Blockchain-based Reverse Auction for V2V charging in smart grid environment

Zakaria Abou El Houda[1,3], Abdelhakim Senhaji Hafid[1], and Lyes Khoukhi[2]

[1]NRL, Department of Computer Science and Operational Research, University of Montreal, Canada
[2]GREYC CNRS, ENSICAEN, Normandie University, France
[3]ICD, University of Technology of Troyes, France
zakaria.abou.el.houda@umontreal.ca, ahafid@iro.umontreal.ca
lyes.khoukhi@ensicaen.fr

***Abstract*—The emergence of Internet of Energy (IoE) paves the way for sustainable and green energy environments that reduce energy costs and integrate Renewable Energy Sources (RESs) as new sources of energy. Electric vehicles (EVs) are one of the main actors of IoE future. The emergence of EVs promises to reduce the environmental crisis (e.g., carbon emissions); however, their charging process will consume massive amounts of electricity and may affect the reliability of the Smart Grid (SG). Recently, vehicle-to-vehicle (V2V) electricity trading approach has gained momentum as a novel strategy that reduces the peak power consumption in SG. In this context, EVs compete to provide electricity with lower prices, while maintaining the V2V electricity trading system secure. However, they lack flexibility, transparency, and authenticity. More importantly, they are based on centralized models (i.e., EV aggregators) which introduce single-point-of-failure and may cause the collapse of the system. In this paper, we propose a fully decentralized blockchain-based system that allows for an automated, fair, and trustworthy V2V electricity trading system; it uses Ethereum's smart contracts to realize the V2V electricity trading system in a fully distributed, transparent, secure, tamper-proof and trustworthy manner. The proposed system is implemented, tested, and deployed on the Ethereum official test network Ropsten. The experiment results show that the proposed solution achieves security, flexibility, efficiency, and cost effectiveness making it a promising solution to new decentralized V2V electricity trading systems in SG.**

***Index Terms*—SG; IoE; V2V; reverse auction; Blockchain.**

I. Introduction

SMART GRID (SG) is the next-generation grid that will play a vital role in modern power systems and will transform classical power grids into the Internet of Energy (IoE). SG proposes the integration of distributed energy resources (DERs) and Renewable Energy Sources (RESs) (e.g., solar and wind energy) as new sources of energy; these sources reduce costs as well as dependency on fossil fuels and integrate sustainable energy resources to improve energy efficiency and allow for green environments. The Electric Power Research Institute (EPRI) estimates that the full development of smart grid will save from $1.3 to $2 trillion [1]. Electric vehicles (EVs) are considered one of the main actors of IoE. EVs aim to reduce greenhouse gases emissions and improve energy efficiency. The large widespread adoption of EVs as well as their high penetration levels will stress the power grid and may cause significant damages. This problem will become more relevant as more EVs are interconnected to the power grid e.g., EVs do not get charged. Moreover, the traditional vehicle-to-grid (V2G) and grid-to-vehicle (G2V) operations are facing numerous challenges related to the security, stability, and reliability of the power system operations i.e., grid congestion [2]. To deal with this issue, vehicle-to-vehicle (V2V) electricity trading has gained momentum from both academia and industry as a new strategy to reduce costs and improve the efficiency and the reliability of the power grid. However, the current V2V electricity trading systems need a centralized third party (i.e., EV aggregator) to maintain the V2V system and to handle the electricity payment between EVs; this introduces a bottleneck that may lead to severe system failures i.e., large-scale blackout that affects other critical infrastructures (e.g., healthcare and transport). Blockchain technology opens the door for a plethora of new types of decentralized applications in a variety of new domains (e.g., security [3]–[7], IoT [8], [9], and Smart Grid [10]). Particularly, it addresses the challenges faced by current centralized V2V electricity trading systems and systematically removes the third parties and intermediaries that introduce additional fees. Due to the decentralized structure of V2V systems, blockchain is an efficient technology that will ensure trust between EVs in such trust-less environments (i.e., SG), and create the future underlying infrastructure for SG. Furthermore, blockchain will allow for a fully automated execution of mutual agreements between EVs using smart contracts.

In this paper, we present the design, specification and implementation of a blockchain-based system that uses Ethereum's smart contracts. The objective is to realize a V2V electricity trading system that is fully decentralized, transparent, secure, tamper-proof, trustworthy, flexible, reliable, and efficient manner.

The implementation of the proposed system is deployed on the Ethereum official test network Ropsten [11], an open blockchain platform. The main contributions of this paper are summarized as follows:

- We propose a V2V smart contract-based system that

makes use of Ethereum's blockchain, to realize a decentralized, secure, trustworthy, flexible and low-cost V2V electricity trading system in SG.
- We design an automated and fair blockchain-based scheme that handles the payment of electricity traded between EVs in a fully automated, transparent and secure manner.
- We propose a blockchain-based scheme for decentralized auctioning in SG; it uses a reverse auction to allows for a fair and an open competitive electricity market between EVs.
- We evaluate the performance of the proposed system in terms of flexibility, security, cost effectiveness and efficiency. The experimental results show that the proposed system achieves flexibility, efficiency, security, and cost effectiveness making it a promising solution to new decentralized V2V electricity trading systems in SG.

The remainder of this paper is organized as follows. Section II presents related works. Section III introduces the system design of the proposed V2V electricity trading system. Section IV presents the implementation of the proposed system. Section V discusses the evaluation of the proposed system. Finally, Section VI concludes the paper.

II. Related Work

Blockchain technology has the potential to radically disrupt the electricity market with its promising key features of decentralization, transparency and immutability. The Peer-to-Peer (P2P) nature of blockchain makes it an ideal candidate for V2V electricity trading systems. Direct P2P electricity trading will remove the need for third parties and lead to cost saving for both parties (i.e., EVs consumers and EVs electricity providers). The Security of V2V systems has been an active research and has gained momentum from both academia and industry; Indeed, several V2V electricity trading systems have been proposed. In the following, we overview some of the most prominent systems.

In [12], Chen et al. proposed an electricity appliance scheduling scheme that uses renewable energy devices and time-varying electricity prices to minimize electricity costs for end-users. However, the proposed scheme considers only the electricity appliance scheduling without allowing end-users to sell their surplus of energy from renewable energy batteries. In [13], Chen et al. extended their previous work [12] to address this problem; however, the reliability and security of the proposed trading system are not considered. In [14], Lam et al. designed a new multi-layer energy trading system among electric vehicles (EVs) and the smart grid environment. In [14], a double auction scheme is used to trade surplus energy between plug-in hybrid electric vehicles (PHEVs), aggregators (i.e., sellers) and SG. The proposed scheme [14] is based on the traditional vehicle-to-grid (V2G) approach which may stress the power grid and may cause significant damages to the power grid (i.e., stability, and reliability of the power system). Moreover, the centralized nature of the proposed scheme introduces a bottleneck and causes the single-point-of-failure. In order to secure the operations in SG, several solutions [15]–[17] proposed the use of public-key infrastructure (PKI) and certificates. Firstly, the centralized nature of these solutions introduces a bottleneck and causes the single-point-of-failure. Secondly, the costs to maintain and setup such solutions are very high.

In [18], Alvaro et al. proposed a new Peer-to-Peer (P2P) energy trading system that significantly reduces energy demands during the peak periods in SG. Firstly, the proposed system can only support a limited number of electric vehicles (EVs). Secondly, a central entity (i.e., EV aggregator) is required to handle the electricity payment and the scheduling of EVs charging and discharging, which causes the single-point-of-failure that may collapse the trading system. In [19], Kang et al. proposed a P2P electricity trading system among plug-in hybrid electric vehicles (PHEVs) using consortium blockchain; it allows for a secure and private locally P2P energy trading system. The proposed system [19] ensures privacy, anonymity, and trust. However, only a small number of peers maintain the blockchain and by targeting those specific peers, an attacker can easily halt the blockchain operations. Moreover, the proposed system did not consider the payment of energy traded between end-users and suffers from the lack of flexibility and authenticity. In [20], Aitzhan et al. proposed a decentralized and secure energy trading system using blockchain technology. The proposed system [20] ensures an anonymous energy prices negotiation; it also provides a secure and fair payment of electricity traded between end-users through multi-signatures and anonymous encrypted message propagation streams. Moreover, the proposed system removes the need for a trusted third party and ensures reliability, security, and privacy. However, the flexibility, profit maximization, and the authenticity of end-users are not considered. In [21], Luo et al. proposed a distributed energy trading system using multi-agent coalition and blockchain. The proposed system contains two layers: (1) an agent coalition that allows for P2P trading and negotiation of electricity between end-users; and (2) a blockchain based layer to control demand response in SG. However, a fair payment of electricity cost, authenticity of end-users and the flexibility are not considered.

To address the shortcomings of the existing solutions [12]-[21], we propose an efficient, flexible, transparent, secure, low-cost, trustworthy and decentralized V2V energy trading system. The proposed system allows EVs (with no limit on the number of EVs) to securely trade their surplus electricity in a decentralized manner based on blockchain using Ethereum's smart contract. An automated and fair payment is integrated with a reverse auction scheme to allow for a fair and competitive V2V energy market; in addition, the proposed V2V electricity trading system removes the need to third parties and enforces permissions to authenticate end-users (i.e., EVs).

III. System design

A. Overview

This section presents a general overview of the proposed vehicle-to-vehicle (V2V) electricity trading system. More specifically, we explain how our proposed system ensures: (1) a fair and automated payment of electricity traded between EVs; (2) a fair and an open competitive V2V electricity market; and (3) an off-chain mutual authentication between EVs.

Fig. 1 shows that our proposed V2V electricity trading system has two main entities: blockchain network (i.e., Ethereum blockchain) and EVs that can be either consumers or electricity providers. Consumers that need electricity (i.e., EV's charging), and electricity providers that trade their surplus electricity in a fully secure and decentralized manner. To facilitate and secure the system of V2V electricity trading in local communities, EVs communicate with each other through our proposed system based on blockchain using smart contracts.

Blockchain network provides a decentralized, secure, transparent, trustworthy, and immutable infrastructure to manage V2V electricity trading system. The matching between the EV consumer and EVs electricity providers as well as the payment of electricity traded between them are based on the blockchain using smart contracts; it consists of: (1) the management functions that add/remove the EVs to/from the V2V trading system; thus, ensuring their authentication; (2) an auction scheme that allows the EV consumer to obtain a lower price from various number of EVs electricity providers through a fair and transparent competition; and (3) an off-chain mutual authentication between the EV consumer and the EV electricity provider that offers the lower price through the use of access tokens. Our proposed V2V electricity trading system is executed on each node in the blockchain network (i.e., Ethereum blockchain) which removes the need for a centralized third party to maintain the electricity transaction and to handle the payment.

EV electricity providers are the owners of EVs that want to trade their surplus electricity through our V2V electricity trading system using Ethereum's blockchain. They monitor and transmit electricity needs to Ethereum's blockchain network through our Ethereum's smart contacts.

EV consumers are the owners of the EV that need to charge his EV through our V2V electricity trading system using Ethereum's blockchain. An EV consumer can interact with EV electricity providers using his Externally Owned Account (EOA) (i.e., the identity of EV in the blockchain) through his mobile phone. To allow lightweight devices (i.e., EVs) to join the blockchain network. The EVs are not required to store the entire copy of blockchain, they can be a light blockchain nodes.

B. *V2V'S Smart Contract*

First, the organization (i.e., contract owner) that aims to manage the V2V electricity trading system between EVs needs to create V2V's smart contract and deploy it on Ethereum blockchain. The use of Ethereum blockchain allows for immutability, "pseudonymity", and transparency. To this end, the organization (o) generates a keypair of private key (i.e., o.EPK) and the corresponding Externally Owned Account (o.EOA). Then, it executes the functions of the smart contract (SC). The V2V's smart contract provides the organization with the flexibility: (1) to add authorized EVs, via SC, to the V2V electricity trading system; it includes the EV's address and other information (e.g., EV notes); (2) to manage the V2V electricity trading system in a fully decentralized and transparent manner; and (3) to remove EVs from the V2V electricity trading system if needed. Similarly, it provides the EV with the flexibility to easily add/remove bids to/from the V2V electricity trading system. The V2V's smart contract is programmed using solidity language [22]. In the following, for sake of simplicity, we provide only some of the functions of our V2V's smart contract; where EV denotes an instance of an EV; now is the time passed in seconds since 1970; msg.sender is the address of the user that sent the transaction to V2V's smart contract.

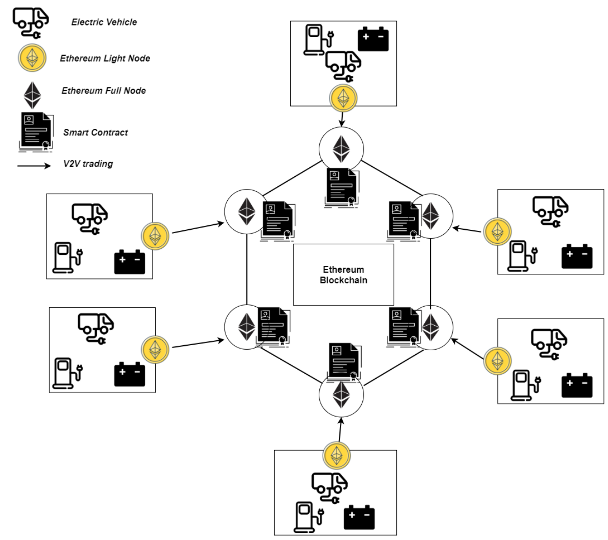

Fig. 1. V2V blockchain-based framework

Algorithm 1 : addEV

```
Input  : EV.EOA, EV.Infos
Output: null
if msg.sender is not owner then
  | throw;
end
if status is not true then
  | throw;
end
if isEV(EV.EOA) == true then
  | throw;
else
  |  length ←EVsAdr.push(EV.EOA)
  |  EVs[EV.EOA]←EV(EV.EOA,EV.Infos, now, length-1)
  |  emit EVAdded(EV.EOA, EV.Infos)
  |  numberOfEVs++
end
```

addEV(EV.EOA, EV.Infos): this function can only be called by the owner of the V2V's smart contract to add EV; it takes EV.EOA and other information (EV.Infos) as arguments. It adds the EV to the V2V electricity trading system as well as the timestamp of when the EV was added. Algorithm 1 illustrates the logic of this function.

Recently, reverse auction has caught the attention of both academia and industry as a competitive bidding approach to trade services with an optimal price [23]. In reverse auction, the roles of EV consumers and EV electricity providers are reversed from forward auction; once an EV consumer is authenticated, he initiates an electricity request through the V2V's smart contract within their community. Then, EV electricity providers, that are authenticated, bid for the price at which they are willing to sell their surplus electricity. At the end of the auction, the best EV electricity provider with the lowest bid wins the auction.

Fig. 2 shows the sequence diagram that exhibits interactions among EV consumers, EV electricity providers, and the smart contract; it includes the calls and the triggered events. EV consumer starts the auction after making a deposit in order to ensure a honest behavior. In this latter, it specifies the amount of energy needed (KWh), the bidding time, and the auction's start price. Afterwards, EV electricity providers start sending their bids to the V2V's smart contract. If the EV electricity provider's bid succeeds, an equivalent amount is taken as deposit and his address is hold in the bid for further connection; otherwise, the bid is not accepted. Once the auction time is over, EV consumers end the auction by calling the function of the V2V's smart contract. This latter calculates the electricity cost (see Eq. 1) and generates the access token needed for the off-chain mutual authentication. The access token is a unique hash created for each EV consumer; it includes, the EV consumer Ethereum address (EVC.EOA), the EV electricity provider Ethereum address (EVP.EOA), the block timestamp (BTS) and the access token time validity (TV); in our implementation, token = keccak256 (EVC.EOA, EVP.EOA, BTS, TV). This access token is signed using the EVC private key (i.e., EVC.EPK), then sent with the corresponding public key (i.e., EVC.PK) to EVP. EVP checks the validity of the signature and the token; if both are valid, EVP provides the required electricity to EVC. Once done, EVC ends the connection. Then, the V2V's smart contract transfers the fee as well as the locked deposit to the EV electricity provider and the remaining balance to the EV consumer (see algo. 2).

$$Cost = Rate * Amount \tag{1}$$

IV. Implementation

The process of deployment is elaborated using truffle framework [24], a decentralized application development framework. First, we have coded the V2V smart contract using the high-level language programming solidity. Then, we compiled it into Ethereum Virtual Machine (EVM) byte code; once compiled, an Application Binary Interface (ABI) is generated.

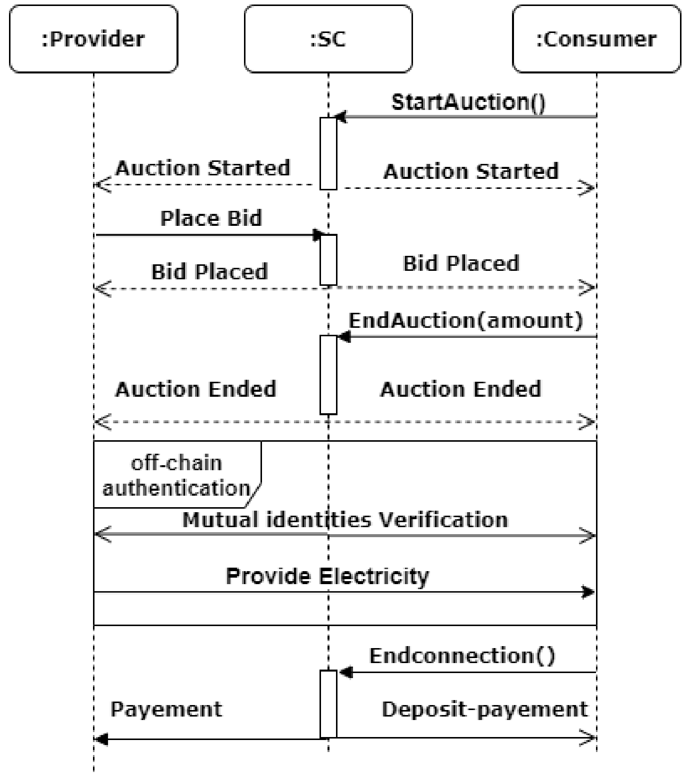

Fig. 2. The Sequence diagram showing the function calls and events of the reverse auction process

Then, we have deployed the V2V smart contract to the blockchain (i.e., Ethereum blockchain). Once it is deployed, it can be self-executed without any human intervention. The efficiency of our V2V smart contract is tested on private as well as public blockchain. First, we have deployed our smart contract-based framework on a private blockchain using Ganache, an Ethereum simulator used for testing the smart contract in a fast way. Afterwards, we have deployed our smart contract-based on a public blockchain (i.e., Ethereum official test network Ropsten). The details of transactions can be found using Ropsten Etherscan.

V. Evaluation

In this section, we evaluate the performance of our proposed V2V electricity trading system in terms of flexibility, eligibility, security, cost effectiveness and efficiency.

A. *Flexibility/Easy-to-Deploy*

Our proposed V2V electricity trading system provides two levels of flexibility: (1) It provides the organization (i.e., contract owner) with the flexibility to easily add/remove EVs to/from the V2V trading system. Similarly, it provides EV consumers with the flexibility to easily add/remove bids to/from the V2V electricity trading system; and (2) It provides the organization with the flexibility to easily join/leave the V2V electricity trading system. To join the V2V electricity trading system, the organization deploys the V2V smart contract;

TABLE I
TRANSACTION DETAILS OF V2V SMART CONTRACT

Details of V2V smart contract Creation Transaction in Ropsten test network	
TxHash	0x0052bd27cc98672b7b43ec793dfb84a672010085f59f3cf05e7a14ff3c77f055
Block Height	7898726
Timestamp	May-13-2020 11:43:01 PM +UTC
From	0xa70836a9a115f774cb848134d0f8b2473e27d181
To	0xc48476043bd09b453ece7c29888230edd3dfbc64
Actual Cost (Ether) Tx	0.00230298 Ether

and to leave, the organization deactivates the V2V electricity trading system using the function ChangeStatus(). All these updates are transparent, immutable and can be verified by anyone in the blockchain (i.e., Ethereum blockchain network).

Algorithm 2 : V2V Connection

Input : EVP.EOA, amount
Output: null
if *status is not true* **then**
  throw;
end
if *msg.sender is not EVC* **then**
  throw;
end
if *EVP.EOA is not EVP* **then**
  throw;
end
if *Bids[msg.sender].status is false* **then**
  throw;
end
if *Bids[msg.sender].closingTime* $>$ *now* **then**
  throw;
end
if *Bids[msg.sender].lowestBid == address(0)* **then**
  throw;
else
  fee ←amount*Bids[msg.sender].lowestBid
  EVC[msg.sender].deposit←–cost
  token←keccak256(msg.sender, EVP.EOA, timestamp, validity)
  EVC[msg.sender].token←token
  emit Connected(EVP.EOA,msg.sender,token,validity);
end

B. Eligibility

Only approved/authorized EVs (i.e., consumers and providers) that are authenticated can participate in the V2V electricity trading system; this is achieved using modifiers i.e., "OnlyOwner" allows only the creator of the contract (i.e., the organization) to execute addEV(), removeEV(), and changeStatus() functions. If an authorized EV tries to execute these functions, the execution will fail. The same restriction rule applies for the "OnlyEVs" modifier to allow only EVs (and also the organization) to place bids, generate access tokens and initiate/end V2V connections.

C. Low cost

In this section, we estimate the costs of the functions used in our V2V smart contract. When we conducted the experiment, the gasPrice was set to $1Gwei$, where $1Gwei = 10^9\ wei = 10^{-9}ether$, and 1 ether was equal to 198.27 USD.

Table. 2 shows our V2V smart contract's operation cost of different functions. The V2V contract creation is performed only once to setup the V2V electricity trading system and costs 0.456 USD. When an EV joins the V2V electricity trading system, the addEV() function needs to be performed and costes 0.015 USD. When an EV is removed, the removeEV() function needs to be performed and costes 0.006 USD. When an EV consumer starts an auction, he needs only to pay 0.024 USD. To place a bid, EV electricty provider needs only to pay 0.032 USD. Similarly, to end the auction/connection, the EV consumer needs only to pay 0.005 USD and 0.004 USD, respectively. Therefore, all functions, provided by our V2V smart contract, have low costs. Thus, the proposed V2V electricity trading system is cost effective.

TABLE II
V2V SMART CONTRACT CREATION AND FUNCTIONS COSTS

Function	Gas Used	Actual Cost(ether)	USD
create V2V smart contract	2302980	0.00230298	0.456
addEV()	76821	0.000076821	0.015
removeEV()	33469	0.000033469	0.006
StartAuction()	121350	0.00012135	0.024
PlaceBid()	165107	0.000165107	0.032
EndAuction()	29167	0.000029167	0.005
EndConnection()	21136	0.000021136	0.004
changeStatus()	30163	0.000030163	0.005

TABLE III
SECURITY ANALYSIS OF OUR V2V SMART CONTRACT

Parameters	V2V smart contract
EVM Code Coverage	86
Integer Underflow	False
Parity Multisig Bug 2	False
Callstack Depth Attack Vulnerability	False
Transaction-Ordering Dependence (TOD)	False
Timestamp Dependency	False
Re-Entrancy Vulnerability	False

D. Security Analysis

First, our V2V electricity trading system ensures transparency and preserves "pseudonymity"; it ensures the integrity since all the V2V electricity trading transactions and events are recorded on the Ethereum blockchain; moreover, these transactions are cryptographically signed by EVs. Thus, ensuring the Non-repudiation. Our proposed V2V electricity trading system does not suffer from single-point-of-failure problem since it runs on a decentralized platform (i.e.,Ethereum blockchain). There is no need to a centralized third party to maintain the V2V energy system; thus, the reliability and availability of the functions of the V2V electricity trading system are guaranteed.

The proposed V2V electricity trading system is analyzed against well-known security vulnerabilities [25] using Oyente analyzer [26]. These vulnerabilities are critical and may allow an adversary to cause collateral damage and gain profit from the smart contract. Table 3 shows the results of the vulnerability analysis of our V2V smart contract as well as its EVM code coverage. The results show that our V2V smart contract is secure, bug-free, and safe against the well-known security vulnerabilities (i.e., all results were "False"). The results also show that there was no vulnerability related to the Ethereum platform which may result in the form of parity multisig bug 2, transaction ordering dependency, or time-stamp dependency.

VI. Conclusion

In this paper, we proposed a V2V electricity trading system based on blockchain using Ethereum's smart contracts. The proposed V2V smart contract has been tested, evaluated and deployed on Ethereum official test network Ropsten; the experiments results showed that the proposed system achieved security, flexibility, efficiency, and cost effectiveness making it a promising solution to new decentralized V2V electricity trading systems in smart grid environments.

Appendix A

The V2V smart contract was deployed on Ropsten Testnet of Ethereum with the following address:
Organization Owner of account address:
0xa70836a9a115f774cb848134d0f8b2473e27d181.
V2V smart contract address:
0xc48476043bd09b453ece7c29888230edd3dfbc64.

Using this address, the transactions can be seen at:
https://ropsten.etherscan.io/.

References

[1] M. Kanellos, "Smart grid price tag benefits." Accessed: May. 1, 2020. [Online]. Available: https://www.greentechmedia.com/articles/read/smart-grid-price-tag-476-billion-benefits-2-trillion

[2] A. Bourass, S. Cherkaoui, and L. Khoukhi, "Secure optimal itinerary planning for electric vehicles in the smart grid," *IEEE Transactions on Industrial Informatics*, vol. 13, no. 6, pp. 3236–3245, 2017.

[3] Z. Abou El Houda, A. S. Hafid, and L. Khoukhi, "Cochain-sc: An intra- and inter-domain ddos mitigation scheme based on blockchain using sdn and smart contract," *IEEE Access*, vol. 7, pp. 98 893–98 907, 2019.

[4] Z. A. El Houda, L. Khoukhi, and A. Hafid, "Chainsecure - a scalable and proactive solution for protecting blockchain applications using sdn," in *2018 IEEE Global Communications Conference (GLOBECOM)*, 2018, pp. 1–6.

[5] Z. A. El Houda, A. Hafid, and L. Khoukhi, "Co-iot: A collaborative ddos mitigation scheme in iot environment based on blockchain using sdn," in *2019 IEEE Global Communications Conference (GLOBECOM)*, 2019, pp. 1–6.

[6] Z. A. E. Houda, A. Hafid, and L. Khoukhi, "Brainchain - a machine learning approach for protecting blockchain applications using sdn," in *ICC 2020 - 2020 IEEE International Conference on Communications (ICC)*, 2020, pp. 1–6.

[7] Z. Abou El Houda, L. Khoukhi, and A. Senhaji Hafid, "Bringing intelligence to software defined networks: Mitigating ddos attacks," *IEEE Transactions on Network and Service Management*, vol. 17, no. 4, pp. 2523–2535, 2020.

[8] H. Moudoud, S. Cherkaoui, and L. Khoukhi, "An iot blockchain architecture using oracles and smart contracts: the use-case of a food supply chain," in *2019 IEEE 30th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*, 2019, pp. 1–6.

[9] H. Moudoud, L. Khoukhi, and S. Cherkaoui, "Prediction and detection of fdia and ddos attacks in 5g enabled iot," *IEEE Network*, pp. 1–8, 2020.

[10] Z. A. El Houda, A. Hafid, and L. Khoukhi, "Blockchain meets AMI: Towards secure advanced metering infrastructures." To appear in procceding of IEEE ICC 2020, Dublin, June 2020.

[11] "Ropsten." Accessed: May. 1, 2020. [Online]. Available: https://ropsten.etherscan.io/

[12] S. Chen, P. Sinha, and N. B. Shroff, "Scheduling heterogeneous delay tolerant tasks in smart grid with renewable energy," in *2012 IEEE 51st IEEE Conference on Decision and Control (CDC)*, 2012, pp. 1130–1135.

[13] S. Chen, N. B. Shroff, and P. Sinha, "Heterogeneous delay tolerant task scheduling and energy management in the smart grid with renewable energy," *IEEE Journal on Selected Areas in Communications*, vol. 31, no. 7, pp. 1258–1267, 2013.

[14] A. Y. S. Lam, Longbo Huang, A. Silva, and W. Saad, "A multi-layer market for vehicle-to-grid energy trading in the smart grid," in *2012 Proceedings IEEE INFOCOM Workshops*, 2012.

[15] Y. Gong, Y. Cai, Y. Guo, and Y. Fang, "A privacy-preserving scheme for incentive-based demand response in the smart grid," *IEEE Transactions on Smart Grid*, vol. 7, no. 3, pp. 1304–1313, 2016.

[16] D. He, N. Kumar, S. Zeadally, A. Vinel, and L. T. Yang, "Efficient and privacy-preserving data aggregation scheme for smart grid against internal adversaries," *IEEE Transactions on Smart Grid*, vol. 8, no. 5, pp. 2411–2419, 2017.

[17] F. Knirsch, G. Eibl, and D. Engel, "Error-resilient masking approaches for privacy preserving data aggregation," *IEEE Transactions on Smart Grid*, vol. 9, no. 4, pp. 3351–3361, 2018.

[18] R. Alvaro-Hermana, J. Fraile-Ardanuy, P. J. Zufiria, L. Knapen, and D. Janssens, "Peer to peer energy trading with electric vehicles," *IEEE Intelligent Transportation Systems Magazine*, vol. 8, no. 3, pp. 33–44, 2016.

[19] J. Kang, R. Yu, X. Huang, S. Maharjan, Y. Zhang, and E. Hossain, "Enabling localized peer-to-peer electricity trading among plug-in hybrid electric vehicles using consortium blockchains," *IEEE Transactions on Industrial Informatics*, vol. 13, no. 6, pp. 3154–3164, 2017.

[20] N. Z. Aitzhan and D. Svetinovic, "Security and privacy in decentralized energy trading through multi-signatures, blockchain and anonymous messaging streams," *IEEE Transactions on Dependable and Secure Computing*, vol. 15, no. 5, pp. 840–852, 2018.

[21] F. Luo, Z. Y. Dong, G. Liang, J. Murata, and Z. Xu, "A distributed electricity trading system in active distribution networks based on multi-agent coalition and blockchain," *IEEE Transactions on Power Systems*, vol. 34, no. 5, pp. 4097–4108, 2019.

[22] "Solidity." Accessed: May. 1, 2020. [Online]. Available: https://solidity.readthedocs.io/en/develop/

[23] D. C. Wyld, "Current research on reverse auctions: Understanding the nature of reverse auctions and the price and process savings associated with competitive bidding," *International Journal of Managing Value and Supply Chains*, vol. 2, p. 11–23, 2011.

[24] "Truffle." Accessed: May. 1, 2020. [Online]. Available: https://truffleframework.com/

[25] N. Atzei, M. Bartoletti, and T. Cimoli, "A survey of attacks on ethereum smart contracts," *in Principles of Security and Trust. Heidelberg*, vol. 2, p. 164–186, 2017.

[26] "Oyente." Accessed: May. 1, 2020. [Online]. Available: https://github.com/ethereum/oyente