Cooperative Charging in Residential Areas

Dominik Schürmann, Julian Timpner, and Lars Wolf, *Senior Member, IEEE*

***Abstract*—Electric Vehicles (EVs) require a well-developed charging infrastructure. Especially when used for the daily commute, most EV drivers will rely on a nightly charge in their garage, for instance. In typical European urban residential areas, however, private parking and charging resources are severely limited. Therefore, public on-street charging often is the only option. Yet, it faces several limitations that lead to an inefficient and unfair utilization of charging stations, or Electric Vehicle Supply Equipment (EVSE). For instance, EVSEs are often blocked by fully-charged vehicles. We thus propose and evaluate a cooperative protocol for EVs that facilitates coordinated handovers of EVSEs. We integrate this protocol with the ISO 15118 standard and provide a detailed security analysis. In the evaluation, we show that coordinated handovers significantly improve both EVSE utilization (helping to amortize the expensive operating costs) and provide benefits for EV owners by providing sufficient charging resources. This reduces range anxiety and saves them from cruising for charging.**

***Keywords*—E-mobility, charging, EV, EVSE, ISO 15118.**

I. INTRODUCTION

E-MOBILITY has the potential to harness renewable energy sources for ensuring efficacy and affordability of modern transportation systems. The typical challenges of e-mobility, which have to be solved to make EVs feasible and attractive to customers, include limited range and lack of charging infrastructure. This situation is exacerbated by the high installation and maintenance cost of EVSEs of up to 27150 € and 3075 € p.a. [1], respectively. While the problem is less grave in suburban areas (where each house or garage has a power supply) and in commercial parking lots (where centralized optimization for the available charging infrastructure can be applied [2]), it is highly doubtful whether a sufficient coverage with charging infrastructure is realizable for public on-street parking in urban residential areas, especially in light of the expected influx of electric cars in the near future. As an example, the German National Electric Mobility Platform (NPE) predicts about 1 000 000 EVs in Germany by 2020 [1], with a demand of about 70 000 public on-street charging spots alone. Thus, it is crucial to use this sparsely available infrastructure as efficiently as possible. In this paper, we focus on residential areas without private charging infrastructure, where on-street parking and charging is predominant. In these scenarios, several limitations are encountered, which result in an inefficient and unfair utilization of EVSEs.

First, different companies will operate the EVSEs. This will prevent the development of a unified reservation backend. Thus, occupancy information—and, more importantly, predictions—may not be available.

Second, on-street EVSEs are an unmanaged resource that is used in a First Come First Served (FCFS) order according to the working hours of the residents.

Third, fully-charged or even non-charging vehicles often block EVSEs, drastically reducing the total utilization and the chance of finding charging spots for other drivers. Government agencies [3] and standardization institutions [4] envision legal regulations as a means to solve this problem. However, regulations can hardly enforce an efficient usage pattern, as we will elaborate on in Section III.

A. Approach

The combination of e-mobility with autonomous driving capabilities can alleviate some of the aforementioned problems. Automatic driving applications, e.g., for parking assistance (BMW Remote Parking) or highway driving (Tesla Autopilot), are already on the market and fully automated driving has been demonstrated by several car manufacturers. It is therefore expected that limited autonomous driving capabilities, e.g., for parking scenarios, will become market-available in the next decade [5]. A fully charged (autonomous) vehicle could move to a regular parking spot in order to make the EVSE available for the next car. Yet, this does neither solve the occupancy information deficit nor does it provide a coordinated (and thus more efficient) strategy. Consequently, a more complete solution will also facilitate Inter-Vehicle Communication (IVC). IVC enables cars to be notified when an EVSE becomes available. However, if multiple vehicles learn about the availability of an EVSE, they will compete for this scarce resource and only one of them will succeed, while the others will waste time and energy in their failed attempt. To prevent this, we propose a coordinated strategy that incentivizes cooperation and mitigates malicious behavior.

B. Contribution

In this paper, we design, implement and evaluate a cooperative protocol for EVs that facilitates coordinated handovers of EVSEs. This protocol solves the abovementioned problems

---

Manuscript received December 2, 2015; revised March 15, 2016; accepted July 09, 2016. This project has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under Grant Agreement Number [269916, V-Charge].

The authors are with the Institute of Operating Systems and Computer Networks, Technische Universität Braunschweig, 38106 Braunschweig, Germany, (E-mail: [schuermann|timpner|wolf]@ibr.cs.tu-bs.de). *(Dominik Schürmann and Julian Timpner contributed equally to this work.) (Corresponding authors: Dominik Schürmann; Julian Timpner)*

of scarce on-street charging as follows. EVs charging at an EVSE are incentivized to make it available to the next vehicle as soon as possible, while avoiding competition between the possible successors. It further provides occupancy availability and projection to interested EVs. A security analysis shows the protocol's practical feasibility. We integrate this protocol with the ISO 15118 [6], [7] standard, which specifies Vehicle-to-Grid (V2G) communications, certificate infrastructure and payment models for e-mobility, to demonstrate a practical implementation. To the best of our knowledge, we are the first to address the problem of efficiently and securely managing scarce on-street charging in a cooperative manner.

C. Outline

The remainder of this paper is structured as follows. Section II discusses related work on parking/charging management as well as e-mobility architecture and standards. We define our scenario and describe assumptions in Section III. Section IV presents design decisions. The proposed protocol itself and its integration with ISO 15118 is introduced in Section V. Possible attacks on the system and their mitigations are presented in Section VI. Section VII describes our simulation setup. We provide simulation results in Section VII. The paper concludes in Section IX.

II. RELATED WORK

In this section we provide a short summary of related solutions for an efficient charging/parking management. We also present the technical background of V2G communications, especially ISO 15118, as well as related work on e-mobility.

A. Centralized Reservations

A seemingly obvious solution to the three problems described in the introduction is a *central reservation* system—an approach that is widely used in parking management systems. In commercial parking lots or garages, for instance, this allows to take customer requirements (such as arrival/departure time, State of Charge (SoC), etc.) into account for a centralized scheduling and thus for a local optimization of charging resources [2]. For on-street charging, however, a central reservation system is unfeasible for the following reasons.

On the one hand, current developments suggest that the EVSE market will be highly partitioned between utility companies, gas station operators, and even vehicle manufacturers[1]. Thus, a single (i.e., unified) backend, as assumed by Bedogni *et al.* [8], providing EVSE reservations for all these different operators is implausible, just as "gathering [all parking lots] under the same authority is hard if not unfeasible" [9].

On the other hand, if there was a single backend, how would reservations be enforced? In an environment with a severe shortage of parking spots, it is not uncommon that drivers deliberately park in no-park zones (see Section III). Legal regulations alone cannot solve this problem.This is also a weakness in current standardization effort ETSI 101 556-3 [4], which assumes that "there is no point for the EV to stay longer than reserved".

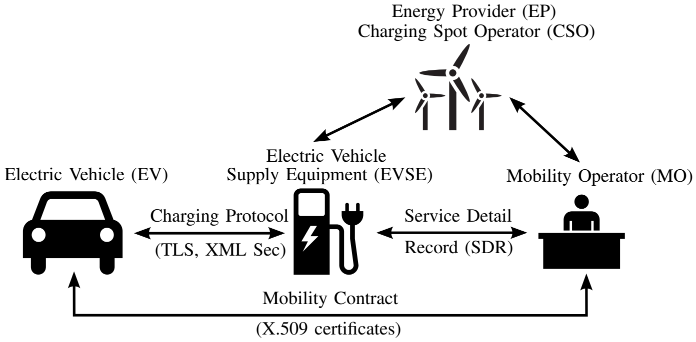


Figure 1: Relationship and security of ISO 15118 actors.

B. Decentralized Reservations

An alternative solution that overcomes some of the mentioned problems is a *decentralized* reservation mechanism. Delot *et al.* [10] present a reservation protocol for parking spaces that avoids the competition between drivers for an available spot. This approach is based on a coordinator vehicle which is responsible for assigning its spot to (one-hop) neighbor vehicles interested in an available parking space. This approach, however, assumes that vehicles in the coordinator's communication range are interested in a free parking space at this point in time. Reservations cannot be made in advance, e.g., via a query-based mechanism. This makes the protocol unsuitable for managing reservations for scarce EVSEs. What is more, we seek to make EVSEs available again as soon as possible (potentially before an EV is fully charged).

Delot *et al.* [10] also provide an in-depth study of parking management approaches. For instance, a game-theoretic approach by Ayala *et al.* [11] takes competition between drivers for available spots into account. Szczurek *et al.* [12] propose machine learning methods for finding the probability that a given parking location will be available at the time of arrival. Similarly, Caliskan *et al.* [13] estimate the future parking lot occupancy from the available information received through a VANET. Verroios *et al.* [14] investigate how to determine the best way to visit parking spots reported to be free. To the best of our knowledge, though, none of the above provides a decentralized and cooperative mechanism for on-street charging scenarios, which differ significantly from traditional parking search scenarios as described above. In addition, our protocol includes a financial incentive system and corresponding security considerations.

C. Charging Architecture: ISO 15118

Ideally, charging should be as simple as parking for the driver—yet, a sophisticated backend architecture and protocols for facilitating information exchange between EV and EVSE are required in the background. In the following, we provide a brief overview of the most important standardization efforts. Due to the extent of the matter, we have to refer the interested reader to the full standards for all details.

As depicted in Figure 1, ISO 15118-1 [6] defines the actors in the backend system and protocols for load management,

---

[1] http://www.teslamotors.com/supercharger

billing and clearing, as well as digital certificates. While it defines several payment options, we focus on the Plug and Charge (PnC) system, as it offers the highest usability. PnC requires the user to have a contract with a Mobility Operator (MO). The MO can be the utility provider that collects charging fees together with the monthly energy bill. The MO also issues X.509 certificates to the driver and EV. After a charging session, the MO receives a Service Detail Record (SDR) with all information required to pay the Energy Provider (EP) (which we assume to be identical to the Charging Spot Operator (CSO), for the sake of readability). After a charging session, the EVSE informs the EP by sending EV-signed meter receipts. The EP can use these in case of disputes. When a billing period ends, the MO provides a bill to the contracted user for received SDRs.

ISO 15118-2 [7] defines detailed communication protocols and application layer messages including security mechanisms based on Transport Layer Security (TLS) and XML Security. The message exchange between EV and EVSE happens in five phases after the EV is physically connected. In the *Communication Setup*, a session is initiated. The EV will then choose the desired charging service and agree with the EVSE on payment options in the *Identification, Authentication and Authorization* phase. We assume a contract-based payment here, as it requires no user interaction and allows PnC. Other payment options include credit, debit and prepaid cards. Before the actual charging process, parameters such as desired departure time, requested amount of energy, available power, etc. are exchanged in *Target Setting and Charge Scheduling*. Periodic ChargingStatus and MeteringReceipt messages provide updates about the charging progress during the *Charge Control and Re-scheduling* phase. In the *End of Charging Process*, the charging session is stopped.

D. E-Mobility and Smart Grid

A hot research topic is the integration of EVs into smart grid applications. This integration allows adopting dynamic pricing tariff schemes, limiting power peaks and lowering electricity bills by shifting consumption [15] towards low-demand times, typically at night. Further, EVs can support the electric grid by supplying energy from their batteries during peak hours [16]. To be fully effective, however, these approaches require many EVs to be plugged into the grid throughout the day. This is reasonable in a suburban environment with private charging infrastructure and several cars per household. In this paper's scenario, however, we focus on downtown areas with on-street charging only. As a consequence, the availability of EVSEs is highly limited (which some authors try to address through planning frameworks for EVSE locations [17]).

Reservation systems that plan routes along where EVSEs are available, either at highway exits [18] or parking lots [19], make sense for long-distance travel, but not for typical commute distances and residential parking as considered in this paper. What is more, we aim to maximize the overall EVSE utilization and EV throughput, which is contradictory to EVs being constantly plugged into the grid. Typical charging station scheduling rather focuses on maximizing revenue for load aggregators [20] or on compensating the time-varying reactive power of the grid [21].

Figure 2: Multiple parking violations due to lack of regular parking spaces [22]. Hatched areas are no-parking zones.

III. SCENARIO

We focus on typical European downtown residential areas with large apartment buildings without private parking infrastructure (see Figure 2). In this environment, public on-street parking is predominant and there is a chronic shortage of parking spots, especially in the evening when most residents return from work. As a result, parking violations are quite common. In particular, drivers deliberately park in no-park zones as depicted in Figure 2, despite the risk of getting fined. This shows that legal regulations do not necessarily lead to correct behavior, if the infrastructure cannot cope with the demand.

A similar overdemand can be expected for public EVSEs, which can lead to fully-charged or non-charging vehicles blocking EVSEs, too. The German government anticipates an influx of up to 1 000 000 EVs by the year 2020, with a demand for about 70 000 public on-street AC EVSE alone (corresponding to 5 % of the total demand). With installation and maintenance cost of about 10500 € and 1750 € p.a. per unit, respectively [1], the financial feasibility of so many on-street EVSEs is highly questionable though. Fast charging DC EVSEs (e.g., Combined Charging System (CCS) [23]) are even more expensive at 27150 € plus 3075 € p.a.

A promising low-cost solution is to turn street lamp-posts into charging stations. In Berlin, Germany, several dozen are already installed, at unit costs of less than 500 €. Being connected to the low-voltage grid (which saves significant installation costs), their charging power is limited to about 3.7 kW which is also the power output of typical home chargers. Yet, most market-available EVs do not support high-power charging per default anyway. Moreover, CCS EVSEs are very expensive and thus scarce. Furthermore, fast charging generally reduces battery capacity and longevity as shown by Li *et al.* [24].

In our scenario, we consider both types of charging. In residential areas, slow (and cheap) charging at 3.7 kW prevails, resulting in several hours of charging time. For fast and emergency charging, CCS EVSEs with a power output of up to 50 kW are available along arterial roads, providing charging times of less than 30 min (resembling classical gas stations).

We assume that vehicles are equipped with IEEE 802.11p radios for Inter-Vehicle Communication (IVC) and have on-

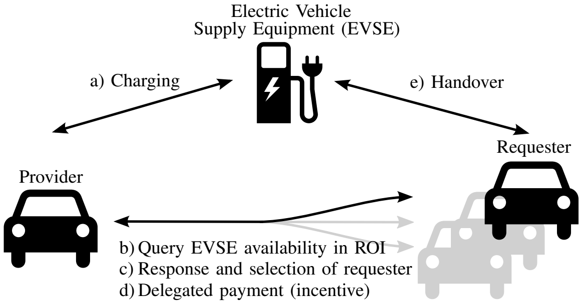


Figure 3: Protocol Design

board digital maps including the position of EVSEs that are generally compatible (in terms of plug standard, voltage, etc.). Further, we assume low-speed autonomous driving/parking capabilities, which have been successfully demonstrated already [25]. This first deployment phase of autonomous vehicles is expected in the next five years [5], which corresponds to the forecasting horizon of when a large number of EVs is to be expected on the streets. Autonomous EVs can either be charged inductively [26] or be connected automatically via robotic arms [27]. These systems can be integrated with lantern-post systems (and thus use the existing low-voltage grid).

IV. PROTOCOL DESIGN

In this section, we look at the scenario's main research issues as described in Section I and propose solutions. Figure 3 depicts the resulting protocol design from a high-level perspective, while Section V describes each protocol phase in detail. Initially, a vehicle occupies an EVSE in a specific Region of Interest (ROI) and starts charging (Figure 3, Step a). This EV is called *provider* in the following.

A. Distribution of Occupancy Information

Drivers should be able to learn in advance whether specific EVSEs, for instance close to their home, are currently occupied or when they will be available again. We therefore facilitate IVC to send a query for EVSE availability information into the geographical ROI (Figure 3, Step b, and Figure 4). EVs querying for information are therefore referred to as *requesters*.

The provider(s) in the ROI respond with the estimated time to complete the charging process (Figure 3, Step c). The requester EV thus learns about whether or not it is practical to drive to this particular EVSE.

B. Cooperation instead of Competition

To increase the overall utilization and the efficient use of available EVSEs, we seek a coordinated strategy for handing over EVSEs to the next EV. The main goals are to (i) increase the overall chances to use an EVSE by preventing exclusive First Come First Served (FCFS) usage, and (ii) to avoid inefficient competition which would result from naïvely broadcasting EVSE availability, for instance.

This is realized as follows. Similar to Delot *et al.* [10], the provider becomes the coordinator for its resource and chooses a successor from the set of interested requesters (Figure 3, Step c). While different selection processes are conceivable, we deliberately use a uniform distribution to randomly select a successor from the set of requesters. We do so to ensure a fair selection process. As the selection process is random, requesters do not need to provide any additional personally identifiable information. Future models might select the highest bidder or the EV with the least charging time remaining in order to maximize EVSE usage. However, this would introduce security risks, as such properties cannot easily be verified and business models for malicious nodes could arise.

C. Incentivized Cooperation

In order to minimize blocking of EVSEs by fully-charged or non-charging vehicles, we propose a financial incentive system for making EVSEs available to other vehicles as soon as possible.

The basic idea is to reimburse a provider, who vacates an EVSE for a requester, for the expenses of (i) reparking and (ii) possibly forgoing a full battery charge by leaving early. We measure these expenses in kWh, meaning that providers do not actually get paid for vacating an EVSE. Instead, the provider can split his bill with a requester, who then pays the EP for a certain amount of energy of the provider's current charging session.

1) Payment Model: As described in Section II-C, the EVSE informs the EP about a charging session by sending EV-signed meter receipts consisting of a timestamp and the charged kWh. The provider EV keeps copies and has the requester EV sign a share of the receipts. The signed receipts are forwarded to the EVSE which acknowledges the delegated payment (Figure 3, Step d). The provider vacates the EVSE and the requester takes his place, starting the charging process (Figure 3, Step e).

The exact amount that is delegated to the requester depends on the provider's current State of Charge (SoC).

We assume that every driver estimates a minimum energy level required for the next driving task, SoC_{min}. This estimation can, for example, be based on recorded energy consumptions from previous commuting times, which vary depending on the traffic situation and other uncertainties. In our scenario, drivers are not willing to vacate an EVSE if $SoC < SoC_{\text{min}}$.

If, however, $SoC \geq SoC_{\text{min}}$, a driver would vacate the EVSE and thus forego a full battery charge in exchange for a small incentive. If the provider's SoC is close to 100 %, he is more likely to do so and the incentive can be smaller. The lower the actual SoC is, the larger the incentive needs to be. To the best of our knowledge, there is no study on the percentage of users willing to do this.

2) Cost: The total cost c that the provider bills the requester for vacating an EVSE includes the cost of forgoing a full battery charge and the cost c_{park} of reparking. Providers will only participate in the protocol if the available meter receipts cover the cost c, as follows. The cost c_{park} of reparking depends on the scenario, i.e., how many parking spots are available in the vicinity in comparison to the total demand, the time of day, the day of the week, etc. This can be estimated by each vehicle from empirical values, coordinated between a group of vehicles as proposed in Parking Communities [28], or be provided by a backend service [29]. The cost of forgoing a full battery charge can be expressed as a percental surcharge on c_{park}:

$$\begin{aligned} SoC \geq SoC_{\text{min}} : c &= c_{\text{park}} \cdot (1 + (1 - SoC)) \\ &= c_{\text{park}} \cdot (2 - SoC). \end{aligned}$$

Consequently, if $SoC = 100\,\%$, only the cost of reparking needs to be reimbursed: $c = c_{\text{park}}$.

3) Discussion: The model has several benefits. First, no actual money is transferred and no new virtual currencies are required, as it integrates with the existing ISO 15118 standard. Second, it handles different pricing models: some EPs charge per hour, others per kWh. Hybrid models exist as well. Meter receipts include both the charged kWh as well as the charging time and can thus be used independently from the actual pricing model. In particular, if a bill is split between provider and requester, both of them can pay their share according to their respective tariff model. The total revenue of the EVSEs operator is not affected, as charging sessions are always paid completely (but may be split between provider and requester).

In the future, energy prices may vary greatly, possibly in minutes. ISO 15118 prepares for this: EVSEs provide EVs with a sales tariff table to calculate a charging schedule. The proposed protocol can take advantage of this as follows: EV A is not willing to pay the current high price and thus waits for when charging is cheaper according to the tariff table. EV B, on the other hand, is willing to accept a higher price to charge as soon as possible. Consequently, B hands over the EVSE according to the proposed protocol, for as long as the higher price is valid. When B has been charged to SoC_{min}, it hands over the EVSE to A again.

V. PROTOCOL INTEGRATION WITH ISO 15118

In this section, we build upon the design decisions in Section IV to derive a cooperative protocol for EVs that facilitates coordinated EVSE handovers. The terms *resource*, *requester*, and *provider* are used as introduced the previous section. We integrate this protocol with ISO 15118-2 [7], which specifies Vehicle-to-Grid (V2G) communications as described in Section II-C. Consequently, Figure 5 and Figure 6 include clearly marked references to the standard (as described in Section II-C) where it interfaces with our original contributions.

A. Phase I: Query

In Phase I, requesters send a SpotReq message via geocast[2] [30] into the EVSE areas that come into question (because of their vicinity to the driver's home location, for instance). Figure 4 depicts this situation. In addition, vehicles might query backend services for occupancy information [29]. If there is an EVSE available, the requester drives there. This is the case, either if the backend knows about the EVSE status or if no SpotRes message is received. However, if the EVSE is occupied, the occupying EV (provider) can be considered a full-fledged network node as connected EVs do not suffer from a limited energy supply. The provider will thus respond with a SpotRes message as depicted in Figure 5.

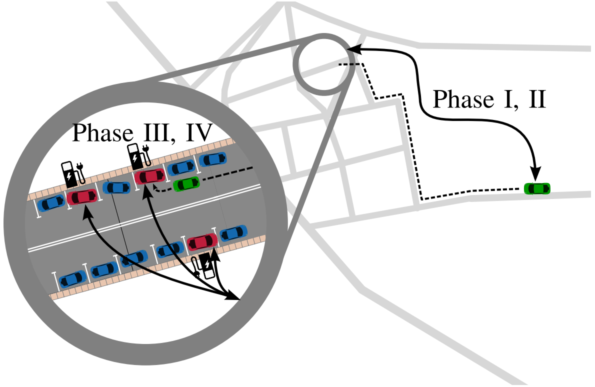


Figure 4: Phase I: A requester geocasts a SpotReq into a ROI while driving home and receives SpotRes messages. Phase II: Provider selects requester. Phase III: Requester waits close to the provider while exchanging receipts. Phase IV: Payment is delegated and the EVSE is handed over.

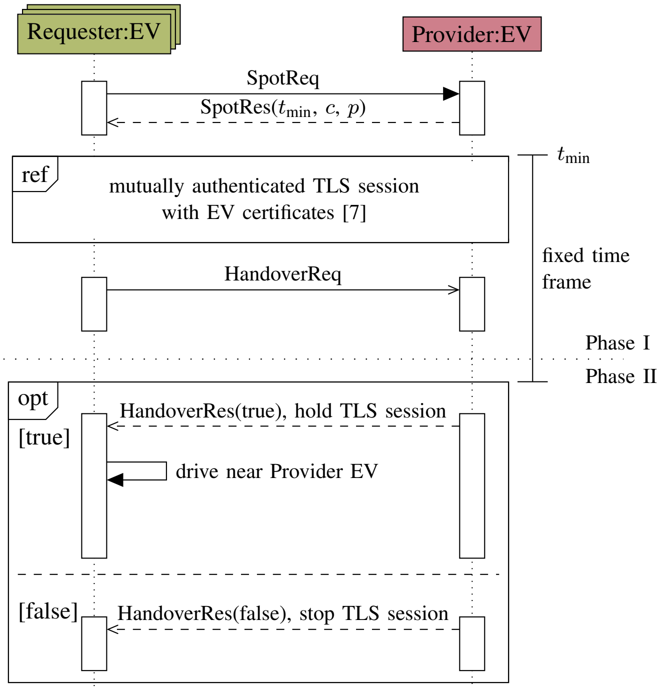


Figure 5: Phase I and II: Query and Competition.

1) Provider: The provider can further estimate (based on its current SoC and the EVSE's power output) when it will have reached SoC_{min}. SpotRes thus contains an estimated time

---

[2] A geocast is a special form of multicast in which destination nodes are identified by geographical positions.

$t_{\min}$ of when $SoC_{\min}$ has been reached, that is the earliest point in time when the charging resource can be released, such that another EV can charge. Moreover, SpotRes includes the provider's estimated cost c to vacate the EVSE early (see Section IV-C) as well as a proof p that the provider is actually charging (by means of a valid metering receipt per ISO 15118).

2) *Requester:* It is noteworthy that the SpotReq/SpotRes message pair is authenticated via regular Vehicle-to-Vehicle (V2V) Public Key Infrastructure (PKI) certificates [31]. Due to geocasting, the provider is not known at this point. Thus, the provider's certificate is not available and the query cannot be encrypted. Requesters check the plausibility of c after receiving a SpotRes message and then decide to (a) drive to a different EVSE or to (b) park in a regular parking spot and wait until $t_{\min}$. EVs still interested in the occupied EVSE at $t_{\min}$ announce their interest and their taking part in the selection process via a HandoverReq. This polling mechanism avoids having the provider to keep track of vehicles that have sent queries at some point in the past, thus reducing storage overhead. From now on, mutually authenticated TLS sessions will be established between requester(s) and provider using EV certificates signed by the V2V PKI as shown in Figure 5. The provider notices the demand for "his" blocked EVSE with the first HandoverReq. It starts a timer, waiting for other HandoverReq to arrive.

B. Phase II: Competition

After a timeout, Phase II starts with the selection process. The provider determines a successor as described in Section IV-B. The selected requester is notified via a HandoverRes and instructed to hold the TLS session. It can now either notify the driver or, if applicable, automatedly drive towards the EVSE and wait close to the provider as shown in Figure 4 (green car). All other petitioners are also notified and the corresponding TLS sessions are stopped (see Figure 5). The rejected requesters wait for HandoverRes messages from other providers they may have queried or, if necessary, periodically send additional SpotReq messages to (increasingly larger) ROIs. Note that the time frame between $t_{\min}$ and the beginning of Phase II is fixed, so that the overhead of keeping TLS sessions alive is limited.

C. Phase III: Receipt Exchange

While the selected requester is approaching the EVSE, the provider is typically still charging and following the ISO 15118 protocol for V2G communications between EVs and EVSEs. In particular, in the *Charge Control and Re-scheduling* loop (see Figure 6), it receives MeterInfo data in the ChargingStatusRes and sends signed MeteringReceiptReq messages to the EVSE. The signed meter receipts can be used for billing purposes as they provide proof that the charging process has taken place, as explained in Section II-C. The provider keeps records of these receipts.

Remember that all communication between requester and provider is now secured via the previoulsy created TLS session (see Phase II). Using this secure connection, the provider sends a share of the receipts to the requester via the V2VConnectReq/-Res message pair. This share equals the cost c in kWh as defined in Section IV-C. The requester checks the validity of the received receipts and compares them against the cost c of the initial SpotRes message.

D. Phase IV: Payment Delegation

The last phase is concerned with the actual payment as shown in Figure 6 (lower half). To this end, the requester first sets up a communication session with the EVSE *resource*. As the EVSE has no wireless networking support itself, this connection setup is done multi-hop via the provider, who is still physically connected to the EVSE. In other words, the requester's ISO 15118 [7] TLS session, which is only unilaterally authenticated, is tunneled through the mutually authenticated TLS session between both vehicles.

The requester agrees to pay the split bill by signing the meter receipts using his own contract certificate. It sends the signed meter receipts to the resource with the DelegatedPayReq. The resource verifies the requester's signature and acknowledges the pay delegation to the provider including the E-Mobility Account Identifier (eMAID), which uniquely identifies the requester. The provider can now safely assume that the requester is assuming liability and further forwards the DelegatedPayRes as an acknowledgement. It can now close the connection with the resource and drive away, while the requester takes its place. The requester is now able to continue the session using a direct connection proceeding to its own *Charge Control and Re-scheduling* loop.

VI. ATTACK MODEL

To evaluate the security of our protocol, possible attack scenarios are discussed in detail. Our security design is based on well known primitives, which we accept as assumptions. This includes the Public Key Infrastructure (PKI) of the V2V communication [31] as well as Transport Layer Security (TLS). Following the Dolev–Yao model, we also assume that the resource EVSE, i.e., the endpoint, is not compromised. Nevertheless, before going into protocol details, classical attacks are discussed in the context of our protocol design.

A. Classical Attacks

Man-in-the-Middle (MitM) An attacker who acts as a MitM in the TLS connection between requester and provider could decipher, inject, and alter messages.

Solution: These attacks are prevented by executing the mutually authenticated TLS handshake using EV certificates, which are in turn signed by an Original Equipment Manufacturer (OEM) organized via the V2V PKI.

Impersonation and Sybil attacks Impersonating another EV would allow to acquire a charging spot that was already paid for by the legitimate EV. This could be done by replaying an eavesdropped message. Sybil attacks would allow to increase the probability to be selected in the Phase II, i.e., by using many fake vehicle identities while querying.

Solution: Similar to the MitM scenario, these attacks are mitigated by the V2V PKI and TLS' replay protection mechanisms [32].

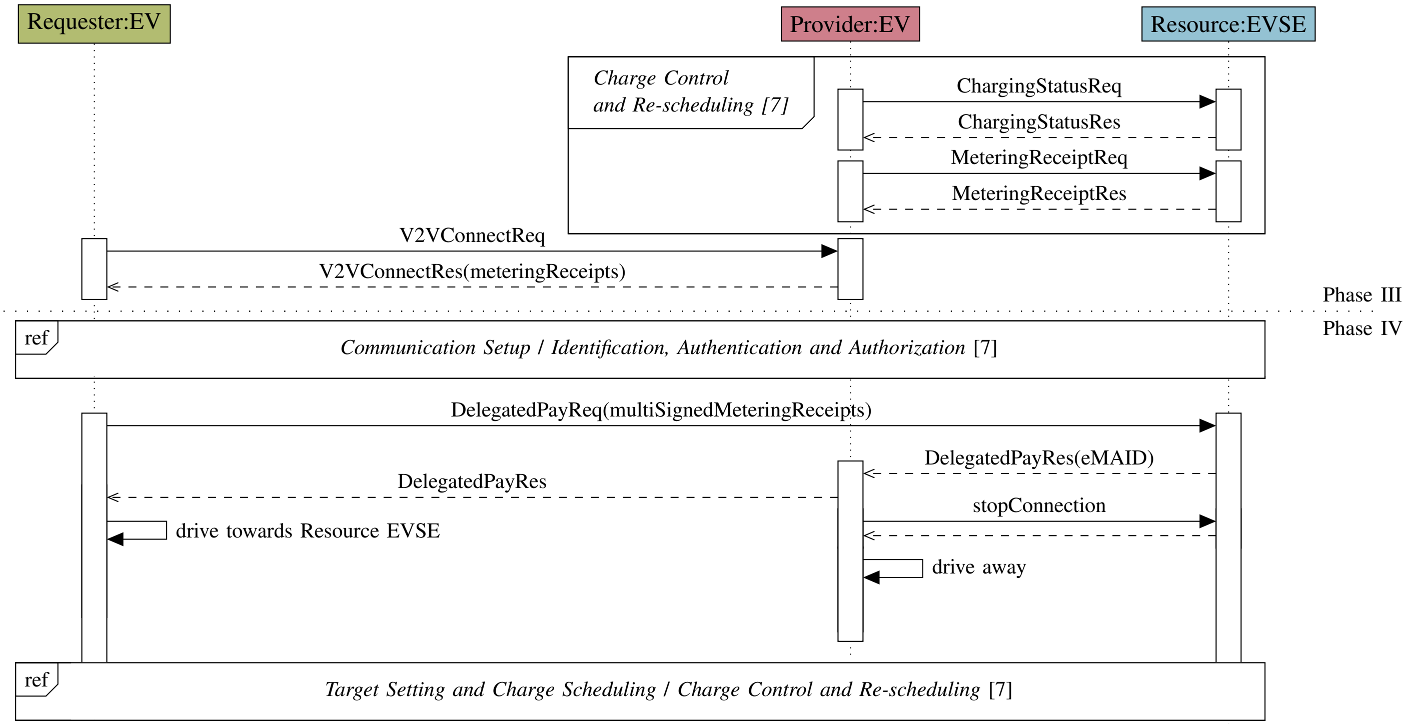


Figure 6: Phase III and IV: Receipt Exchange and Payment Delegation.

Compromising private keys If private keys are compromised, the corresponding certificates have to be revoked to prevent their usage by adversaries.

Solution: Mechanisms to distribute revocations are revocation lists or queries via Online Certificate Status Protocol (OCSP). ISO 15118-2 [7] requires OCSP for Sub-CA certificates inside the chain to the EVSE certificate. EVSE certificates themselves are short-term, thus no revocation mechanism is deployed here. How EV certificates are revoked is defined by the V2V PKI.

B. Denial of Service (DoS)

Naïve DoS A simple DoS can be executed by sending many SpotReq messages.

Solution: Thanks to EV certificates and digital signatures in V2V communication, providers can block excessive requesters by their identity.

Requesting charging spot without MO contract An EV requests a parking spot via SpotReq but does not have a valid contract with a MO.

Solution: In case this EV is selected, the contract is verified by the resource in Phase III of the protocol. If this verification fails, the resource stops the process and informs the provider. The provider cancels the protocol and waits for new SpotReq messages. The attacking EV should then be blocked by its identity.

Requester sending invalid multiSignedMeteringReceipts If the requester sends multiSignedMeteringReceipts with invalid signatures, the resource cancels the process.

Solution: Similar to the previous scenario the provider falls back to receive new SpotReq messages.

Requester not sending multiSignedMeteringReceipts The requester can cancel the protocol without informing the provider or resource, e.g., by not sending multiSignedMeteringReceipts.

Solution: The protocol defines a timeout to handle this situation. After its expiry, the provider falls back to receive new SpotReq messages.

C. Protocol Attacks

Location privacy The SpotReq/-Res messages can be read by neighboring EVs as they are not encrypted. Thus, other EVs know when and where a charging spot is vacated.

Solution: SpotReq messages cannot be encrypted as they are sent via geocast routing to a target location, not to a specific previously known EV. This is a conceptual limitation of such routing algorithms.

Replaying multiSignedMeteringReceipts The requester replays multiSignedMeteringReceipts from a previous payment delegation.

Solution: These meteringReceipts cannot be used again because only meteringReceipts valid for this particular session are accepted, i.e., meteringReceipts that were created before and signed by the EVSE.

Honeypot The provider sends a HandoverRes(true) to multiple requesters, thus decoying them to drive to his resource. He then splits his metering receipts between the waiting requesters, delegating a larger percentage of his bill than usually possible. Only one requester can obtain the EVSE after the provider leaves, though.

Solution: This fraud is easily detectable: A requester, who has paid for EVSE access, has the metering receipts as a proof which can be used by a clearing house to resolve this. In fact, the physical attacks *Third-Party occupying EVSE* and *Provider not driving away* are very similar.

D. Physical Attacks

Naïve blocking of charging spot An EV could block the charging spot to make profit.

Solution: As explained in the *Replaying multiSignedMeteringReceipts* scenario, no valid meteringReceipts are available that could be delegated. Thus a provider cannot easily make a business out of this.

Third-party occupying EVSE A third-party vehicle drives into the spot vacated by the provider although the requester has paid for it.

Solution: This improbable scenario is averted by requiring the requester to drive as near as possible to the current provider before proceeding with Phase III.

Provider not driving away After a delegated payment by the requester to the resource, the provider does not drive away and still occupies the charging spot.

Solution: In this case, the requester should park besides the provider and inform local authorities. Because the provider still occupies the spot, it can easily be held responsible for not following the protocol and be towed away. A naïve solution to this attack is to postpone the payment until the provider vacated the spot. However, this bears the risk for the provider to not get paid, which is more difficult to resolve than the original attack.

VII. SIMULATOR EXTENSION AND CONFIGURATION

Veins [33], a framework for vehicular network simulations based on SUMO and OMNeT++, has been extended to support our scenarios. We extend SUMO vehicles with a battery, working day movement, and a behavior model.

A. Battery Model

The EV's battery model has been adopted from Bedogni *et al.* [8]. Because a realistic simulation of battery physics would be too resource consuming, their battery model is an efficient approximation for large scale vehicle simulations. In comparison to real-world EV battery discharging, it is still highly accurate [8]. Incorporating force, current speed, and vehicle properties, the average power consumption P_{mean} is calculated for each step t_{step}. The total battery capacity B_{capacity} and the efficiency η of transforming electric energy to mechanical energy are configured as constants. Battery discharging, i.e., the consumed battery capacity SoC_t for each simulation step t_{step} is calculated as:

$$SoC_t = SoC_{t-1} - \frac{P_{\text{mean}} \cdot t_{\text{step}}}{B_{\text{capacity}}} \cdot \frac{1}{\eta}$$

Table I: Summary of simulation parameters.

EVs	Number of EVs	325 [a]
	Vehicle type	e-Golf
	Weight	1585 kg
	Energy usage	12.7 kWh/100km
	Battery capacity	24 kWh
	Max charging power	AC 3.6 kW, DC 50 kW [b]
	Charging time 3.6 kW	~8 h [c]
EVSEs	Number of AC EVSEs	22 [a] / 44
	Charging power	AC 3.7 kW, DC 40 kW
Movement	Start of day	between 07:00 - 09:00 [d]
	Working duration	8 h (+ up to 60 min [d])
	Pr for leisure activities	30 %
	Avg. speed outside[e]	70 km/h
	Commuting distances	cf. Figure 8
	Pr to charge at work	25 % [a]
	SoC_{eager}	High ($\geq$85 %)[f] / Low (50 %)

[a] estimation based on Nationale Plattform Elektromobilität [1]
[b] with special CCS charging equipment
[c] approx. calculation based on Bedogni *et al.* [8]
[d] leisure activities, uniform distribution
[e] for workplaces outside of the simulated area
[f] threshold based on commuting distance, forces recharging after every trip

Battery recharging uses $pow(t)$, the power delivered by an EVSE for each simulation step t_{step}, and $w(SoC_{t-1})$, a battery-depended coefficient representing charging characteristics. Recharging is calculated as:

$$SoC_t = SoC_{t-1} + \frac{(pow(t) \cdot t_{\text{step}}) \cdot w(SoC_{t-1})}{B_{\text{capacity}}}$$

By varying $pow(t)$, AC and fast DC charging can be simulated. As represented in Table I, we assume a Volkswagen *e-Golf* as the vehicle type, lamp-post AC EVSEs (cf. Section III), and fast charging DC EVSEs.

B. Map

As described in Section III, we focus on a typical residential area, namely a city district of Braunschweig, Germany. The Östliches Ringgebiet[3] is densely populated (6400 people/km^2), with an area of 4 km^2 and a population of 26 616 people [34]. This area has been exported from OpenStreetMap and converted to a SUMO road network. As depicted in Figure 7, 22 AC EVSEs (based on NPE estimation [1]) have been sensibly placed inside this area. In addition, a second scenario with 44 EVSEs has been generated to simulate a highly optimistic estimation. DC EVSEs' locations are not mapped, instead these are dynamically used while commuting between home area and workplace.

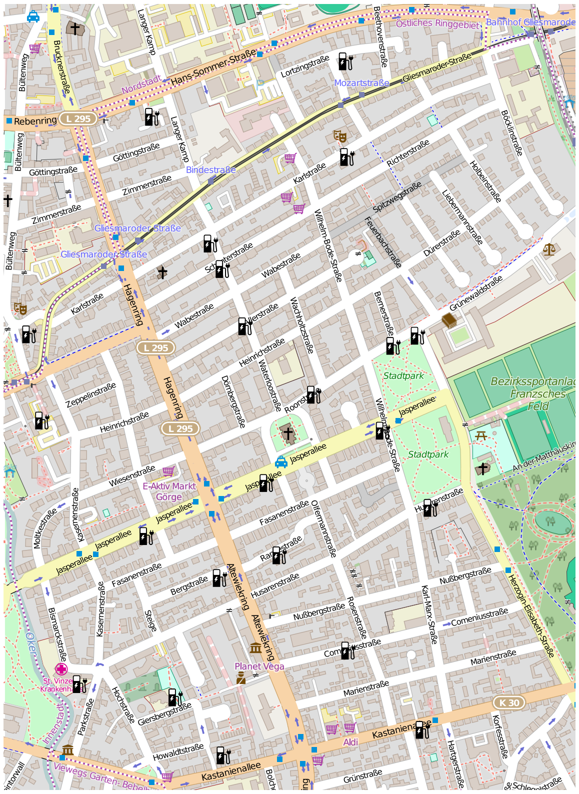


Figure 7: Map of Östliches Ringgebiet with 22 EVSEs.

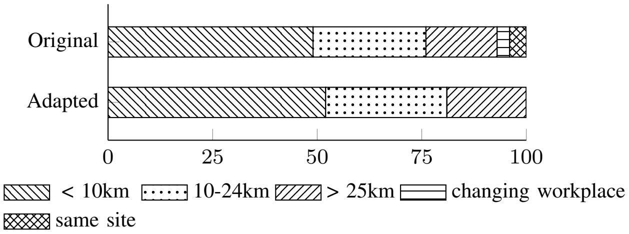


Figure 8: Distribution of commuting distances (from Statistisches Bundesamt [35]). For our simulation, *same site* values are neglected and *changing workplace* values are proportionally distributed among the remaining parts.

Table II: Lookup table to determine the search radius and n, the number of EVSEs an EV is trying to recharge at.

Distance [km]	SoC [%]	n	Radius [m]
$1 \leq x < 10$	$\text{SoC} < 15$	1^{a}	150
	$15 \leq \text{SoC} < 25$	2^{a}	200
	$25 \leq \text{SoC} < 50$	4	400
	$50 \leq \text{SoC} < 75$	2	200
	$75 \leq \text{SoC} < 90$	2	200
	$90 \leq \text{SoC} < 100$	1	150
$10 \leq x < 25$	$\text{SoC} < 25$	5	500
	$25 \leq \text{SoC} < 50$	4	500
	$50 \leq \text{SoC} < 75$	3	400
	$75 \leq \text{SoC} < 90$	2	300
	$90 \leq \text{SoC} < 100$	1	150
$25 \leq x \leq 60$	$\text{SoC} < 50$	5	500
	$50 \leq \text{SoC} < 75$	4	400
	$75 \leq \text{SoC} < 90$	3	300
	$90 \leq \text{SoC} < 100$	2	150

[a] SoC is so low that only a small number of EVSEs can be tried lest the battery fully discharges.

C. Working Day Movement

We have implemented a simplified version of the Working Day Movement by Ekman *et al.* [36]. A home area and a workplace location are assigned to each individual vehicle where the distance between these locations is based on the vehicle's commuting distance. The latter are distributed according to Figure 8. Home areas are randomly mapped into the simulated area. Depending on the commuting distance, workplaces are likely to lie outside of the simulated map. If vehicles leave the map (and thus town), we assume an average speed of 70 km/h. A SoC_{min} value is assigned to each individual vehicle. In our simulation, it is a fixed value based on the vehicle's average energy consumption and the vehicle's commuting distance. In real-world implementations, however, SoC_{min} can be calculated dynamically if historic data such as previous energy consumptions are available (cf. Section IV-C). As presented in Table I, a working day starts between 07:00–09:00 when the EVs drive to their assigned workplaces. Besides parking at work for 8 h (plus a 30 % chance of up to 60 min to simulate shopping or leisure activities), EVs also have a 25 % chance to charge at work. On their way back home, the drivers' eagerness to charge comes into play. Current research [37] shows that drivers feel an urge to charge earlier than actually necessary. If an EV's SoC_t falls below the eagerness threshold SoC_{eager}, it tries to find charging in its home area. The higher SoC_{eager}, the earlier a driver wants to charge. If an EV is looking for charging, its search radius and the maximum number n of EVSEs it will try to charge at are looked up in Table II, which defines a rough approximation of realistic human behavior. An EV with a low commuting distance, for example, that has a SoC_t of 50 % or lower tries up to 4 EVSEs in a radius of 400 m, i.e., without the proposed protocol it drives to each one and checks if it is occupied or not until a free one is found. A larger commuting distance results in a higher urge to recharge in general and a lower SoC_t means that more EVSEs are tried in a larger radius. If an EV's SoC_t reaches the lowest defined threshold in the lookup table while driving, a DC emergency charging at 40 kW (cf. Table I) is dynamically scheduled. Thus, fully discharged vehicles are prevented.

---

[3] https://en.wikipedia.org/wiki/%C3%96stliches_Ringgebiet

D. Scenarios

Two general scenarios have been implemented. The uncooperative scenario (abbreviated as U) without our protocol, where EVs block EVSEs until the next morning, and the cooperative scenario (C), simulating the protocol behavior defined in Section V. To evaluate effects resulting from an increased number of available EVSEs or different SoC_{eager} levels, we define the following 8 fine grained configurations:

U-22-H Configuration U-22-H represents an uncooperative scenario with 22 EVSEs and a high $SoC_{\text{eager}} \geq 85\,\%$. The number of EVs and EVSEs correspond to the NPE predictions [1]. Furthermore, a high SoC_{eager} value represents careful/selfish drivers recharging their EVs after every trip even though their SoC is sufficiently high for the next trip.

U-22-L In contrast, in U-22-L a rather low SoC_{eager} of $50\,\%$ represents less anxious and more friendly drivers. It has been shown that the mean and median SoCs [37] at which recharging is performed are 55.5 % and 56 %, respectively. The number of EVSEs and EVs is not modified.

U-44-H, U-44-L In configurations U-44-H and U-44-L, the number of EVSEs is doubled. All remaining parameters are chosen analogue to U-22-H and U-22-L, respectively.

C-22-H, C-22-L, C-44-H, C-44-L To simulate our cooperative protocol, the same configurations are used. Additionally, each scenario is extended by $SoC_{\text{min}} = 90\,\%$ (minimum SoC required for the next driving task, see Section IV-C).

VIII. EVALUATION

In this section we evaluate the efficiency of the proposed protocol in terms of its impact on the number of satisfied charging requests, the number of required emergency DC charging sessions and EVSE utilization.

A. Satisfied Charging Requests

Figure 9 depicts the total number of charging sessions per day for each configuration. In the uncooperative scenarios, the available EVSEs clearly cannot satisfy the demand, as the number of charging sessions equals the number of available charging resources. The primary reason of course is that EVs misuse the EVSEs as parking spots after they have been fully charged. Noticeably more EVs are recharging in the cooperative scenario. From Day 3 on, the number of charging sessions increases as a lot of vehicles consumed most of their energy on the first days and are now required to recharge. Especially in C-22-H and C-44-H (in comparison to U-22-H and U-44-H, respectively), a substantial increase from 22 (or 44) to 160 charging sessions due to EVSE handovers is visible. C-22-L and C-44-L show a more moderate increase beginning on Day 3, caused by a lower number of requesters because of a more friendly SoC_{eager} of $50\,\%$.

For a more detailed analysis of how many charging requests can actually be satisfied and how many futile attempts are required to do so, Figure 10 exemplarily plots the following metrics for U-22-H and C-22-H:

1) **Maximum visits** m: Sum of each individual maximum number of EVSEs an EV considers to visit in order to recharge: $0 \leq m \leq n$ (cf. Table II)

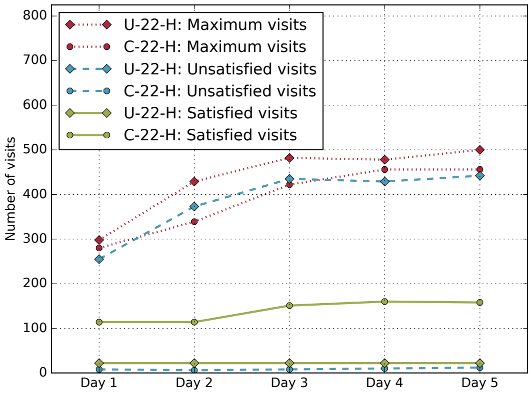


Figure 10: Comparison of the number of satisfied and unsatisfied visits between U-22-H and C-22-H.

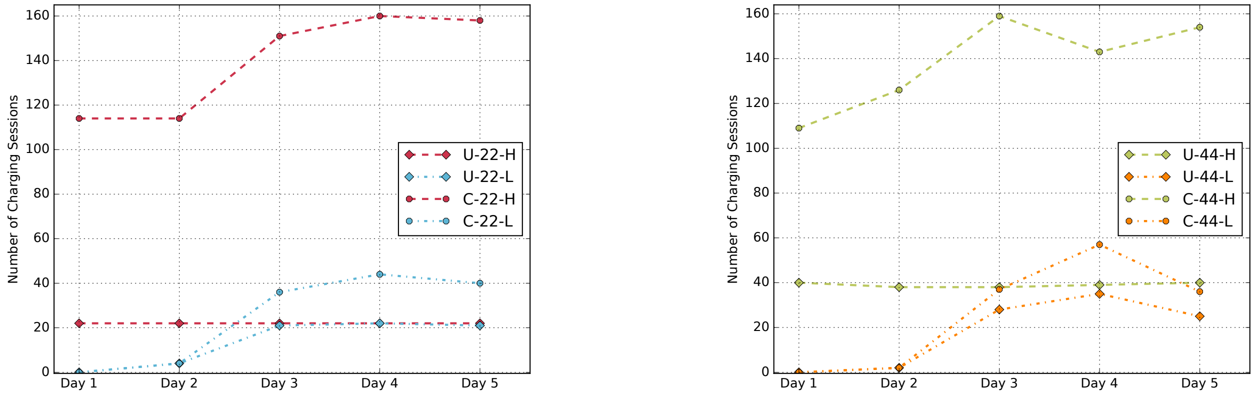
2) **Unsatisfied visits** u: Total number of visited EVSEs that were occupied: $0 \leq u \leq m$
3) **Satisfied visits** s: Total number of visited EVSEs that were available: $s \in \{0, 1\}$

Note that $m \neq u + s$ because if an EV would try up to $m = 3$ EVSEs and the first EVSE is available, there are no unsatisfied visits $u = 0$, but $s = 1$.

In the uncooperative scenario, Figure 10 shows a very high number of futile visits to occupied EVSEs, indicating a constant high need to recharge which cannot be satisfied in most cases. Up to about 440 unsatisfied visits per day are required to achieve 22 satisfied visits only. Again, these 22 (or 44 in U-44-H/L) visits equal the total number of available EVSEs which clearly indicates an overload situation. Configurations with a low eagerness to charge (U-22-L and U-44-L) just delay this overload until Day 3 (not shown).

In the cooperative scenario as shown by Figure 10, almost no unsatisfied visits occur for two reasons. First, EVs do not have to drive to occupied EVSEs since they learn about their availability beforehand via SpotReq/SpotRes message pairs. If all EVSEs in its ROI are occupied, an EV drives directly to its home zone. Second, EVSE handovers avoid competition so that only the chosen requester will drive to it. Hence, unsatisfied visits are generally avoided. However, sporadic unsatisfied visits can occur if at least two EVs are heading towards the same available EVSE at the same time because they both received a positive SpotRes message. The total number of such occurences is negligible, though, as Figure 10 shows. Further, the number of satisfied visits is considerably higher than in the corresponding uncooperative scenario, namely up to 160 (cf. Figure 9a).

In sum, the proposed protocol enables up to 160 vehicles to charge per day, while only 22 EVs were able to do so in the uncooperative scenario with the same number of EVSEs. At the same time, the number of unsatisfied visits per day is reduced from about 440 to less than 12, thus saving time and energy as well as reducing traffic. Even in a more optimistic scenario with 44 EVSEs the increase of charging sessions (159 compared to 44) and the saved futile visits (up to 329) are



(a) 22 EVSEs

(b) 44 EVSEs

Figure 9: Comparison of the number of charging sessions per day between uncooperative and cooperative scenarios.

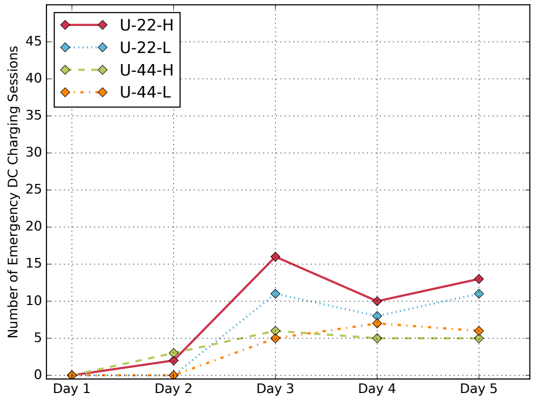


Figure 11: Number of emergency DC charging sessions in the uncooperative scenario.

substantial.

B. Emergency DC Charging

As the previous section has shown, 22 EVSEs cannot satisfy the number of charging requests in the uncooperative scenario. This also applies to low eagerness configurations, in which drivers are very friendly and only search for an EVSE if it is really necessary. Even doubling the available EVSEs to 44 does not significantly reduce the problem.

Another proof for this overload situation is depicted in Figure 11, which shows the number of required emergency DC charging sessions per day. DC charging sessions are performed if all EVSEs that are considered by a specific EV are occupied, but the EV's current SoC requires charging to cover the upcoming commuting distance. As shown, DC charging is necessary to prevent fully discharged EVs' batteries starting from Day 2 for U-22/44-H and Day 3 for U-22/44-L, respectively.

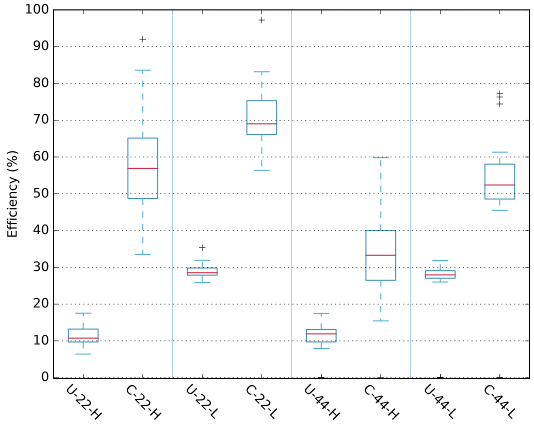


Figure 12: Efficiency of EVSE utilization in uncooperative and cooperative scenarios.

In the cooperative scenario, however, there is no need for DC charging at all throughout the simulation period (not depicted). Thus, each EV recharges and maintains a SoC that is high enough to cover upcoming commuting distances via regular AC EVSEs alone. This not only shows that the existing number of 22 EVSEs can completely satisfy the total demand if the proposed protocol is used, but that the more expensive and harmful (in terms of battery life [24]) DC charging can be avoided.

C. EVSE Utilization

Figure 12 shows the efficiency of EVSE utilization. In particular, the corresponding uncooperative and cooperative configurations are directly compared. The efficiency is measured as the ratio of how long an EVSE was actually providing energy and how long it was blocked by an EV. A high efficiency thus indicates that the EVSE was not misused as a parking spot by fully-charged or non-charging vehicles.

Figure 12 illustrates the highly inefficient use of EVSEs in the uncooperative scenarios—recharging in U-22-H is finished after about 11 % of the occupancy time. For the remaining time, the EVSE is misused as a parking spot. EVs with a lower SoC_{eager} in U-22-L need more time to fully recharge, leading to a higher but still insufficient utilization. EVSE handovers significantly reduce the amount of time EVSEs are blocked by non-charging EVs, as the significant increase of charging sessions per day in Section VIII-A shows. Further, DC charging can be completely avoided (see Section VIII-B). Consequently, the EVSE efficiency improves substantially as shown in Figure 12. For 22 EVSEs, an increase of up to 46 % is possible. Moreover, it is observable that the variance in the cooperative scenario is higher because of a larger range of EVs' SoCs recharging at different EVSEs. In an optimistic (but more unrealistic) scenario with 44 EVSEs, there is still an improvement of about 21 %. The reason for the smaller improvement is of course due to fewer requesters per EVSE in the cooperative scenario as the demand is distributed across more EVSEs.

IX. CONCLUSION

In this paper, we have presented a cooperative protocol for EVs that facilitates coordinated handovers of EVSEs to solve the challenges of scarce on-street charging. EVs charging at an EVSE are incentivized to make it available to the next vehicle as soon as possible, while avoiding competition between the possible successors. It further provides occupancy availability and projection to interested EVs. In a detailed security analysis we have shown the protocol's practical feasibility. We have further integrated this protocol with the ISO 15118 [6], [7] standard, which specifies V2G communications, certificate infrastructure and payment models for e-mobility, to demonstrate a practical implementation.

Simulation results show that in an uncooperative (i.e., without our protocol) scenario, the anticipated number of publicly available AC EVSEs in an urban residential area cannot satisfy the expected charging demand. This overload results in a large number of emergency DC charging sessions (which strain battery life) as well as additional mileage and energy consumption for vehicles that are cruising to find charging resources. Even doubling the number of available EVSEs does not considerably improve the situation. We have shown that the proposed protocol is able to substantially improve the efficient utilization of existing EVSEs by 21 % to 46 %. The number of daily charging sessions can be increased by a factor of 7. As a result, emergency DC charging as well as cruising for charging resources can be completely avoided. In sum, coordinated handovers have been shown to significantly improve both EVSE utilization (helping to amortize the expensive operating costs) and to provide benefits for EV owners by providing sufficient charging resources. This reduces range anxiety and saves them from cruising for charging.

A. Future Work

In this paper we assume low-speed autonomous driving capabilities that allow for automatically executing handovers. Future versions might be based on a smartphone application that notifies drivers of a handover request which they can either confirm or decline. Nightly handovers would then be affected by the driver's mood, behavior or if he/she is sleeping. Moreover, we are planning to evaluate the impact of alternative incentive models which have been out of scope for this paper.

ACKNOWLEDGMENT

We would like to thank Florian Franke for his support.

REFERENCES

[1] Nationale Plattform Elektromobilität, "Fortschrittsbericht 2014 – Bilanz der Marktvorbereitung", Gem. Geschäftsst. Elektromobilität der Bundesreg., Dec. 2014, p. 76.

[2] J. Timpner and L. Wolf, "Design and Evaluation of Charging Station Scheduling Strategies for Electric Vehicles", *IEEE Trans. Intell. Transp. Sys.*, vol. 15, no. 2, pp. 579–588, 2014.

[3] Nationale Plattform Elektromobilität, "Vision und Roadmap der Nationalen Plattform Elektromobilität", Gem. Geschäftsst. Elektromobilität der Bundesreg., 2013, p. 27.

[4] *TS 101 556-3 - V1.1.1 - Intelligent Transport Systems (ITS); Infrastructure to Vehicle Communications; Part 3: Communications system for the planning and reservation of EV energy supply using wireless networks*, ETSI, 2014.

[5] Inventivio GmbH. (2015). Autonomous car forecasts, [Online]. Available: http://www.driverless-future.com/?page_id=384 (visited on 08/19/2015).

[6] *ISO/IEC DIS 15118-1: Road vehicles – Vehicle to grid communication interface – Part 1: General information and use-case definition*, Int. Organization for Standardization, 2013.

[7] *ISO/IEC DIS 15118-2: Road vehicles – Vehicle to grid communication interface – Part 2: Network and application protocol requirements*, Int. Organization for Standardization, 2014.

[8] L. Bedogni, L. Bononi, M. DiFelice, *et al.*, "An Integrated Simulation Framework to Model Electric Vehicles Operations and Services", *IEEE Trans. Vehicular Technology*, vol. PP, no. 99, pp. 1–17, 2015.

[9] N. Mejri, M. Ayari, R. Langar, *et al.*, "Cooperation Versus Competition Towards An Efficient Parking Assignment Solution", in *IEEE Communications*, Jun. 2014, pp. 2921–2926.

[10] T. Delot, S. Ilarri, S. Lecomte, *et al.*, "Sharing with caution: Managing parking spaces in vehicular networks", *Mobile Information Systems*, vol. 9, no. 1, pp. 69–98, 2013.

[11] D. Ayala, O. Wolfson, B. Xu, *et al.*, "Parking in Competitive Settings: A Gravitational Approach", in *13th IEEE MDM*, Jul. 2012, pp. 27–32.

[12] P. Szczurek, B. Xu, O. Wolfson, *et al.*, "Learning the Relevance of Parking Information in VANETs", in *Seventh ACM VANET*, Sep. 2010, pp. 81–82.

[13] M. Caliskan, A. Barthels, B. Scheuermann, *et al.*, "Predicting Parking Lot Occupancy in Vehicular Ad Hoc Networks", in *65th IEEE VTC (Spring)*, Apr. 2007, pp. 277–281.

[14] V. Verroios, V. Efstathiou, and A. Delis, "Reaching Available Public Parking Spaces in Urban Environments Using Ad Hoc Networking", in *12th IEEE MDM*, Jun. 2011, pp. 141–151.

[15] N. G. Paterakis, O. Erdinc, I. N. Pappi, *et al.*, "Coordinated Operation of a Neighborhood of Smart Households Comprising Electric Vehicles, Energy Storage and Distributed Generation", *IEEE Trans. Smart Grid*, vol. PP, no. 99, pp. 1–12, 2016.

[16] M. J. E. Alam, K. M. Muttaqi, and D. Sutanto, “Effective Utilization of Available PEV Battery Capacity for Mitigation of Solar PV Impact and Grid Support With Integrated V2G Functionality”, *IEEE Trans. Smart Grid*, vol. PP, no. 99, pp. 1–10, 2015.

[17] H. Zhang, Z. Hu, Z. Xu, *et al.*, “An Integrated Planning Framework for Different Types of PEV Charging Facilities in Urban Area”, *IEEE Trans. Smart Grid*, vol. PP, no. 99, pp. 1–12, 2015.

[18] H. Qin and W. Zhang, “Charging Scheduling with Minimal Waiting in A Network of Electric Vehicles and Charging Stations”, in *8th ACM VANET*, Sep. 2011, pp. 51–60.

[19] S. Hashimoto, R. Kanamori, and T. Ito, “Auction-Based Parking Reservation System with Electricity Trading”, in *IEEE 15th Business Informatics*, Jul. 2013, pp. 33–40.

[20] C. Jin, J. Tang, and P Ghosh, “Optimizing Electric Vehicle Charging With Energy Storage in the Electricity Market”, *IEEE Trans. Smart Grid*, vol. 4, no. 1, pp. 311–320, 2013.

[21] B. Jiang and Y. Fei, “Decentralized scheduling of PEV on-street parking and charging for smart grid reactive power compensation”, in *IEEE ISGT*, Feb. 2013.

[22] M. Korth. (May 15, 2015). ÖSTLICHES RINGGEBIET: MORGENS UM 7 IST DIE WELT IN UNORDNUNG, [Online]. Available: http://www.unser38.de/braunschweig-innenstadt/menschen/oestliches-ringgebiet-morgens-um-7-ist-die-welt-in-unordnung-d12320.html (visited on 10/30/2015).

[23] *IEC 62196-3:2014 - Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 3: Dimensional compatibility and interchangeability requirements for d.c. and a.c./d.c. pin and contact-tube vehicle couplers*, Electrotechnical Commission (IEC), 2014.

[24] Y. Li, F. El Gabaly, T. R. Ferguson, *et al.*, “Current-induced transition from particle-by-particle to concurrent intercalation in phase-separating battery electrodes”, *Nature Materials*, vol. 13, no. 12, pp. 1149–1156, Dec. 2014.

[25] P. Furgale, U. Schwesinger, M. Rufli, *et al.*, “Toward Automated Driving in Cities using Close-to-Market Sensors: An Overview of the V-Charge Project”, in *IEEE IV*, Jun. 2013, pp. 809–816.

[26] J. Meins, F. Soyck, B. Engel, *et al.*, “Application of high-power inductive charging of electric buses in scheduled line service”, in *Hybrid and Electric Vehicles Symposium*, ITS Niedersachsen, Feb. 2014.

[27] “Produkte: e-smartConnect”, *ATZelektronik*, no. 4, pp. 30–33, Apr. 2015.

[28] J. Timpner, D. Schürmann, and L. Wolf, “Trustworthy Parking Communities: Helping Your Neighbor to Find a Space”, *IEEE Trans. Dependable and Secure Comp.*, vol. 13, no. 1, 2016.

[29] B. C. Communications. (Jun. 3, 2015). The next step in connected navigation – on-street parking prediction, [Online]. Available: https://www.press.bmwgroup.com/global/pressDetail.html?id=T0220542EN (visited on 01/02/2016).

[30] J. Timpner and L. Wolf, “Query-response geocast for vehicular crowd sensing”, *Ad Hoc Networks*, vol. 36, Part 2, no. Veh. Netw. for Mobile Crowd Sensing, pp. 435–449, Jun. 2016.

[31] P. Papadimitratos, L. Buttyan, T. Holczer, *et al.*, “Secure vehicular communication systems: design and architecture”, *IEEE Communications Mag.*, vol. 46, no. 11, pp. 100–109, Nov. 2008.

[32] T. Dierks and E. Rescorla, *The Transport Layer Security Protocol Version 1.2*, RFC 5246, Updated by RFCs 5746, 5878, 6176, IETF, Aug. 2008.

[33] C. Sommer, R. German, and F. Dressler, “Bidirectionally Coupled Network and Road Traffic Simulation for Improved IVC Analysis”, *IEEE Trans. Mobile Comp.*, vol. 10, no. 1, pp. 3–15, Jan. 2011.

[34] Stadt Braunschweig. (2010). Braunschweig in der Statistik, [Online]. Available: http://www.braunschweig.de/politik_verwaltung/statistik/BS_Statistik_Jahrbuch_2010_neu.pdf (visited on 10/03/2015).

[35] (2014). Berufspendler: Infrastruktur wichtiger als Benzinpreis, [Online]. Available: https://www.destatis.de/DE/Publikationen/STATmagazin/Arbeitsmarkt/2014_05/2014_05Pendler.html (visited on 10/03/2015).

[36] F. Ekman, A. Keränen, J. Karvo, *et al.*, “Working day movement model”, in *ACM MobilityModels*, 2008, pp. 33–40.

[37] G. M. Fetene, C. G. Prato, S. Kaplan, *et al.*, “Harnessing Big-Data for Estimating the Energy Consumption and Driving Range of Electric Vehicles”, in *95th Annual Meeting of the Transp. Research Board*, 2016.

Dominik Schürmann received the BS and MS degrees in 2010 and 2014 respectively, from Technische Universität Braunschweig. Since 2014, he works as a research fellow at the Institute of Operating Systems and Computer Networks at Technische Universität Braunschweig, where he is also pursuing a PhD degree. His research interests include unobtrusive security in distributed systems and cryptographic algorithms in general.

Julian Timpner received the BS and MS degrees in computer science in 2009 and 2012, respectively, from Technische Universität Braunschweig. In 2010, he was a visiting student at the University of California, San Diego. Since 2012, he works as a research fellow at the Institute of Operating Systems and Computer Networks at Technische Universität Braunschweig, where he is also pursuing a PhD degree. His research interests include vehicular networks and e-mobility.

Lars Wolf received the diploma degree in 1991 and the doctoral degree in 1995, both in computer science. From 1991 to 1996 he worked at IBM’s European Networking Center, until he joined the Technische Universität Darmstadt as assistant professor. Dr. Wolf joined Universität Karlsruhe (TH), in 1999 where he was associated professor in the computer science department and alternate director of the computer center. Since spring 2002 Lars Wolf is full professor for computer science at the Technische Universität Braunschweig where he is head of the Institute of Operating Systems and Computer Networks. His current research interests include wireless and mobile networking in general, sensor networks, vehicular networks, delay-tolerant networks, and network & system support for mobile systems.