of RVL, and 24.1% higher compared to that of MVL.

The convergence progress of the economic advantages of the randomly selected CB and optimum loan extent of the randomly selected borrower is shown in Fig 7, respectively. It is evident that each of the economic advantages and the optimum loan extent quickly approach their optimum amounts after 19 iterations, respectively.

Efficiency effects of CG ratio ζ_k on CB, and effects of ξ_k on borrowers are shown in Fig. 8. According to Fig. 8(a),

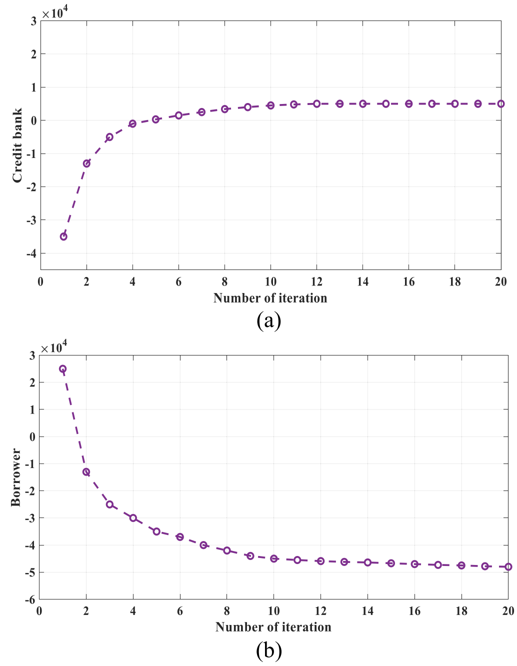

Fig. 7. Convergence progress. (a) Economic advantages of the CB. (b) Optimum loan extent of the borrows.

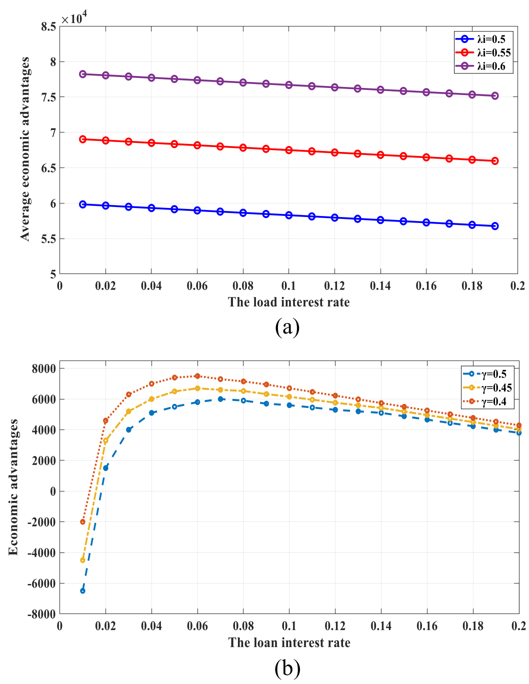

Fig. 8. Variables impacts of variable adjusting. (a) Mean economic advantages of borrowers. (b) Economic advantages of CB.

the economic advantages of CB reduce as ζ_k rises. Due to the fact that a borrower with a premiere CG is more likely to refund the loan timely, leading to a lower penalty for the CB. Fig. 8(b) illustrates how the repayment capability of borrower ξ_k helps improve the economic benefit average for borrowers. The findings in Figs. 4–8 support the conclusion that the suggested EBC and a credit-based payment layout are useful and effective in ET in the IIoT. The proposed technique can be improved by using advanced technologies, e.g., Internet of things and Ad hoc [24]–[25], which are the future work of this article.

VI. Conclusion

In this article, a unified EBC according to consortium BC for securing ET in several typical IIoT scenarios was presented that includes including V2Gs, MGs, and EHNs. In order to avoid the transaction delays that result from transaction confirmation, a credit-based payment layout was developed that facilitates frequent and fast ET between energy ties via credit-based payments. In order to maximize CB's economic benefits, an optimum pricing plan for EC loans according to the Stackelberg game was offered. In order to assess the EBC and the payment layout according to the credit, security and efficiency analyses are performed, respectively. Based on a security analysis, the EBC provides a safe ET, and outcomes indicate that the credit-based payment layout and EBC were efficient and useful for ET. Further study of a few interesting issues was worthwhile, like optimizing the number of energy aggregators and devising specific layouts for extreme scenarios, such as ties with very poor or very good credit values. Results demonstrate the high efficiency of the proposed technique, compared to the existing techniques.

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