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Abstract

Electric vehicles (EVs) are currently promoted by government and industry as an alternative to traditional internal combustion engine (ICE) propelled vehicles. However, e-mobility has not yet reached a level of technological maturity that allows for the same degree of mobility offered by ICE propelled vehicles. In this paper, we argue that the adaption of roaming concepts to enable EV charging across geographical and service provider boundaries is likely to be a crucial element for e-mobility to be successful. To that end, we derive requirements and design principles for roaming concepts in e-mobility. Furthermore, we present and briefly evaluate a prototype implementation of an e-mobility roaming platform as a proof-of-concept.

1   Introduction

As limited fossil resources are certain to extinguish in the not so far future and environmental impact of ICE propelled vehicles is vast, public interest in a new, sustainable way of individual transportation grows. E-mobility is widely expected to reduce dependency on oil and lower environmental impact of individual transportation. Thus, governments and industry all over the world spend significant efforts to replace the ageing concept of ICE vehicles with full or hybrid EVs (Diamond, 2009). This is well documented by significant investments into e-mobility technology and infrastructure in major economies (Becker et al., 2009).

However, e-mobility has not yet reached a level of technological maturity that allows for the same degree of mobility offered by ICE propelled vehicles (Chan, 2007), novel business models and services have to evolve and meet the needs of e-mobility technology and the implications for its users. Current business model trends in e-mobility indicate that, unlike traditional car drivers, EV users will have a prominent relationship to one exclusive e-mobility service provider handling all mobility related services, including deployment and operation of charging infrastructure (Bessler et al., 2011). As charging is a crucial process to guarantee a certain degree of mobility of EV users, they depend on a well distributed and compatible charging infrastructure. As it seems highly unlikely for one single e-mobility service provider to be able to establish a sufficiently dense and widespread network of charging sites both on a local and especially on a global level, EV users should be enabled to roam between their native and suitable foreign service providers. Thus, physical infrastructure owned by various local service providers should be bundled and provided to the customer with one single interface as one homogeneous virtual infrastructure.

Roaming, in general, is a service enabling subscribers of one service provider network to use foreign service provider resources, if the native network is not available – e.g. in another country. Kumar (2007) defines roaming as follows: "[...] service roaming is broadly defined as the mechanism enabling the possibility of offering the same or similar service to a roaming user in a visited network." The concept of roaming is widely known in context of mobile telecommunication. In this paper, we argue that the adaption of roaming concepts to enable EV charging across geographical and service provider boundaries is likely to be a crucial element for e-mobility to be successful, as it substantially reduces range anxiety by extending the native service providers charging network with additional charging infrastructure of foreign service providers. The basic concept of roaming in an e-mobility context is depicted in fig. 1.
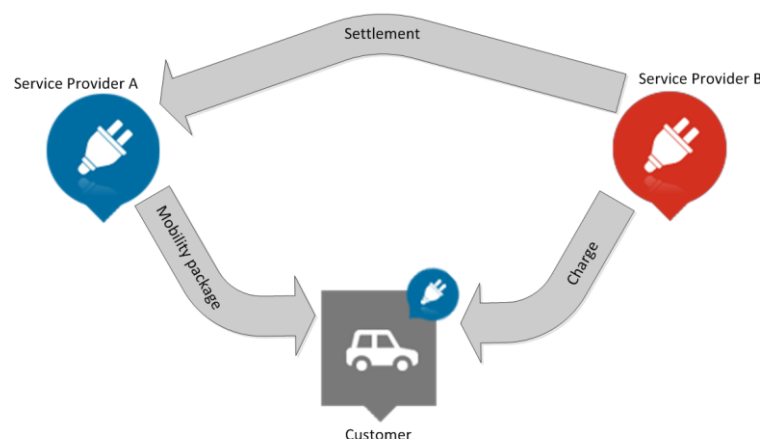

Figure 1.   Roaming: Charging at a foreign service provider (red) requires settlement of consumed services between native (blue) and foreign service provider.

The remainder of this paper is structured as follows. We first describe emerging challenges for e-mobility substantiating our call for roaming as a key-enabler of e-mobility. Second, we derive requirements and design principles for a roaming concept in e-mobility, thereby addressing the described challenges. Third, we present a prototype implementation of an e-mobility roaming platform meeting these requirements as a proof-of-concept. Finally we briefly evaluate the platform, discuss its implications and conclude our work.

2 Emerging challenges with implications on roaming in e-mobility

As of today, ICE propelled vehicles cover most individual transportation needs. Consumers got used to large maximum ranges and - after exceeding the maximum range – to refueling within few minutes. These performance values do not hold for EVs. Instead of a fuel tank, energy for propulsion of EVs is stored in a battery with considerably lower capacity. Additionally, EV users have to take time consuming recharging cycles into account. The term range anxiety describes these shortcomings of e-mobility from a consumer's point of view. It is the fear of an EV driver not to reach his destination due to range limitations and lengthy recharging cycles. Rapid progress in fundamental technological innovation to overcome range anxiety, as the development of batteries with significantly higher energy density, is not to be expected in the near future (BCG, 2010). Therefore, an early and successful introduction of e-mobility to a widespread audience requires solutions that neutralize range anxiety by other means. Gaining access to more charging infrastructure results in lower range limitations, however requires well integrated technology. Internet of Things technology could provide the capability of extending EV range limitations by providing access for customers of one infrastructure provider to the infrastructure of another provider when travelling outside the geographical coverage area of the home network – a concept widely known as roaming. This would include mobility management, authentication, authorization and billing procedures (Uckelmann and Scholz-Reiter, 2011) as part of a traditional roaming task.

A functioning e-mobility eco-system requires the deployment of complex and expensive physical infrastructure such as charging sites and appropriate power grids (Taylor et al., 2010). If consumers do not purchase EVs, the installation and operation of necessary infrastructure will not be profitable for the industry and e-mobility itself will consequently not be feasible in the long run. Beside fortunate cases, where an EV may be purchased as an additional gadget to be used just in urban areas, EVs certainly take on a competitor's role opposing traditional ICE propelled vehicles (Lemoine et al., 2008). One reason to choose an EV over a traditional car should be the promise of an at least comparable range of the vehicles. To achieve range parity between EVs and traditional cars, EV range limitations and duration of recharging cycles are to be reduced or managed in a way that consumers' range anxiety is kept at a minimum. Beside technical limitations of EVs and the driver's resulting range anxiety, the cost of EVs naturally has a major influence on the consumers' buying decision (Chéron and Zins, 1997). EVs themselves are less costly producible than ICE vehicles, but they have a completely different price structure. Electric motors are less complex than ICEs. Due to their fundamental characteristics gear shifting is not necessary, which reduces complexity of the vehicle's drive train. Batteries, however, are far more expensive than a fuel tank and make the purchase of an EV considerable more expensive than a comparable ICE vehicle. Running costs of an EV, on the other hand, are way beneath those of an ICE vehicle. As prices for gasoline are on the rise, the cost for a full charge of an EV battery is almost negligible. Hence, the main challenge to make EVs attractive to consumers is to neutralize range anxiety and to turn the unique price structure of EVs into new business models providing financial incentives for consumers.

The impending transition to e-mobility does not only affect in-vehicle technology and infrastructure, as substitution of ICEs with electric motors, using batteries for energy storage and installation of charging sites. Technical shortcomings and the unique price structure of EVs impose implications on consumers and hence on the market. As industry anticipates future market potential from a functioning e-mobility eco-system, companies offering e-mobility solutions have to find their niche in this

immature, fast changing market and develop viable business models that ultimately reflect the needs of consumers. An eco-system has to evolve that can keep up with the promises of an electric future of mobility (Chau and Wong, 2002). The transition from ICE to electric propulsion changes interdependencies of the old players in the mobility market and brings new players to the table: Electricity and grid providers enter the unknown market of mobility, OEMs increasingly have to rely on first tier suppliers, because they are not yet as familiar with electric technology and ICT providers have to develop novel solutions to handle requirements of e-mobility and reduce range anxiety by intelligently managing new mobility services, such as charging and roaming. In this complex eco-system there are also new companies evolving, having the goal of being full e-mobility service providers.

One example for such a company is Israelian e-mobility pioneer Better Place. They already are full e-mobility service providers, offering EVs together with service contracts for charging. The importance of business model innovation for the introduction of functioning e-mobility services is evident in the fact that customers neither have to buy a battery for their EV nor have to pay for electricity directly. Instead, Batteries and electricity are included in the service contract, which is sealed with the purchase of an EV. Customers of Better Place buy an EV, seal a service contract and pay per driven kilometer. This way, Better Place claims, to have reduced total cost of ownership (TCO) of an EV compared to an ICE vehicle by 10 to 20 percent (Barry, 2011). Doing so, they provide financial incentives to customers creating a possible competitive advantage over ICE vehicles. This example illustrates how high entry-cost barriers of EVs can be reduced by the successful deployment of a new business model. It shows how technological challenges of e-mobility can be approached in a competitive way, supports the importance of e-mobility service providers offering all-in-one solutions to their customers and hence substantiates the need for roaming services.

3 Requirements for e-mobility roaming

The concept of a central roaming platform raises many functional and non- functional requirements. In this section we derive five key requirements for e-mobility roaming. These requirements particularly address the above challenges and lay grounds for the later introduced design principles on which we build a prototype implementation of a e-mobility roaming platform.

Business models of e-mobility service providers may likely diverge strongly from each other. As a result, service providers will offer their customers various service contracts that may or may not include e.g. a battery lease or payment by driven distance. How charging of EVs is cleared - given these possibilities - is up to each one of the service providers and their attached business models. However, when roaming, charging services of a foreign service provider have to be cleared within the terms and conditions of the customer's native service provider, which requires business model independency of the roaming platform (1). Interoperability also is a crucial factor from a technical point of view. A roaming platform interacts with all sorts of software from well-known standard solutions to small custom build applications. Possible e-mobility service providers come from all sorts of industries and reach from SME to global operating companies, which naturally reflects on their IT-systems. Hence, beside the physical compatibility through standardization of charging plugs, interoperability of various IT systems has to be granted (2). A roaming platform will be interconnected with key business process and is likely to play an important role for mobility service providers, which leads to further requirements: Data provided by the platform has to be consistent and correct, which is a challenge because data from various sources is aggregated (3). Reliability of the platform is important to ensure steady availability (4). Companies have to provide a certain amount of their highly sensitive customer data in order to perform roaming and have to be convinced that their data is save and not misused, which substantiates the importance of data security and consistency (5).
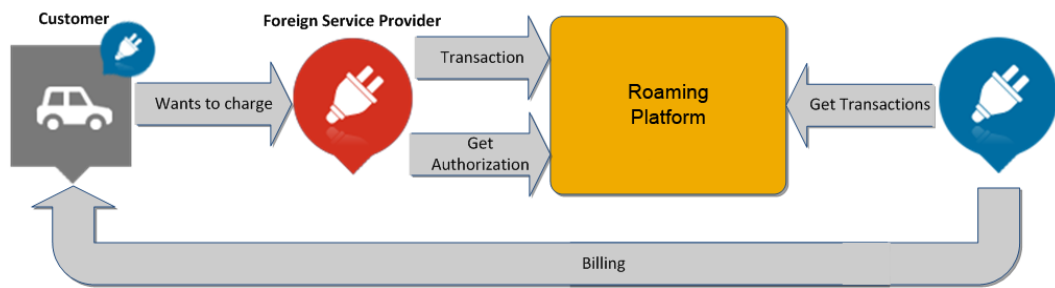
Figure 2.   *Electric mobility roaming concept: Customers wanting to charge at a foreign service provider (red) are authorized via an independent roaming platform. After charging is completed, transactional data is stored and provided to the customer's native service provider (blue). Native service providers are enabled to bill their customers directly and within their own service plans.*

4   Concept

Being able to charge at a foreign service provider's charging site is the most basic roaming scenario. The easiest way to enable customers to roam between native and foreign e-mobility service providers is to establish a central, independent roaming platform that is able to identify and authorize customers of different service providers. When a customer approaches a foreign service provider charging site, he identifies himself with his native customer card. Thereon the foreign service provider requests roaming authorization from the central roaming platform and, if authorization is granted, the foreign customer is allowed to start charging. After charging is finished, the foreign service provider submits transaction data back to the roaming platform, where it is stored, processed and forwarded to the customer's native service provider for billing and clearing. This scenario, illustrated in fig. 2, builds the basis for our concept of e-mobility roaming.

These requirements led us to three design principles for e-mobility roaming services, which were applied to components and services offered by our later implemented roaming platform. The platform is be able to connect to service providers, authorize charging and other e-mobility service processes and retrieve, store and provide transactional data. The architecture being proposed will be specifically targeted on EV roaming in contrast to other general IoT architectures like in (Clayman and Galis, 2011).

Business model independency: The market conditions for EV roaming are complex and involve many companies with different business models and interests. All these stakeholders play an important role for the success of EVs. Therefore, it is necessary to allow any company to participate. A centralized roaming platform is the only gateway to participate in roaming and it is essential that the platform offers interfaces that are compatible to any, or at least most, business models. This involves mainly the functionality and the way the interface is exposed by the platform. On the one hand, the set of functionality has to be defined so that every necessary operation is possible but no impossible operations are required. On the other hand it is important that the data is stored and exchanged in a universal way. For instance identifiers have to be treated in a common way without format restrictions. To stay aligned with this principle is a balancing act between compatibility and functionality.

One face to the customer: Roaming implicates frequent interaction between customers and numerous companies. Because current e-mobility business model trends indicate to be based on monthly payment , without a functioning roaming system, the customer would receive a number of different bills and would have to deal with several administrative processes. These facts create a barrier for the adaption of e-mobility and substantiate the need for roaming services. In order to convince customers

to use EVs, this complexity has to be hidden from the customers. Therefore, the platform always acts only between the involved service providers - the customer never deals with it. A customer will always use the administrative infrastructure and processes of its native provider.

Data reduction: In the information age data is one of the most important assets of a company (Castells, 2011). Centralized roaming requires data exchange between different companies and can be seen as a potential thread to a valuable asset of the company. This fear can be reduced using encryption and other security-relevant technologies. However, the most efficient way to minimize concerns about security is to reduce the stored data. For roaming, customer names and account information are not of interest. Therefore, only an identifier needs to be stored.
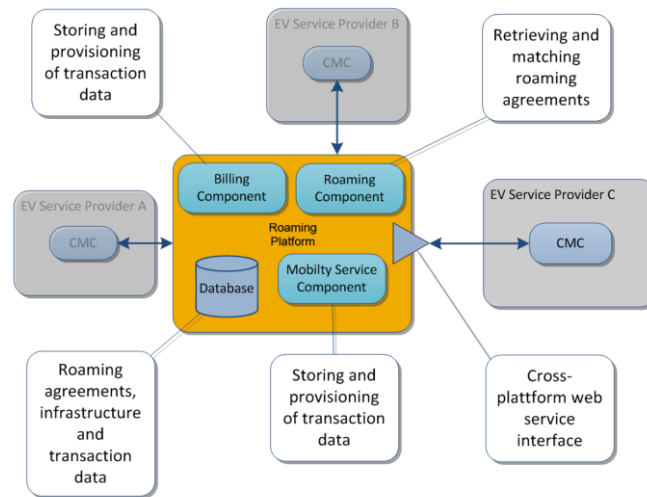

Figure 3.   Components of electric mobility roaming platform: Database, Roaming, Billing and Mobility Service

Design principles ensure that all components have a common ground and that they can be combined with each other. A major challenge when transforming the design principles into a proper model was to find a simple representation of all involved entities that fulfills the requirements and principles. Fig. 3 shows the outline of our proposal for a central roaming platform with its components: billing, roaming, mobility services and web service interface. For the introduced roaming model the aim is to keep the number of involved entity types as small as possible, which results in having two main entities, service provider and mobility services. Service provider are to be understood as stakeholders offering a certain mobility service. This keeps complexity low and requires a generic description. Defining both objects in this manner enforces also our first design principle. A generic description makes it easier to create a business model independent description of business entities. Service provider descriptions only consist of data like the company's name and address. This data structure is common for every company and does not create any restrictions. To create a common representation for services is more difficult because different service types have different manifestations. In the proposed roaming model all services are treated equally. That means there is no difference between charging services and services that are only enabled by roaming. Again, this is used to enforce business model independency. Services are modeled only as useable entities and the system only categorizes them into groups. The system allows service providers to decide if they want to bill services using the functionality of the platform or do the payment directly. With this basic description of a service every necessary service can be modeled. It has to be emphasized that charging services and for instance a restaurant are mapped to the same entity in the roaming model. To perform all necessary operation other infrastructural data, like contractual agreements to connect service providers, charging sites and customers, is necessary and for this entities the concept of data reduction is important. For example customers are stored only with an identifier and a connection towards their native service provider.

The implemented roaming model aims in having a small number of entity types and reducing implementation effort for the systems itself as well as the IT systems of the service providers. The functionality of the roaming platform is fitted to create a platform that is hidden from the customer and interacts only between service providers.

5 Implementation

A prototype of the roaming platform was implemented and integrated with commercial e-mobility service provider systems. Fig. 4 shows a screenshot of the system's simulation environment. The implementation is based on J2EE technologies and uses several related technologies. The roaming platform runs on a SAP Netweaver CE 7.2 and leverages its service composition and creation capabilities to create a flexible but reliable system. All components are designed as Enterprise Java Beans to allow the system to scale based on the business needs. The EJBs are structured following a 3-tier architecture consisting of a data access layer (DAL), a business logic layer and a presentation layer (Java Server Programming Java Ee5 Black Book, 2008).
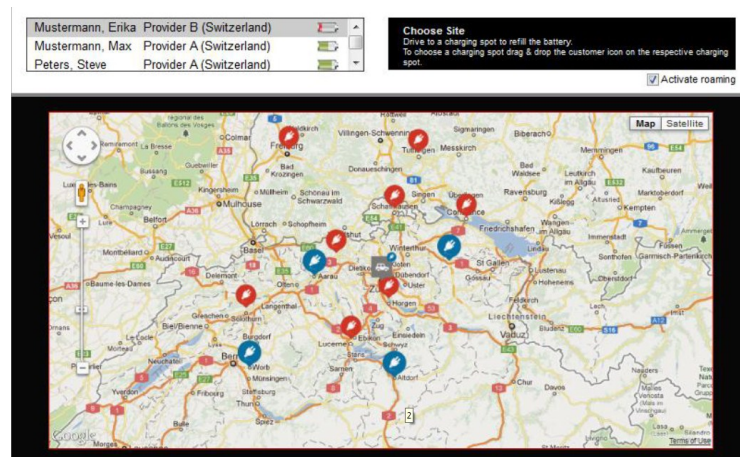

Figure 4.   *Roaming platform simulation environment: The system was tested by simulating electric vehicle drivers (grey), native (blue) and foreign (red) charging sites.*

The data access layer uses Java Persistence API (JPA) to map database tables on entities. This mapping is created using a model first approach whereby the database was designed according to the design principles stated before. The business logic layer on top of the DAL consists of Stateless Session Beans and performs all previously described operations. Finally, this layer is exposed by a layer consisting of SOAP 1.2 web services (Pautasso et al., 2008). These services are the contact point for service providers when they start using the roaming platform. The feasibility of this interface has already been proven with the integration of the EV service provider Better Place . There, the roaming platform was integrated in their overall processes without any bigger changes and further implementation efforts.

Fig. 5 shows the relational data structure of the implemented e-mobility roaming platform. Following our design principles, a minimum of data is stored to guarantee customer privacy and overall simplicity. An example for this concept is the customer object that only consists of a customer id and a flag indicating if the customer is allowed to use roaming. As the main objective is to retrieve, store and provide transactional data, the entities are focused on mobility services and their transactions. These two entities are surrounded by structural data that is necessary to perform the mapping between different service providers.
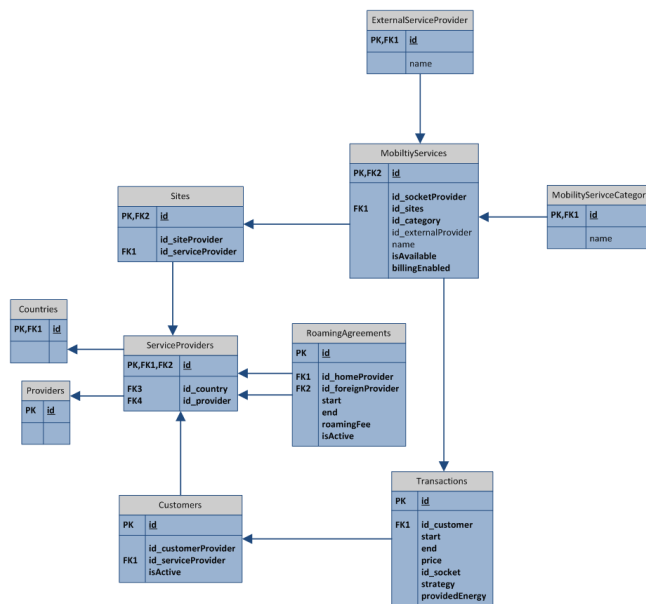
Figure 5.   Relational data structure of the roaming platform: Only a minimum of data is stored

The implementation of the described prototype had to tackle several challenges. The concept of identifiers for entities is one of the main challenges while creating the roaming model. All companies have an own concept for identifiers and the system has to be able to deal with them. One option would be to include a mapping layer in the system architecture and map external identifier to an internal format. But this increases complexity and requires a lot of effort to ensure proper functionality. To avoid this, external identifiers are used throughout the system. This can causes ambiguity and therefore a combination of external identifier and company-id is necessary. The company-id is the only restriction that the roaming platform makes. This identifier is defined regarding the market conditions where country specific providers belong to global enterprises. It consists of the country code and a global enterprise identifier that is granted by the system. Company-ids are defined as a combination of country code and enterprise id. This definition is shown below.

<div align="center">

<country code>.<enterprise code>

</div>

This restriction is easy to implement and does not create any stronger barriers for the adoption of the roaming model. The last open question is the set of functionality. It is constraint by the principle of business model independency and only vital core functions are exposed. This means the platform supports the roaming process and the billing between the service providers. The roaming process is designed variable and contains only two mandatory steps, authorization and data notification. Both operation are built on the previously described entities and are compatible to every existing EV charging provider. More complex is the billing. There are various options like discounts or different billing periods. It is impossible to provide a billing for every case. Also, the principle of "one face to the customer" is violated by doing so. Because of that, the system only provides transaction data to the service provider and they do the billing with their own customers, routing the money to foreign customers. The customers only have to pay one bill and all clearing is done in the background.
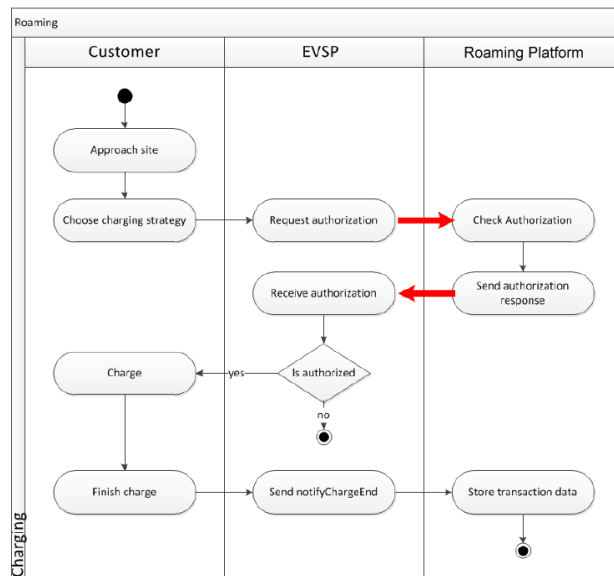
Figure 6.   Authorization process for charging: Customer, electric vehicle Service provider (EVSP) and Roaming Platform.

Finally, to give an example of the technical implementation of a roaming process, the authorization process necessary for all e-mobility services offered through the roaming platform is illustrated in fig. 6. In this case we focus on the charging process. The roaming platform makes only two restrictions. That is on the one hand, the authorization request that identifies the customer and the charging site and on the other hand the notification of the finished transaction.

6   Evaluation

Our system was integrated and tested with Better Place's commercial systems on site. For our testing purposes, Better Place's in-vehicle HMI (fig. 7) has been deployed on an off-the-shelf tablet PC – however its functionality has not been modified from the actual in-vehicle version. This HMI served as virtual EV to evaluate the integration of Better Place's systems with the roaming platform. The tests included the authorization process, a simulated charging process, the end-charging notification and storage of transaction data. We assess the system's characteristics and performance given the below criteria as follows:

Scalability is important for the system, since when consumers adapt more and more to e-mobility the need for roaming may grow quickly. Although we could not evaluate scalability in our one-to-one test scenario, we can say that in general web service architectures scale easily and load balancing and distribution over several servers should not cause severe problems.

Complexity of using the roaming platform for the service provider proved to be low. The service provider could use his own identifiers and only had to implement a simple interface to connect to the roaming platform. However for a larger test setting, business model independency and especially the concept of mapped identifiers may increase system and implementation complexity.

Operability of the roaming platform is mainly influenced by the maintenance of data. Keeping data consistent requires work from the platform provider as well as the involved service providers. Every new or removed customer has to be submitted to the roaming system. This can cause overhead traffic and should be simplified in a real-life scenario. For our tests, all necessary customer data was priory set up via a simple web service interface.

Compatibility involves two aspects to be analyzed: technical and business model compatibility. Technical interoperability is ensured by the SOAP interface. This proved to be valid due to the immediate success when integrating the platform with Better Place's commercial systems. Business compatibility is more complex. Our tests indicated that the designed interface can easily be integrated into existing business processes. However, it has to be shown how well other service providers can access the system. Another limitation may lay in the possible lack of provided functionality for future applications. This results from the enforcement of business model compatibility.

Robustness is crucial in real-life integration scenarios. The system rendered to be robust in our tests, as it always showed expected behavior and has not crashed once. As the system has not been tested under real-life conditions, we can however not clearly asses robustness of the system under realistic work load.

Adaptability of the platform could be demonstrated through the business model independent interface. During our tests the system was able to adapt to all situations within the test scenario and act accordingly. Additionally, the system showed high adaptability to several use cases when other than charging services were elaborated and successfully tested using the simulation environment.

Figure 7.   Better Place's in-vehicle HMI.

7   Discussion

The here presented roaming platform for e-mobility is able to retrieve, store and provide transactional data of services connected to e-mobility. We gave a brief assessment of performance and characteristics of the system. Our tests prove the technical feasibility of a central e-mobility roaming platform, however not under real-life conditions. This is a limitation of this paper. Because our tests involved only one virtual EV and were conducted in a short period of time, we could not conclusively asses how the system would perform under continuous load caused by multiple EV drivers and service providers. Further, for the viability of our model, we assume a standardization of physical charging infrastructure, such as charging plugs or even battery switching stations. Also, we argue that multiple e-mobility service providers will evolve. Without this assumption roaming would not be necessary.

As we proved technical feasibility of a central e-mobility roaming concept, it is important to understand that in a real-life scenario e-mobility service providers will have to commit to roaming agreements to be able to incorporate the proposed roaming concept. Even if it is possible to process all kinds of roaming agreements with transactional data a central e-mobility roaming platform can provide, it is completely unclear how roaming agreements between service providers will look like.

Technical implications of e-mobility require considerably different business models than those we know from gasoline fueled vehicles. EV users are likely to be put into a role more or less similar to mobile phone users. In mobile telecommunications roaming agreements between service providers are mostly bilateral and hence do not incorporate a central roaming platform that systematically manages roaming agreements on behalf of the involved service providers. As a result, mobile phone users are

charged with high prices when they make calls, write SMS or consume data services in a foreign network. Consequently, the European commission assesses "competitive problems" of mobile telecommunication and acknowledges high prices for roaming with ongoing regulations since 2007 (European Commission, 2011). An EV user's relationship to a e-mobility service provider is likely to be of the same nature than mobile phone users have to their telecommunication provider. Given these conditions, EV users will encounter the same problems when it comes to roaming. However, as it may be acceptable for mobile phone users to diminish their mobile phone usage in roaming situations, it is certainly not for EV drivers. For example in a foreign country EV users cannot just quit using their vehicle when there is no affordable foreign service provider to recharge their batteries. EV users certainly depend on a well-balanced roaming network and reasonable roaming agreements between service providers.

How roaming agreements are shaped is rather a political than a technical question. Consumers are looking for an alternative to gasoline fueled vehicles. It should offer a similar level of mobility and cause little range anxiety. As shown, a well-balanced roaming network is crucial to achieve this. From a consumer point of view, roaming agreements should result in the ability to seamlessly charge in any service provider's network at low overall cost. The same situation consumers experience with mobile telecommunication is not desirable to grant successful introduction of e-mobility. Therefore a bilateral solution does not seem to be suitable to meet the needs of consumers. E-Mobility service providers have a vital interest to provide as much charging infrastructure as possible to reduce their customers range anxiety. However they are in a rivalry situation with local competitors. It does not make economic sense to offer charging infrastructure to customers of foreign service providers without monetization. A clearing house approach could provide financial incentives for service providers and enable for the disposal of charging infrastructure. Foremost governments who are willing to enforce the introduction of e-mobility have to watch the developments carefully. They have to represent the consumers' interests and may regulate the market from the beginning to avoid undesirable situations.

8   Conclusion

In this paper we have presented a roaming platform for e-mobility as proof-of-concept. We believe, roaming is crucial for the introduction of e-mobility to a widespread audience. Roaming – as it enables EV drivers to extend their available charging network to foreign service provider infrastructure - is a key factor to reduce range anxiety and give EVs an edge to compete against ICE propelled vehicles on consumer markets. We proposed a centralized roaming platform and proved its technical feasibility. With a prototype implementation of a e-mobility roaming platform, we demonstrated the process of identification and authorization at foreign charging infrastructure and forwarding of transactional data to the driver's native service provider. Finally, we briefly evaluated crucial characteristics of the implemented system.

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