SMART AND SECURE CHARGING OF ELECTRIC VEHICLES IN PUBLIC PARKING SPACES

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ABSTRACT:
Governments worldwide are starting to give incentives to promote the use of (hybrid) electrical vehicles to achieve cleaner and more energy-efficient road transport with a low carbon footprint. Through tax/VAT reductions and free additional services — such as free parking, and/or battery charging or lower traffic congestion taxes — private users, public organizations and car fleet operators are stimulated to adopt the plug-in (hybrid) electrical vehicle (PHEV). This upcoming breakthrough of PHEVs will impose various challenges to the power grid, such as a significant increase of the load in residential areas and parking spaces as the limited range requires frequent charging. Another challenge is the seamless driver and car identification and fraud-sensitive measuring of the charged energy anywhere a car is charged. On the other hand new opportunities are created as these vehicles allow the storage of power on a wide scale, and typically offer some flexibility during the charging process which can be exploited by smart charging services to balance demand and supply or maximize the local consumption of renewable energy. In this paper we discuss the main actors involved in the charging of leased cars in public parking spaces. We present a novel service architecture and detail the security aspects. Furthermore we discuss how a market-based smart charging algorithm that is plugged into the architecture can exploit the flexibility of the parked cars to maximize the consumption of local generated wind energy. We conclude this paper with the presentation of a new business model for the smart charging of leased cars in public parking spaces, detailing the different actors and value flows.

INTRODUCTION

Plug-in-(hybrid)-electric vehicles (PHEVs) appear often in the media at this moment, for example with the recent election of the Opel Ampera/Chevrolet Volt as car of the year 2012. However, market shares are still very small due to expensive batteries, limited ranges and the lack of ubiquitous charging infrastructure. Governments actively promote this new technology to reduce the carbon footprint of the road transport (if they are charged with electricity from renewable sources), and reduce their dependency on oil. These vehicles will impose some challenges to the power grid such as a significant increase of the load in residential areas. For an average household, charging an PHEV at home means a doubling of the average load [1]. To avoid expensive upgrades to the (distribution) power grid it is important that the charging of these vehicles is carefully managed. This is possible, as personal vehicles are only used 4% of the time for transportation, and the remaining 96% can be used for other purposes [2]. So, there is enough flexibility available that can be exploited by smart charging services to deliver applications to the grid, for example to reduce peak loads or balance demand and supply.

Current limitations of PHEVs are the limited ranges and the long charging times. It is therefore expected that these cars will initially be used as a second vehicle, for short trips in the neighbourhood or for driving to work. When people are working or shopping, enough time is available to recharge the battery of the car. Consequently, company cars are an interesting market and charging infrastructure should be deployed in public and private parking spaces. When such leased cars are charged, it is important that the driver, car and possibly also the battery are securely identified. This allows the car leasing company to check if the car is charged in accordance with the agreements (e.g., fast charging could be limited to avoid the rapid ageing of the battery which is an important asset for the car leasing company). The parking owner can offer different tariffs and payment options based on the type of customer and possibly also based on the offered flexibility during the charging process. This flexibility can be used by smart charging services to for example reduce imbalance costs or improve the consumption of green energy in a city or neighbourhood. It is clear that new service architectures, business models and smart algorithms are needed for these environments. In this paper we present an innovative service architecture that allows the secure charging of (leased) cars in public parking spaces. Smart charging algorithms can be plugged in to benefit from the offered flexibility of the parked cars. We also discuss a new business model with the relevant actors and value flows.

FUTURE-PROOF SERVICE ARCHITECTURE FOR CHARGING INFRASTRUCTURE

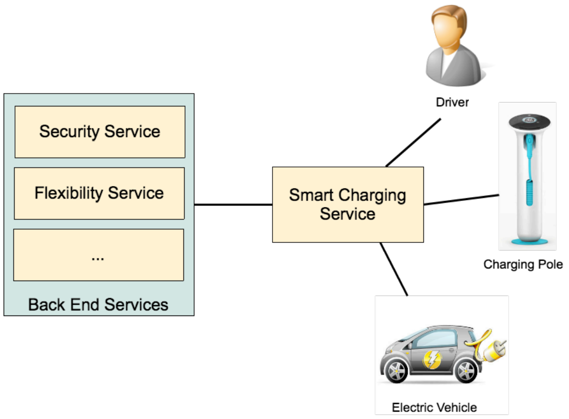

Figure 1. Smart charging service architecture

Figure 1 gives a general overview of the designed service architecture. The smart charging service is responsible for communicating with the driver, electric vehicle and the charging pole which are authenticated and authorised in a secure way before the actual charging starts. The driver indicates when he/she will leave and possibly expresses some preferences, for example to only charge with green energy or charge as fast as possible.

A flexibility service in the back end allows a third party to exploit the offered flexibility of the vehicles e.g., to minimize imbalance costs. The user settings (deadline, preferences) and requests from the external party are translated into charging schedules by an optimization algorithm. This algorithm consists of a global component as part of the flexibility service in the back end and a local component in the smart charging service. In the back end also other services can be deployed, e.g., for billing, auditing, etc.

Secure Charging

The security requirements demand that the system needs to resist unauthorized usage while still providing its services to legitimate users. These requirements need to be supported by a set of security services (the security subsystem) as shown in Figure 2.

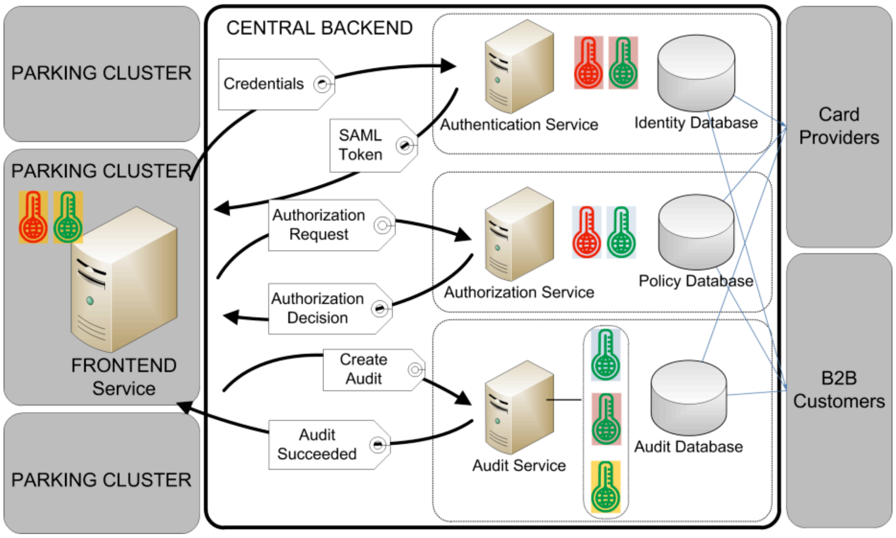

Figure 2. Overview of the security subsystem

Authentication: There should be no anonymous charges. The system needs to know who wants to charge, with which car, which battery and for which company (when applicable). The identities of the driver, car and/or battery are determined based on a parking card with RFID and chip. The identities of car and battery (and other information as well) may also be retrieved automatically from the vehicle itself by means of a secure communication process over the power line connecting vehicle and charging pole [7]. The identities and their known attributes are managed centrally on the back-end server of the parking owner, and business-to-business (B2B) customers are offered self-management to issue and revoke the parking cards. The technology standard we used for exchanging authentication information is the Security Assertion Markup Language (SAML) [3].

Authorization: The system needs to verify if the charging process is permitted: Is the requesting person authorized to charge the battery within the given context? The authorization of users is based on the selected and activated policies from a fixed set of known policies offered by the parking owner. B2B customers can self-manage which policies are enforced on which set of card numbers. The set of pre-defined policies that can be activated are based on several constraints on identity attributes such as the company of the user, the role of the user (employee, manager, etc.), the location of the parking garage, date and time (charging can be constrained based on the fact if it is night, day, a weekday or weekend) and the car-driver relationship (the user must be the designated driver for the car). For defining authorization policies and automating their use, we used a popular attribute-based access control language called Extensible Access Control Markup Language (XACML) [4].

Audit: A secure log of all important actions must be stored, in order to facilitate the billing process, and to detect malicious and dubious behavior by the users. These actions include the start of the charging process, the end of the charging process, authentication attempts by users, in order to know successful and failed authentication attempts and authorization attempts of the system, in order to know why a charging request was denied or permitted. The secure log includes a proof of integrity and origin. To create this proof, public key cryptography is used.

SMART CHARGING

Objectives

Smart charging is often done in the context of renewable energy production. Indeed, since the production pattern of e.g., wind or solar energy is far less predictable than the energy production schedule of conventional power plants, smart charging is a powerful solution to reduce the strain on the electricity grid by consuming the power at the same time as it is produced. There are however other benefits linked to controlling the PHEV charging. On the local level, smart charging can be used to cap the total power consumption. This is often needed in public parking sites since the local power grid typically has not been designed to meet the unconstraint power demand of a large fleet of PHEVs. In a financial context, the storage of energy in PHEVs can be used for trading, e.g., to buy electricity at the moments it is cheapest.

While creating the charging schedules, one has to take into account several constraints, both hard and soft. Good examples of hard constraints are capacity limits of the network or power limits of the battery. On the other hand, user constraints such as a requested state of charge (SOC) at departure time, are to be treated as soft constraints. This means that a violation of such constraint is allowed, but comes with a cost.
We have chosen to measure the quality of the schedules using a dedicated set of KPIs. Violations of the soft constraints therefore yield poor values of some performance indicators.

- *User satisfaction:* to approximate user satisfaction, we compute the fraction of charge sessions that end with a SOC that is equal or higher than the requested level.
- *Green charging:* to measure the impact on renewables, we determine how well the power consumption can be tailored to match a given amount of wind production. More precisely, we compute the average mean squared error of the imbalance.
- *Scalability:* To judge the scalability of the algorithm, we measure average CPU time and communication load (due to scheduling) per PHEV as a function of the total number of PHEVs.

Market-based PHEV charging algorithm

The market-based PHEV charging approach we adopted for the presented architecture is based on concepts from market-based multi-agent system (MAS) control [5]. In market-based MAS control, devices are controlled by device agents and organized in a tree structure with intermediate agents and a unique auctioneer. While market-based MAS control is focused on demand and supply matching in a cluster of devices, our approach coordinates PHEVs to maximize renewable energy usage (Figure 3). A central concept in our market-based charging approach is the PHEV demand function, constructed by an individual PHEV (Figure 4). This demand function is a mapping between charging power and priority. At high priorities, consumers are willing to consume less and at low priorities, consumers are willing to consume more. The slope of the PHEV demand function is determined by the priority heuristic $prio_H$, which indicates the “urgency” for a PHEV to charge its battery:

$$prio_H = \frac{\Delta E}{\Delta t \cdot P_{\max}}$$

ΔE is the energy left to charge, Δt is the time left for charging and $P_{\max}$ is the maximum charging power of an PHEV (also limited by the charging pole). The priority heuristics differs for each PHEV and will determine how energy is divided between PHEVs.

The overall coordination mechanism consists of 3 steps: aggregation, optimization and control. In the aggregation step (1), PHEV demand functions are aggregated towards the auctioneer agent. In the optimization step (2), the auctioneer agent calculates the equilibrium priority $prio_{equi}$, at which PHEVs charge at a collective power closest to the generation of renewable energy. In the control step (3), the equilibrium priority is sent to all PHEV agents, where this priority is matched with a charging power in their local demand function. The fundamentals of this mechanism originate from traditional demand and supply matching in economics.

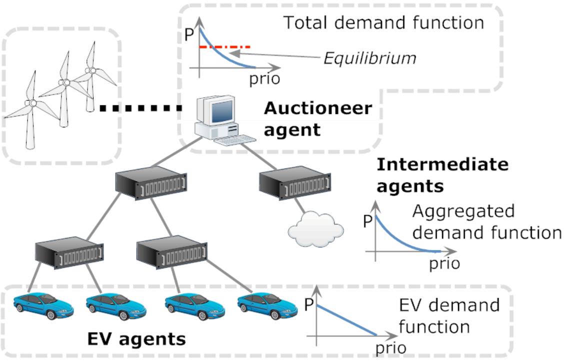

Figure 3: Market-base control for electric vehicles

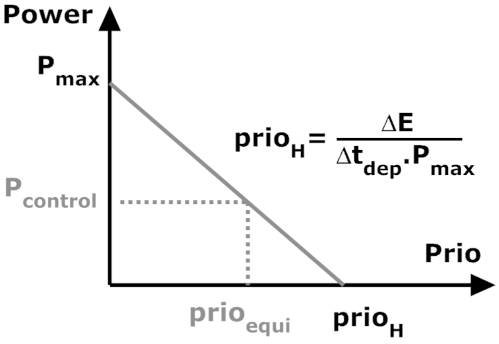

Figure 4: PHEV demand function

Evaluation results

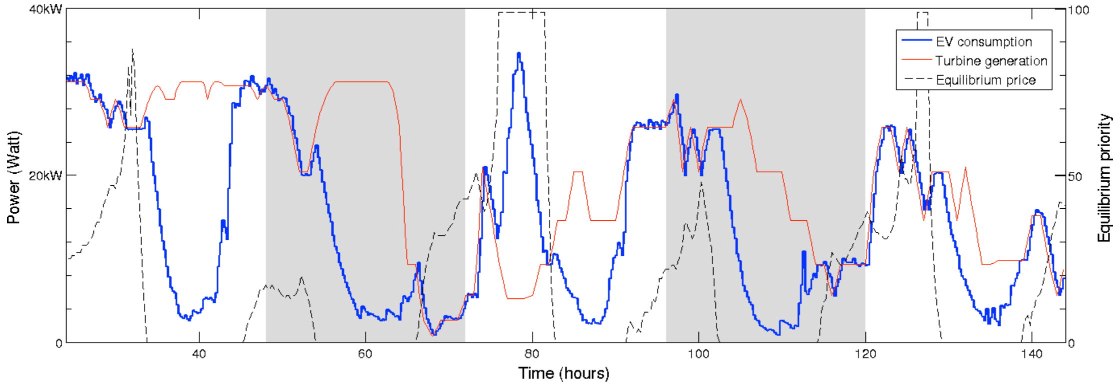

Figure 5: Typical simulation run for 5 days (shaded/white parts indicate different days).

The market-based PHEV charging approach is evaluated in a simulation experiment. The goal of this experiment is to maximize consumption of renewable energy, while complying with PHEV driver preferences. In the simulated scenario, we consider 100 PHEV drivers, which charge at public charging stations. PHEV charging times are based on a statistical availability model [6], the battery capacity of an PHEV is 10 kWh and the maximum PHEV charging power is 3 kW. Furthermore, we assume that PHEVs have to be fully charged at departure time. In terms of renewable energy, we assume a small wind turbine with installed maximum power of 30 kW.

The results of this simulation experiment are shown in Figure 5. In general, generation is followed as closely as possible. Deviations are caused by a low number of charging PHEVs (day 1) or a high number of charging PHEVs (day 3), compared to available wind energy. In this scenario, PHEVs were all charged in time.

BUSINESS MODEL FOR CHARGING ELECTRIC VEHICLES

The introduction of PHEVs in the existing market will require a shift in the existing business models for leasing companies, parking providers and fuel card services. Since PHEVs offer widespread storage of electricity, the charging flexibility of their batteries can be aggregated to offer balancing services to actors active in the electricity market. Additionally, the data necessary to offer such services will be generated on different locations by different actors, resulting in new value flows.

These three aspects, related to the introduction of PHEVs, have been translated in a new business model for this market, as depicted in Figure 6. The methodology followed to draw this business model starts from the elementary roles identified in the value network. For example, in case the PHEV is a leasing car, the car ownership role can be subdivided into 5 different sub-roles. The legal owner of the vehicle and battery is the leasing company, while the economic owner is the employer offering the car to its employees. It is important to notice that the actors taking up these roles are not necessary the same for the car and the battery. The last sub-role is the social owner, the user of the PHEV.

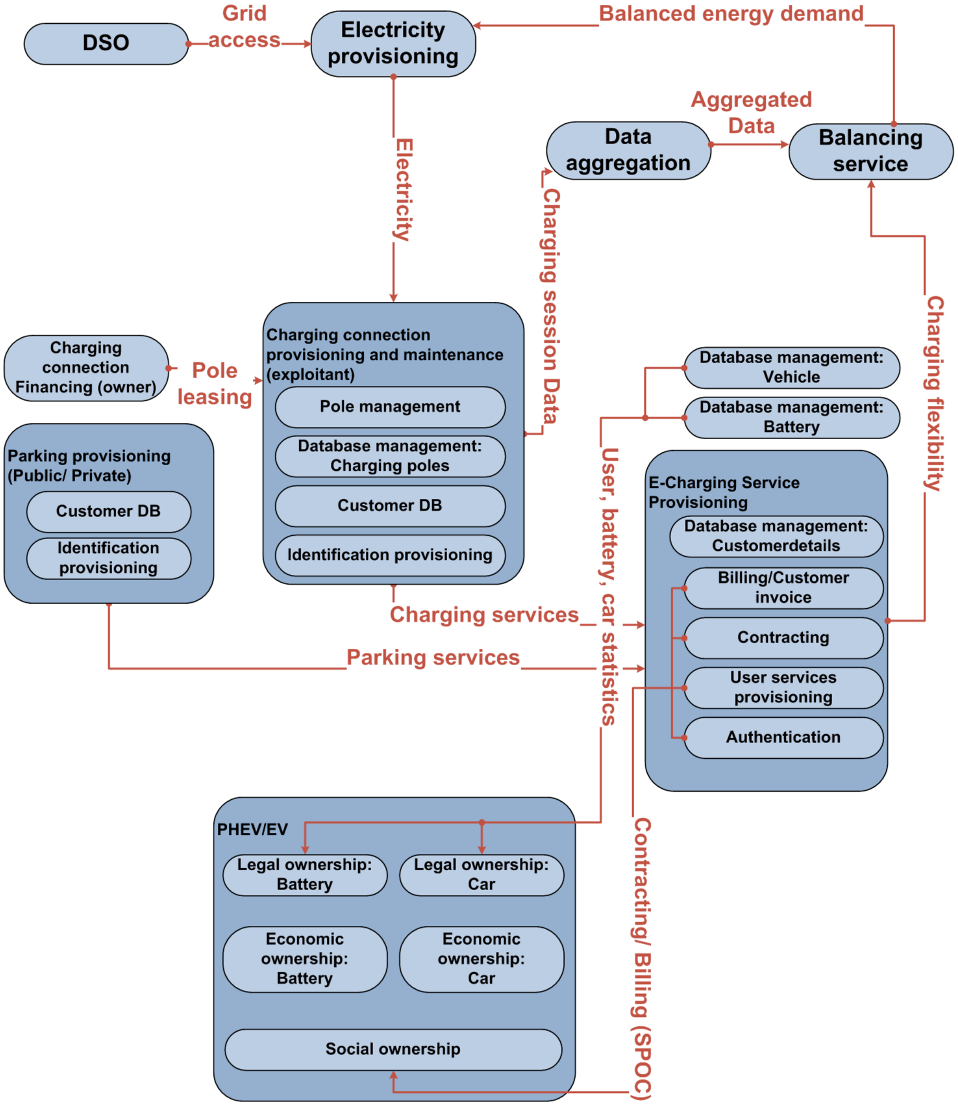

Figure 6. New value network with service flows

The other major actors in this new ecosystem are the service provider, the charging connection provider, the parking provider and the balancer. The service provider is the single point of contact (SPOC) for the end user, responsible for contracts and billing. Since this service provider has a portfolio of PHEV users, he can offer the flexibility from these vehicles to the balancer. In addition, he is also responsible for contracts with charging connection owners, much like the current fuel card system. The driver is offered a fuel card by his service provider, which allows him to refuel at certain petrol stations, or in this case, charging poles. The ownership of the charging location can be distributed between different actors: the owner of the charging infrastructure, the company responsible for the continuous operation of this infrastructure and the owner of the parking space. The split between owner and operator of the infrastructure is inspired by the current value network for electricity distribution. Inter-municipal companies finance and own the infrastructure, but the operation of the network is outsourced to the distribution system operator. The upper level of the value network comprises the balancer. His main role is aggregating the flexibility from the distributed PHEVs. This flexibility is applied to counter issues on the electricity grid, e.g., imbalance, congestion, etc. Based on this business model, the value flows between the different actors can be identified. From the different actor-dependent cost-benefit models, these flows can be quantified. This quantification will result in tariff plans for the different services, since a stable equilibrium is required in the value network.

CONCLUSIONS

In this paper we presented a novel service architecture and business model for the smart charging of electric vehicles in public parking spaces and the relevant actors. The architecture allows the driver, car and battery to be identified in a secure way and smart charging algorithms can be plugged in to exploit the offered flexibility of the parked cars, e.g., to balance demand and supply or to maximize the local consumption of green energy.

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