Modeling and Optimization for Efficient Electrical Mobility: Challenges from the E-Tour Project

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Introduction. Electrical vehicles (EVs) will play a tremendously important role in the road traffic of the future. The main reasons are that EVs offer the potential to reduce the dependency on dwindling fossil fuel reserves, while at the same time they help curb the emission of climate-relevant gases and other harmful pollutants. Against that background, the German government has launched an initiative to bring one million electrical vehicles to the street by the year 2020 [1]. Interestingly, a significant portion of the funding is devoted to research and development of information and communication technology centered around electrical mobility. As part of this research effort, the Technical University of Munich participates in the E-Tour Allgäu project, which was granted a total funding of 5.8 million Euros and runs from 2009 to 2011. The goal of E-Tour Allgäu is to show how sustainable electrical transportation, using local and renewable energy sources, can be realized in a rural hilly region southwest of Munich, called the Allgäu. In this region, a diverse fleet of roughly 35 EVs will be operated and monitored under typical modes of usage, such as commuting to nearby Munich.

Although the project has only recently started, it is already apparent that electrical mobility rises several challenges that can and need to be addressed by constraint reasoning and optimization methods. Below, we outline two of the problems considered in E-Tour Allgäu:

Cruising range prediction and energetic route optimization. Limited battery capacity is the major obstacle to more wide-spread usage of EVs. For instance, the electric version of BMW's Mini can merely store the equivalent of 1.5 liters of diesel fuel in its lithium-ion-accumulators. Even though electrical engines are much more efficient than conventional ones, this translates to limited cruising ranges of only 100 to 150 kilometers. Taking also in account that EV batteries need several hours to recharge, accurate prediction of remaining cruising range and energy-optimized driving behavior [2] become very important issues. We are therefore developing an assistive system that estimates the energy consumption for specific route segments, initially based on the length and elevation profile of that segment. Over time – by complementing and refining this information with real consumption measurements and other parameters such as vehicle type, load, traffic, wind, etc. – we hope to build a "energy consumption road map", which allows to compute the amount of energy needed to travel a certain route. Based on this map, it will be possible to perform energy-based route optimization, which minimizes energy consumption instead of travel time or distance. While route optimization (at least in its most abstract form of finding shortest paths in a weighted network) is a well-studied problem, optimization gets more complicated in the context of electrical mobility; for instance, EVs can recuperate energy during braking, thus energy can be regained during deceleration. Overall, the challenge is that more elaborate, mixed discrete-continuous and possibly stochastic models are needed that take into account more of the vehicle dynamics and human behavior, together with efficient reasoning algorithms that quickly find optimal or near-optimal solutions.

Optimal strategies for energy buffering in batteries. The expansion of renewable energies, such as wind or solar power, comes at the cost of an increasingly fluctuating energy supply in power grids. Here too, EVs can offer a solution; if cars are not in use, their batteries can be used to buffer energy to compensate for the irregular availability of renewable energy sources. According to a recent study, based on current prices and technology, EV owners could make several hundred Euros per year just by purchasing electricity less expensively whenever large volumes of electricity are available at non-peak times, and selling back electricity to the grid to temporarily cover peak load demands. However, to be useful both for the vehicle owners and utility companies, this decentralized buffering and trading of electrical energy must happen in a fully automated way. Also, participation in the energy market comes at a certain risk in terms of mobility or comfort of the human user, as he might find the car's battery not sufficiently charged for his upcoming trip. The challenge here is to develop models and algorithms that allow to derive optimal and user-acceptable control strategies for electricity buffering with EV batteries. In particularly, we currently consider the following problem: given a model of physical battery behavior and a stochastic model of human car usage (which predicts when the car will be driven), compute a control strategy that maximizes the effectiveness of energy buffering, but at the same time keeps the mobility risk of the user (the possibility that he cannot drive the car because it is insufficiently charged) below a certain threshold (for instance, 1 percent). This problem is a variant of the *risk allocation* problem studied in [3], so we expect that similar methods based on hybrid, stochastic constraints can be used to model and solve this grid stabilization problem.

References

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