Processing Electric Vehicle Charging Transactions in a Blockchain-based Information System

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Abstract

Electromobility, electric vehicles (EVs) and charging infrastructure are major building blocks for a sustainable energy future. With the emergence of sustainable IS topics, energy informatics as the comprising research discipline receives increasing attention. One of the most contemporary research areas in this context is the adoption of electric vehicles (EVs) and their integration into the smart power grid of the future. Blockchain is a promising technology to complement lack in charging infrastructure by disrupting existing business models and enabling peer-to-peer sharing of charging stations (CSs). In this paper we investigate how to store and validate EV charging-related data on blockchain and how to process EV charging payment transactions in a blockchain-based IS. Within the ongoing research activity, we evaluate blockchain technologies regarding their applicability for this scenario. Further we implement the presented decentralized app (dApp) design and its smart contracts as a proof-of-concept for the technical feasibility of the solution, considering factors such as interoperability, data storage, trust and scalability.

Keywords

Energy Informatics, E-Mobility, Electric Vehicle Charging, Blockchain, dApp, Sharing Economy, P2P.

Introduction

Awareness for sustainability topics has increased in research communities across multiple areas. Also for the IS research discipline, Watson et al. (2010) make a strong statement to adopt Green IS and specifically Energy Informatics. The IS community has certain responsibilities to contribute to a sustainable digital future by utilizing the disrupting power of IS within this field (Dedrick 2010; Melville 2010; Watson et al. 2010). Seven years later, Elliot and Webster (2017) outline a call for more innovative empirical research contributing to the research field of environmental sustainability in IS. On the quest for a decarbonized and sustainable energy system supported by IS, electromobility is envisioned to play a fundamental role (Kossahl et al. 2012). Especially the required charging infrastructure, which links the mobility sector to smart power grids, is a central concern within the energy informatics discipline. It enables concepts such as utilization of EVs as flexible power loads or energy storage for demand response. At the same time, this leads to challenges such as integration of fast charging stations and additional loads into the power grid. While adoption of electric cars starts to rise slowly, major issues still hinder broader acceptance of e-mobility. One obstacle is the shorter range of EVs compared to combustion engine vehicles (Egbue and Long 2012). To mitigate this shortcoming, a sufficient charging infrastructure with publicly available fast and slow CSs will be necessary. The concurrent lack of public charging infrastructure constitutes a critical issue for e-mobility. Setting up, maintaining and operating a public CS, especially for fast charging, implies high costs for the owner, a private or commercial Charging Station Operator (CSO). Due to yet low demand for public charging, owning and operating a CS is in most cases economically not viable (Madina et al. 2016). The market is missing profitable business models during the current phase of low EV adoption. Within this paper, peer-to-peer (p2p) sharing of charging infrastructure will be considered as major approach to solve this two-side market problem and by making private charging options publicly available.

In this research study, we focus on the technical feasibility of blockchain-based charging transaction processing and the integration of blockchain technology into a decentralized charging IS. Blockchain technology bears potential to enable this kind of sharing model by removing 3rd party intermediaries, such as clearing houses or roaming providers. The socioeconomic perspective (including regulatory, economic constraints and business models) is important but will only partly be considered in this work. The research introduced in this paper aims at providing insights regarding the following issues:

- *How to validate and store EV charging-related data on blockchain?*
- *How to process EV charging payment transactions in a blockchain-based IS?*

We further aim to propose and develop a proof-of-concept in order to show, that blockchain enables an overlying charging IS to store charging-related data decentralized while concurrently maintaining trust. In such a decentralized blockchain-based IS, payment transactions are validated by consensus without 3rd party intermediaries and are automatically processed by smart contracts.

Theoretical Foundation

E-mobility terminology is very inconsistent among the research body. In this work, we adhere to definitions as specified by the Open Charge Alliance in the Open Charge Point Protocol (OCPP) Specification 2.0 (OpenChargeAlliance 2018). The *Electric Vehicle Supply Equipment (EVSE)* is the part of a CS which delivers energy to one EV at a time. It can be operated and managed independently from the CS. A CS can have one or multiple EVSEs. The operating software is called *Charging Station Management System (CSMS)*. It is used to authorize EV users to charge at that specific CS. The CSO manages one or many CSs with support of a centralized CSMS. CSO is sometimes also referred to as *E-Mobility Service Provider (EMSP)*. A *Clearing House (CH)* is used to enable roaming and settle financial transaction between CSOs. We consider all chargeable EVs and do not differentiate between battery EV, plug-in hybrid or any other type, as charging transactions are the same. In Europe, standardized and open protocols are used for communication between systems and actors to ensure interoperability. Typically, a three-tier approach is applied (Buamod et al. 2015). Tier 1 considers the communication between EV and EVSE (via standard ISO/IEC 15118). It includes charging schedule and authorization of one EV with the EVSE. Tier 2 contains the communication between EVSE and centralized CSMS or CSO (via OCPP). Authorization, metering and billing data are the main components. Tier 3 handles the communication in a roaming network between the centralized CSMS and its CSO with different EMSPs or a Clearing House (via OICP/OCHP). In the U.S., American standards defined by the Society Automotive Engineers (SAE) are applied (Buamod et al. 2015).

For our research approach we apply blockchain, the core technology of most cryptocurrencies, which was initially introduced as the underlying technology of Bitcoin in 2008 (Nakamoto 2008). Blockchain is a distributed ledger technology (DLT) for validating and storing transactions. It applies cryptographic mechanisms such as public/private key infrastructure and cryptographic hash functions, which are used for specific consensus mechanisms within the p2p network, e.g. Proof-of-Work for Bitcoin. Due to their distributed nature, blockchain-based systems do not need 3rd party intermediaries for transaction validation and verification, making them a suitable approach for p2p sharing of CSs. Smart contracts as specified by Buterin (2014) are pieces of software code running on the blockchain network, which automatically initiate or execute transactions, invoked from certain conditions. By connecting a smart contract to an oracle, real-world data can be used as condition for automated transaction execution. Different blockchain technologies exist and can broadly be classified as public (permission-less), consortium/federated (permissioned) and private (permissioned). The technologies differ regarding certain characteristics, e.g. deployed consensus mechanism (Proof-of-X), scalability or performance (transaction throughput).

Related Work

Evidence for evolving research and growing importance of energy informatics and its sub-discipline e-mobility within the IS community is reported by Kossahl et al. (2012). Increasing EV market penetration is expected to impact electricity demand and power load. Smart charging is a concept enabled by IS which reduces the impact of EV charging on the power system on energetic and economic level (Schmidt and Busse 2013). Both, smart charging and blockchain-based transaction processing alike, require increasing computational intelligence and connectivity deployed in the vehicles and charging infrastructure.

Subsequently, interoperability and standardization on software and hardware level play a vital role in EV charging. One approach to tackle this requirement is the E-Mobility Information System Architecture, proposed by Schuh et al. (2013). It is extracted from a collection of generic IS architectures and mapped onto an adaptation of the domain-specific Smart Grid Architecture Model (SGAM). It provides guidelines for the architecture design of IS supporting different business models in e-mobility. With the enhancing technological capabilities of CSs and EVs, application of blockchain technology for e-mobility and specifically EV charging becomes another use case in the energy sector besides e.g. utilization in microgrids or for electricity trading. Until lately, the field of blockchain for e-mobility has not received much attention from the IS research community (Albrecht et al. 2018). Kim et al. (2017) propose a mobile charger billing system using lightweight blockchain. Hua et al. (2018) apply blockchain technology to battery swapping. Knirsch et al. (2017) propose EV charging with dynamic pricing tariffs based on blockchain and Kang et al. (2017) evaluate consortium blockchains regarding their suitability for p2p electricity trading between plug-in hybrid EVs. The current research is lacking solutions which provide interoperable and trustworthy transaction processing of EV charging payments. With this study, we aim to contribute to the research body by proving technical feasibility and efficiency of a blockchain-based decentralized charging IS compared to a traditional centralized CSMS.

Validation and Processing of a Charging Transaction on Blockchain

A complete charging process typically consists of six high-level steps (Figure 1), whereas steps three to five represent the actual charging transaction. For each of the charging transaction steps, different concepts exist, e.g. for authorization. Different authorization methods of an EV (user) with the CS are existent, for example RFID, credit card or initiated from the CSMS via mobile device. In this paper, we will not further consider the authorization, but will assume plug and charge as specified by OCPP 2.0. The actual energy transfer between CS and EV may contain one or multiple transfer periods within one charging process. For simplification, we assume only one energy transfer period.
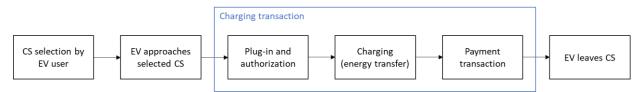

Figure 1 Charging process steps and charging transaction

We propose a dApp and smart contract design for integration of a charging transaction with blockchain, which will be implemented by a proof-of-concept to show the feasibility of this solution. Here, the EV represents a node in the blockchain network, holding a wallet with tokens. This can either be the EV user with a mobile app or the vehicle itself. The EV starts the charging transaction by plugging in and requesting authorization as soon as a physical connection and communication to the CS are established (Figure 2). When authorizing with the CS, the EV also transmits its public key *pk_EV* to the CS. The CS authorizes the EV and transmits its public key *pk_CS* to the EV. The EV sends an amount of tokens *tx_payment* (containing also *pk_EV*) to the smart contract *ChargingPayment* on the blockchain (BC). The amount of *tx_payment* is the max. amount possible for this charging transaction plus a buffer. The transaction is validated by the blockchain's consensus mechanism and the smart contract locks in the payment as escrow. Upon recognizing this information (a transaction with included *pk_EV*) from the blockchain ledger, charging is enabled. The EV requests to start the energy transfer from the CS and sends a transaction *tx_startEV* to the smart contract. The CS also sends a transaction *tx_startCS* with the same timestamp to the smart contract. In this way, consistent data about the charging process is stored on the blockchain. The CS listens for *tx_startEV* and starts energy transfer to the EV as soon as it recognizes the transaction which was validated by consensus. When the battery is fully charged, or the user wants to abort, the EV requests ending the energy transfer and sends transaction *tx_endEV*. As soon as the block with *tx_endEV* is validated on the blockchain, it recognizes the transaction and stops energy transfer. The CS then sends *tx_endCS* to the smart contract *ChargingPayment*. The smart contract verifies the inputs from the transaction and calculates the amount payable to the CS depending on the charging process (amount of energy, charging rate). If the timestamps match, *ChargingPayment* executes and sends out *tx_paymentCS* to the CS and *tx_paymentRest* to the EV. *tx_paymentRest* is the difference of *tx_payment* and

tx_paymentCS. In this blockchain-based charging transaction, we have multiple transactions between EV, CS and Smart Contract (Blockchain) which contain different data. This is only one example, different design decisions depending on the scenario must be taken. For example, *tx_start* and *tx_end* can either be initiated by the EV, the CS, by both or being determined based on pre-defined time slots.
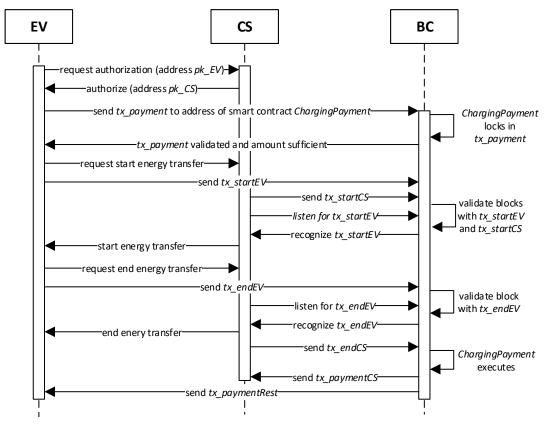

Figure 2 Blockchain-enabled charging transaction

Depending on the business model of the CSO and its charging infrastructure, pricing can be either time- or energy-based, requiring different smart contract designs. Additionally, an oracle could be utilized to directly acquire real-world data from EV or CS, such as the physically measured amount of energy, and use it as input for the smart contract code. This would reduce complexity of the process, but lead to further data security issues, making fraud in the system easier.

Discussion

In the current intra-CSO charging setting, the centralized CSMS is a transaction processing system for financial transactions and settlement of payments. When considering inter-CSO charging, roaming between CSOs is applied. Those centralized ecosystems suffer from single point of failures and inefficiency due to intermediary 3rd parties, making public and private CS operation costly and dependent on other parties. A blockchain-based decentralized charging IS can mitigate these problems by enabling p2p sharing of charging infrastructure without central authority. Additionally, blockchain technology allows almost instant settlement while at the same time ensures trust from the consensus mechanism. Typically, transaction processing has to maintain integrity of a software system. This can only partly be ensured by a blockchain solution. Read and write operations are available, but for most public blockchain technologies, update and delete are not part of the core functionality; the blockchain is immutable. A token model implemented in a public blockchain solution offers certain advantages. The tokens in this scenario are used as currency for settling payment transactions between EV and CS wallet, allowing contract-less EV charging and p2p transactions. A token model could either be integrated into or on top of an existing network such as Ethereum or it could be completely de-coupled and deployed on an own blockchain network.

Next Steps and Further Research

In this paper we present an approach for blockchain-based processing of charging payment transactions, removing the detour via roaming networks and clearing houses, enabling direct p2p sharing of charging infrastructure. In this research study, we plan to evaluate the technical feasibility of validating and storing charging-related data and processing payment transaction with blockchain. The next steps of this activity will be the further development of requirements for such a system, the evaluation of suitable blockchain technologies and the implementation of the proposed dApp and smart contract design as a prototype for proof-of-concept. Based on this, we plan to assess and evaluate technical shortcomings and challenges of a blockchain-based approach, such as limited data storage space, computing efficiency, data privacy (public keys might be relatable to vehicles), user experience (management of public/private key), interoperability, scalability and transaction throughput. In follow-up research studies, we intend to focus on the socioeconomic perspective, evaluating economic viability, trust, regulatory issues, business models and implications from an embedded token model, and to compare with centralized solutions. Additionally, we plan to extend our research to direct Vehicle-to-Vehicle charging transactions and utilization of EVs as dynamic energy storage, enabling Vehicle-to-Grid and Demand Response transactions.

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