Prototyping A Mobile Routing Assistant for Optimizing Energy Scheduling and Charging of Electric Vehicles

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ABSTRACT
In order to increase the consumer acceptance of electric vehicles (EVs) and to enable an efficient operation of charging station networks, we argue for an intelligent routing service to assist EV drivers in searching and reserving public charging points. In this work, we present out ongoing user-centered research towards a generic reservation mechanism for a smartphone-based routing assistant. We describe fundamental use cases to be covered and outline basic thoughts and experiences from the design process. The main contribution is an interactive prototype which is based on standard Web technologies and thus can be accessed from various mobile platforms for experimentation. Besides using the prototype for early user tests, we plan to finally connect it to our functional server-side routing platform and run a field trial to assess the benefits of such a reservation and routing concept for drivers in a real-world setup.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Graphical user interfaces (GUI), Prototyping.*

Keywords
Electric vehicle, mobile app, e-charging station, reservation

1. INTRODUCTION
Despite the huge potential of electric vehicles (EVs) for reducing greenhouse gas emissions and optimistic predictions on their market penetration, today's actual sales are still low compared to traditional gasoline-powered vehicles. Besides the currently high price of EVs, concerns regarding the required public infrastructure and necessary changes in the personal driving behavior might discourage the faster adaption of such vehicles. Recharging the EV battery can last from 10 minutes (quick charging) up to several hours. Firstly, due to the relatively small range of EVs of approx. 100 km, a phenomenon called range anxiety [3] may prevent users to fully exploit even this reduced range. Secondly, the offering of recharging stations in urban areas in park houses, at gas stations, in shopping malls, on the street, etc. will become quickly unmanageable while their actual availability at the time of arrival is unknown to the driver on the move.

The Austrian project KOFLA [10] investigates a suitable service platform for supporting EV drivers in finding and making reservations for public charging stations. The basic idea is to have a central broker that brings together EVs requesting recharging energy, and recharging stations that have free recharging capacity (energy, parking places, etc.). Such a brokerage engine will offer benefits for each of the stakeholders involved in the EV charging process:

- The *EV driver* will be directed to an available charging station close to his actual destination. At the same time, an intelligent scheduling algorithm avoids overloading of the grid and thus allows for arbitrary charging times. The expected result is a higher acceptance of EVs since charging is possible even during peak load periods in the energy grid.
- The *charging point provider* will benefit from a better utilization of his infrastructure since the demand can be anticipated and the charging resources planned well in advance.
- The *energy grid operator* gains valuable information for energy balancing and thus is not confronted with unexpected high loads caused by charging EVs. Additionally, collected usage data can be used for further planning of the recharging infrastructure both for the grid operator and the owner of charging points.

As we presented the results of initial mobility studies and simulations for defining the actual requirements, load balancing and scheduling concepts and implementations, as well as a suitable system architecture for realizing the proposed services in previous publications in [1] and [2], the present work focuses on the prototyping of a mobile assistant for giving EV drivers comfortable access to the platform services. We describe the ongoing work on a respective application for smartphones. We deliberately target no all-in-one solution covering the entire charging process (e.g. including payment features, etc.) but focus on a generic reservation concept. In the following, we give an overview about related work on optimizing the EV charging infrastructure and supporting EV drivers through mobile applications. We then introduce the identified use cases and present the development of our interactive Web-based application prototype for user tests.

2. RELATED WORK
Several recently presented research works are concerned with preparing suitable charging infrastructure, estimating the impact of EV charging on the energy grids and with investigating approaches for energy scheduling and load balancing to cope with expected high numbers of EVs.

For example, Chen et al. [5] analyzed real-life parking information in Seattle, US and determined common parking locations and durations for installing a restricted number of charging stations across the city. Lopes et al. [12] analyzed the behavior of the low voltage grid and the changes in the global generation profile considering different levels of EV penetrations to determine the maximum share of EVs current energy grids may bear. In a similar vein, Clement et al. [4] and Verzijlbergh et al. [14] explored the impact of EV charging for residential low

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voltage networks and showed that a significant number of transformers will be overloaded if no charge control is applied. Based on simulations and a case study, Sánchez-Martin and Sánchez [13] suggest a consumption control management system to deal with the battery charging at parking garages with plug-in EVs. None of these research projects considered mobile applications for EV drivers to collect data about charging needs and thus to estimate upcoming demands on the energy network. One of the rare respective examples making use of a mobile application is the work by Mal and Gadh [11]. Their framework for enabling aggregated scheduled charging of EVs includes an app for monitoring and controlling the charging of vehicles. However, also this solution does not make use of a reservation mechanism as proposed in this paper.

More generally, a series of applications for smartphones is currently available from different software distribution platforms to support (potential) EV drivers. Respective mobile apps include advisers such as *iEV2*[1] and *eMotionApp*[2] which analyze their users' mobility behavior and needs and help them decide whether to buy a private EV. Other EV apps are directly provided by car manufacturers and act as remote controls for specific functions of the vehicle, allow viewing status information such as the current state of charge (SOC), or provide statistics on environmental contributions such as greenhouse gas savings. Examples include *Volvo C30 Electric*[3], *Nissan LEAF*[4], *smart drive*[5], and *OnStar RemoteLink*[6] for GM Chevrolet Volt. *GreenCharge*[7] is a more generic solution supporting GM Chevrolet Volt and Nissan Leaf.

Several apps are dedicated to searching for charging infrastructure and offer comfortable access to remote databases. Most of them follow a community-driven approach allowing the easy adding and updating of charging points by users. Popular solutions include *Plugshare*[8], *CarStations*[9], *Plugsurfing*[10], *Recargo*[11], and *ChargePoint*[12]. The latter features a basic reservation system and availability information, however, is restricted to its custom network of charging stations. Upcoming applications such as the *WattStation* app [6] by *General Electric* also include payment functionality over the smartphone.

3. USE CASES

We conducted a use case workshop with different stakeholders including experienced EV users as well as representatives from public transportation companies and energy providers. Four basic use cases could be identified for supporting an EV driver in finding an available public charging station. As mentioned above, we deliberately excluded payment functionality etc. and services requiring a wireless connection to the charging point itself. In the following, we describe the four use cases and include considerations for their practical implementation.

3.1 Specifying destination for navigation

Obviously, for providing the driver with information about available charging stations close to the destination of his tour, this location needs to be known to the application. At the same time, this address will be used for guiding the driver by a navigation system. While context-aware mobile applications may try to derive this information (e.g. by checking personal calendar entries), the safest way is simply entering the street address of the targeted destination in analogy to traditional navigation solutions.

3.2 Searching for charging stations

A suitable application needs to provide a search feature for charging stations close to the entered destination. This includes specifying several further charging parameters such as the estimated charging duration or the expected SOC after charging as well as the charging speeds supported by the car which may be configured once over a settings menu. To enable an efficient scheduling of potential reservation requests, also the estimated time of arrival needs to be transmitted.

3.3 Sending reservation request

To make sure to have an available charging station close to the destination, a driver may issue a reservation request for a particular charging point. In our setup, such a reservation request directly follows a search for charging stations. Thus, specific charging parameters are already known and the availability of the charging point was already checked during the search. In order to avoid haphazard reservations and to reduce inaccuracies in estimating arrival times and thus to enable a more accurate and robust scheduling, the introduction of a few practical constraints seem to be beneficial. These include allowing only for one pending reservation at a time and permitting reservation only within a specific time window before arriving at the specified charging point (e.g. 3 hours) and discarding the reservations of late arrived cars.

3.4 Redirection to charging station and guiding to actual destination

When a reservation request was sent and successfully confirmed by the server-side platform, the driver shall be guided to the respective charging station by traditional turn-by-turn navigation and audio signals. Since for the most cases this includes a slight redirection away from the actually desired destination, the application should also support a pedestrian navigation mode for showing the way from the parked vehicle to actual destination.

4. PROTOTYPING

Based on the use cases described above, we prototyped a respective mobile application. We started by creating several designs and simple mockups and finally implemented an interactive Web-based software prototype.

4.1 Mockups and Experiences

As first steps, we conducted simple paper prototyping and sketched screens and user interface elements. We created various design alternatives and put special emphasis on techniques to specify the reservation parameters in terms of planned parking duration and/or expected driving range after the charging process.

[1] http://itunes.apple.com/app/iev-2/id527020422

[2] http://itunes.apple.com/ch/app/emotionapp/id493864486

[3] http://itunes.apple.com/app/volvo-c30-electric/id471884606

[4] http://itunes.apple.com/app/nissan-leaf/id407814405

[5] http://itunes.apple.com/app/smart-drive-eu/id373864064

[6] http://itunes.apple.com/app/onstar-remotelink/id393584149

[7] http://itunes.apple.com/app/greencharge/id480215136

[8] http://itunes.apple.com/app/plugshare/id421788217

[9] http://itunes.apple.com/app/carstations/id461066178

[10] http://itunes.apple.com/app/plugsurfing/id455198327

[11] http://itunes.apple.com/app/recargo/id405168584

[12] http://itunes.apple.com/app/chargepoint/id356866743

Figure 1. One design mockup includes a slider for specifying the charging duration and the expected range.

First mockups included a slider concept as a visually appealing way to specify this information. The variant in Figure 1 focusses on specifying the driving range with the slider. Its bar shows the estimated charging duration for the selected range as soon as the user lifts his finger. Whereas this combined slider display of range and duration seemed beneficial at first sight, we identified several drawbacks while further elaborating on the concept. First, experiments with related touch-based slider controls on mobile devices showed their inaccuracy for such fine-granular settings. Thus, we decided to go for more traditional spinner controls. Second, specifying the expected range forces the user to park his EV at the particular charging station for the calculated duration. Since we target a comfortable solution avoiding any major adaptations of users' mobility behavior and thus to increase the acceptance of EVs, we agreed to focus on the actual parking duration: drivers typically know how long their vehicle will stand at the parking spot (e.g. during a shopping tour or a restaurant visit, etc.). They probably will not change such routines and extend the parking duration to reach a specific battery level or range.

Overall, we wanted our application to be as self-explaining as possible and thus decided for a wizard-like user interface guiding the user through the different steps of making a reservation for a particular charging station.

4.2 Interactive Prototype

We implemented an interactive prototype to gather early feedback from real users in a next step. We restricted the functionality of our first prototype to the four above-mentioned use cases and focused on the actual reservation process to keep expenses for prototyping low. To make the prototype easily accessible for interested people and even allow them to test on their personal smartphone we decided to go for a platform-independent Web application. Its latest version is publicly accessible [9] and features both a mobile emulator view for desktop browsers as well as a plain variant to be accessed from mobile devices.

Our prototype is based on traditional Web technologies such as HTML, JavaScript, and CSS. For displaying maps, visualizing points-of-interest and providing a routing feature we integrated the respective services offered by the *Google Maps JavaScript API* [8] and *the Google Directions API* [7]. We made use of the *Yahoo! User Interface Library* [15] for integrating sliding and fading effects to closer resemble the look-and-feel of a native mobile application. Further, we designed some custom icons and symbols to embellish the interface.

Figure 2: Simple form for entering the destination.

Figure 3: Specifying the duration of stay.

Figure 4: The user may choose to be notified about charging stations becoming available.

Figure 5: Available charging stations in walking distance to the destination are shown on the map.

Figure 6: When a reservation request is sent, the estimated arrival time is calculated for scheduling the reservation.

Figure 7: Traditional navigation leads to the charging station while the distance of the closest charging station is shown.

Figure 2 shows the start screen of the application. The user is asked to enter the street address of his destination and confirm by touching the bottom right button. In analogy to a traditional navigation solution, the user is informed about the route length and estimated duration on the succeeding screen (Figure 3). The adjacent map view shows the area around the destination location. Additionally, the application displays the estimated SOC at the destination in form of a battery image to illustrate the charging demand. The planned duration at the destination may be entered by specifying the respective hours and minutes through the plus and minutes buttons (native mobile applications may use available spinner controls). By pushing the search button (with the magnifying glass) the application starts looking for charging stations which are available at the calculated time of arrival and are located within walking distance from the specified destination. In the current version of the interactive prototype number and locations of charging stations are locally generated on a random base.

In case no charging station is available, the driver is notified and may choose to be notified if a suitable charging station suddenly becomes available (Figure 4). Otherwise the map view is updated with corresponding markers (Figure 5) and enabled for interaction such as panning for exploring all found charging stations.

In a first design we used green and red icons to indicate the availability of charging stations with the aim to increase the awareness of totally deployed charging stations. Finally, we decided to hide the unnecessary occupied charging points and show only the available ones to reduce cluttering on small mobile displays. The current markers as depicted in Figure 5 contain information about the electricity price of this charging point as well as small symbols to indicate the plug type and whether this point supports fast charging. Preferences concerning plug type and fast charging etc. could be specified in respective configuration settings.

By touching a charging point marker, the user is asked to confirm his reservation request for the estimated arrival time and the given duration (Figure 6). When he does so, the application switches to a traditional navigation screen in bird's eye view (Figure 7) with turn-by-turn instructions (such as following the road for the next 1.2 kilometers) guiding the driver to the selected charging station. In our prototype this functionality is represented by a still image, since the implementation of such a 2.5D navigation is time-consuming and does not belong to the core functionality of the prototype. Additionally, the navigation screen shows the current SOC and the distance of the available charging station closest to the driver's current location in order to still support spontaneous charging at nearby charging points.

Since the driver is not guided directly to his desired destination but redirected to the selected charging station, the application switches from vehicle to pedestrian navigation mode guiding the user to his actual destination as soon as the vehicle has arrived at the destination charging station. This final step is not covered by the recent version of the prototype.

5. CONCLUSIONS AND OUTLOOK

In this paper we introduced our ongoing work on a smartphone-based assistant for EV drivers. The application will help to ensure the availability of a public charging station close to the driver's destination and due to more accurate forecasting enable optimized load balancing and energy scheduling for the charging point owner and the grid operator. We presented some typical use cases for the envisioned trip planning scenario and gave insights in the design and implementation of our interactive Web-based application prototype.

Our current prototype covers the fundamental reservation process, however, is a not a complete EV driver assistant yet. Besides the prototypical integration of additional features such as the mentioned pedestrian navigation mode and multi-modal routing considering public means of transport, we plan to improve the visual appearance and polish the user interface to give it a more native look. We then will conduct user tests to collect feedback and elaborate our prototype. As an important part of future work, we plan to connect the app prototype to our reservation and routing platform in order to have a truly functional application. Necessary steps include the implementation of Web-accessible service interfaces such as REST (Representational State Transfer) for making use of our custom routing algorithm and the charging station database, e.g. via AJAX (Asynchronous JavaScript and XML) calls from the mobile application. Finally, we plan to distribute the application to drivers of an EV fleet and to carry out field tests to gain real-world experience with the prototype and to learn more about the acceptance of such advanced reservation mechanisms for public EV charging stations.

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