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Towards a Holistic Approach for Problems in the Energy and Mobility Domain☆

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Abstract

With the current rise of electric vehicles, it is possible to use those vehicles for storing surplus energy from renewable energy sources; however, this can be in conflict with providing and ensuring the mobility of the vehicle's user.

At DAI-Labor, we have a large number of both, past and upcoming projects concerned with those two aspects of managing electric vehicles: energy and mobility. To unify and facilitate developments in those projects, we developed common domain models describing the different aspects of the e-mobility domain. Those domain models are used in many of our projects for optimising charging schedules and for ensuring the user's mobility.

Keywords: human mobility, mobility platform, intermodal routing, trip optimisation, mobility assistance

1. Introduction

Admittedly, the two domains *energy* and *mobility* do not sound like a natural match. Yet, ever since the resurrection of electric vehicles, it becomes more and more apparent that solutions from the former may contribute to the latter and vice versa.

As an example, consider the many attempts to use electric vehicles for challenges that are mainly confined to power grid infrastructures, e.g. avoiding peak loads, increasing the utilisation of renewable energy, or providing regulatory energy. Most of the above-mentioned challenges can be solved by a well-directed placement of charging- and feeding processes of electric vehicles. This placement, however, does not necessarily support the requirements of an unconditional usage of electric vehicles, e.g. predefined charging levels when a vehicle is needed.

Contrary to that, there are many endeavours where smart grid architectures are used to improve the efficiency of electric vehicles, e.g. to decrease their effective emissions, to improve their availability, or to lower their cost of

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ownership. Available solutions integrate electric vehicles into energy-producing facilities and use locally produced energy to cover their demand. Other approaches implement business models and implement trailblazing business models, such as electric car sharing enterprises. All of these approaches are able to make electric vehicles more attractive, yet, mostly at the expense of the efficiency of the underlying power grid.

Despite the connection between energy and mobility, there are only few attempts to consider both aspects at the same time (e.g. Ruelens et al.[1]). The reasons for that are not entirely clear, though, the little practical experience with electric vehicles and smart grid architectures might be a factor.

The aim of this paper is to outline a solution that accounts for, both, mobility- and energy aspects. Such solution can only evolve from experiences, which we collected in both domains. To this end, we continue by presenting completed energy- (see Section 2.1) and mobility projects (see Section 2.2). Subsequently, we emphasise the increasing symbiosis of energy- and mobility-related problems by presenting requirements of our current projects (see Section 3). In Section 4, we present our domain-specific solutions from which we derive requirements for a more comprehensive approach. We discuss these requirements in Section 5.

2. Previous Work

So far, we developed solutions for both, energy- and mobility-related problems. We present these works in the following and emphasise the evolving connection between both domains.

2.1. Energy Management

The markets for energy generation, distribution and consumption have been undergoing significant changes in the last two decades, concerning their overall infrastructure, technical aspects of control and communication mechanisms, as well as legal and regulatory concerns.

Current challenges are to enhance the overall energy efficiency in all parts of the grid, the management of production, distribution, consumption, metering, and the development of control mechanisms. With the introduction of e-mobility and driver assistant systems, providing, e.g. traffic information and services for finding and booking parking areas and charging stations, both travelling time and environmental impact can be reduced. The same approach can be applied to industrial transportation, as well. In both cases, a variety of actors with conflicting goals are involved, calling for the development of new business models.

Most generation and transmission services require capacities of few to hundreds of megawatts and can be provided by large battery storage systems rather than by end-user-owned assets like vehicle batteries. Yet, comprehensive IT-infrastructures can facilitate joint operation of, e.g. a pool of vehicle batteries to achieve the dispatch of relevant capacities. This approach requires some degree of centralization, such that distribution network operator could be granted tools and permissions to control charging and discharging of a fleet of vehicles (cf.[2]p. 2).

In a more decentralized approach, for end-user applications, energy storage systems can serve in the following ways e.g, for storing renewable DG production, time shifting of demand to avoid peak prices, price arbitrage in real-time pricing situations, plug-in hybrid vehicle integration through off-peak charging, utility control for targeted enhancement, demand-response / load management integration, renewable demand response / load management, and reliability enhancement.

Starting with in-Home Energy Management, the DAI-Labor has successfully established many research projects in the Smart Grid domain within the past years (see[3,4]).

2.2. Agent-based Transport Management

In the transport domain, we are focussing on the improvement of the mobility behaviour of travellers by planning and proposing more efficient and sustainable routes. This includes the integration of enhanced mobility concepts as well as the intelligent combination of different transportation means.

To provide a new mobility concept we developed our dynamic, agent-based ride sharing system *MiFA*. It reduces the search effort for driver and passenger by flexible, autonomous and proactive planning of rides with a multi-criteria optimisation. It also allows the learning from previous rides. For the combination of mobility concepts an agent-based *Intermodal Dayplanner* was realised, which allows planning of routes by using public transport, station-based car sharing and bike sharing. Both approaches were focused on mobility issues, with no connection to the energy domain.

Electric vehicles are known to be sustainable, yet, energy generation is still subject to CO_2 emissions. Within the projects *Mini E 1.0* and *Gesteuertes Laden V2.0* we developed an approach[5,6,7,8] that utilises the vehicle-to-grid technology of electric vehicles in order to store surpluses of wind energy and to use them to cover times with an increased demand. The algorithm ensures mobility of the user and accounts for individual preferences, the availability of charging infrastructure, and properties of the local power network. A similar approach[3] was developed within the *Berlin Elektromobil 2.0* project, where charging and feeding of an entire commercial car fleet was aligned to the requirements of the hosting smart grid infrastructure.

Latter approaches emphasise the need for a holistic consideration of transportation and energy issues, yet, neither an influence of mobility planning on energy constraints, nor a common problem specification language have been considered, thus far.

3. Current Work

After presenting previous work, we continue by presenting our current projects. In doing so, we respectively emphasise problems that affect mobility- and energy-specific aspects.

IMA. The aim of the *Intermodal Mobility Assistance for Megacities* project, or IMA[9], is to increase the quality of life in megacities by providing an open mobility platform with intermodal trip planning and monitoring functionality, integrating different types of mobility and infrastructure. User are informed about recommendations for intermodal routes based on their profiles, semantic service descriptions, and traffic information provided by external services and GPS data collected during the project. Due to the extendability of the platform, security and privacy issues are considered as an important aspect of IMA, which accounts for identity management, encrypted communication, access control for data and services as well as for management, enforcement and conflict resolution of security policies.

NaNu. The project *Mehrschichtbetrieb und Nachtbelieferung mit elektrischen Nutzfahrzeugen* (*Multi-shift operation and night delivery with electric commercial vehicles*), or NaNu, aims to improve the overall efficiency of a delivery transport service by using a set of exchangeable batteries in electric middle-weight trucks. The use of these batteries allows to implement a multi-shift operation mode for electric vehicles, which doubles their utilisation. With this approach we may explore a more efficient performance in both, energy management and consumption and package delivering out of the times with the highest traffic rates. The research challenge in this project is to develop an adaptive multi-agent software architecture that optimises and controls the charging processes. On the one hand, it ensures that the energy levels that electric vehicles need to drive through each route, are available when necessary. On the other hand, when the trucks do not need the batteries, they may be used as storage devices following diverse criteria such as sustainability or grid stabilisation.

Smart e-User. Smart e-User aims to cover some of the existing voids in the electric mobility field. In this case, the objective is focused not only in the transport of goods but also in the private- and business traffic. In order to reach a good performance it is necessary to optimise the charging times and thus the costs. However the introduction of dynamic routes makes this problem more complicated. The system has to adapt itself to the changeable paths and in turn to take into account all those effects that may vary the consumption, such as weather conditions and the traffic load.

Extendable and Adaptive E-mobility Services (EMD). The EMD project focuses on the development of software tools and models which help in the development and deployment of e-mobility services. One contribution of this project is an aggregation of models like a context and domain model for the e-mobility domain, which are used to semantically describe REST or SOAP service interfaces. The second contribution are software tools which ease the orchestration of semantically described services. We aim to provide services that are more extendable, i.e. new services can be integrated in the orchestration without redeployment, such that parameters of service calls in an orchestration and the services called depend on the context of use. To evaluate the advances in the developed software tools one goal of this project is to develop so called *basic services* like an billing service and enrich them using the created model, to finally orchestrate those basic service to, e.g. an intermodal routing service.

Elektrische Flotten für Berlin-Brandenburg. In this project, car sharing fleets with varying configurations are tested. The DAI-Labor focuses on supporting the user in finding and executing an intermodal route via a mobile application. The research focus is on the impact of different fleet configurations and properties of electric vehicles on the interaction with the user. The potential conflict between the mobility requirements of the user and the influence of utilisation and charging management of the fleet is one of the core topics of this project. The topic is handled from the users perspective. This application is developed using model-based UI development.

Micro Smart Grid EUREF. The project Micro Smart Grid EUREF focusses on software architectures and optimisation procedures for Microgrids and Smart Distribution Feeders. In this context, the EUREF test site used in Berlin Elektromobil 2.0 will be extended with further and more diverse vehicle fleets and generation and storage equipment. The project will comprise multiple competing car sharing operators as well as privately owned electric vehicles using the same MSG. Thus, the scheduling algorithm not only has to scale up to much larger fleets, but also has to regard aspects such as fairness w.r.t. serving the different parties. Further aspects are: the combination of mid- and short-term planning regulations, application of machine learning techniques for improved forecasting of demand and supply, and the integration of islanding and self-healing functionalities.

Forschungscampus EUREF. The aim of the Forschungscampus EUREF project is twofold. The first aim is to extend the existing infrastructure to facilitate its electrical autarchy. This infrastructure is the *Europäisches Energieforum*, or *EUREF*, which comprises the above-mentioned MSG EUREF as well as additional office- and entertainment buildings. The second aim is to use develop and implement car sharing concepts that make the infrastructure profitable. In the first phase, the infrastructure's status quo is analysed. Later, this configuration will serve as input for a simulation framework, which will direct the development in order to accomplish autarchy and profitability of the EUREF by the year of 2018. First results showed that both objectives (autarchy and profitable car fleets) affect each other and can not be considered individually.

3.1. Similarities and Differences

When looking at goals and major problem domains of our current projects, we can distinguish between three major categories: energy, mobility and energy-mobility-mix. The first category focuses on energy aspects and comprises elements like sustainability, autarchy and charge management. The second category addresses, among others, trip planning, traffic measurement and route calculation. Further, the last category is considering topics of both domains.
Table 1 illustrates a categorisation of the presented projects.

Table 1. Project domain categorisation.

Project	Energy	Mobility
IMA	-	x
NaNu	x	-
Smart-E-User	x	x
Extendable and Adaptive E-mobility Services	x	x
Elektrische Flotten für Berlin-Brandenburg	x	x
MSG EUREF	x	-
Forschungscampus EUREF	x	-

In the past we have shown solutions for both the energy and the mobility domain, but because both optimisation areas have a strong interdependency and first projects try to address both domains, we need to develop a solution which is able to consider this. In the following section we present our existing approaches and outline a way to bring these domain-specific solutions together.

4. Approach

Our approach comprises two parts. First, we present domain models that we developed for the energy- and for the mobility domain. Secondly, we present the current state of applications that we developed for both domains. In total we present three applications, namely a *Charging Optimisation Component*, an *Intermodal Trip Planning Component*, and the practical attempt to merge domains.

4.1. Models

We developed two different models, one for the energy domain, the other for the mobility domain. We continue by presenting both models in more detail.

4.1.1. Energy Domain Model

Any form of integrated consideration requires a uniform way to represent problems. Based on the analysis of ongoing projects, we can state that project-specific requirements look similar but include challenging differences as well. From our point of view, the most challenging factors are:

Exchangeable batteries: So far, a car battery was assigned to one vehicle only. The NaNu project, however, requires the concept of exchangeable batteries.

Increasing complexity: Energy producer and -consumers, or *prosumers*, were presented as uncontrollable demand- or availability forecasts. Yet, novel concepts, such as hydrogen electrolysers, charge heating power plants, and electrical warm water storages require for a more sophisticated representation.

Multi-operator fleets: Previous work considered individual, bookable fleets, only. On-going projects, however, put a focus on distributed ad-hoc car sharing fleets, privately owned electric vehicles, and transportation fleets. The bottom line is a volatile coupling between vehicles and stations.

Low level requirements: There is always a difference between targeted and real states. The effective current, for instance, is actually determined by bottlenecks (e.g. cable, battery, car, charging station) and frequently deviates from targeted values.

A first draft of the architecture of our common domain model that is incorporating some of the challenges and lessons learned, is shown in Figure 1.

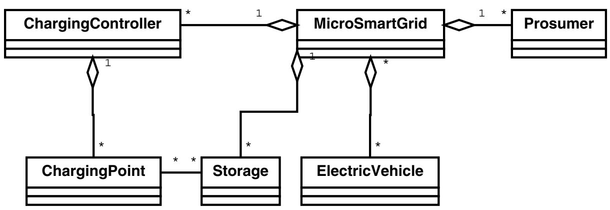

Fig. 1. Draft of architecture of the common domain model.

When observing the model, some aspects become obvious. First, there is neither a connection between an electric vehicle and a charging point, nor battery in the domain model. This information is now considered to be information of a state of the current system, and is therefore not included in the static architecture. This condition is required by NaNu, where batteries are interchangeable, and by the Micro SmartGrid EUREF, where a volatile association is needed in order to account for multi-operator fleets. Secondly, the cardinality of the relationship of electric vehicles to the Micro Smart Grid has changed from 1:n to n:m in order to express that that vehicles can reside in different grids. Thirdly, the introduction of charging points into the model was required, since the overall current capacity of the charging station induces a limit on the current at each of its charging points. Fourth, different battery types (e.g. lead, Li-Ion) imply different charging behaviour, thus, specific attributes were introduced in order to account for individual charging- and feeding behaviour. Finally, due to similar properties, local battery storage and vehicle battery storage are represented by the same class, using an attribute to differentiate the different kinds.

4.1.2. Mobility Domain Model

In contrast to many other projects that have been described in Section 3, the project IMA has a stronger focus on mobility and transportation issues than on energy aspects. Therefore we decided to develop a domain model which covers the different aspects of mobility assistance, which are listed in the following.

1. *Mobility Service:* since in IMA we want to dynamically embed different types of mobility service into the platform we need a clear definition which information a service does provide. Therefore we defined the mobility service class that contains information about pricing, costs, service type, etc.
2. *Means of Transport:* each type of transport needs to be modelled. Our model covers description for cars, bikes, electric vehicles, pedelecs and public transport vehicles, such as metro, bus and suburban train.
3. *Infrastructure:* mobility assistance is only applicable with respective infrastructure. Our model therefore represents roads, traffic information, charging stations and parking spots.
4. *Routing:* defines the route with its modular steps in order to assist the user throughout the trip en detail
5. *Events:* as routing requests are always time-related, results need to have more information then just the route. These are departure, transfer and arrival times, references to vehicles, information about costs, ecological footprint, amongst others.
6. *User Data:* user-centric mobility assistance can only work if there is a detailed representation of the user's attributes, such as drivers license, memberships, disabilities or routing preferences.

For many of these sub-domains there do already exist standards or efforts for reaching standardisation. However, the level of detail in each of these domains is fairly high, which lead us to the decision to make use of their most relevant aspects in our model but to neglect the rest. The model is designed according to extendibility, especially for the Mobility Service package.

4.2. Applications

In total, we developed three applications, namely a Charging Optimisation Component, an Intermodal Trip Planning Component, and the practical attempt to merge domains. We continue by presenting these three applications in more detail.

4.2.1. Charging Optimisation Component

One application of the common energy domain model is for implementing a planning, or scheduling component, optimizing charging intervals of electric vehicles. This is a requirement in many of our e-mobility projects, as it contributes to stabilising the load of the local grid, making best use of available renewable energy sources while maintaining the mobility of the involved users.

In the Berlin Elektromobil 2.0 project, we created such a scheduling system based on a generic optimisation framework developed in an earlier project, *EnEffCo*[4]. In a first prototype, we made use not only of the optimisation framework, but also of the generic process model developed in that earlier project. While the results of the optimisation were already serviceable, the generic meta model was not suited for modelling the system in an adequate level of detail[3]. For instance, neither does the model support charging stations with continuous levels of charging, nor does it allow for flexible assignments of bookings to electric vehicles to be used. Thus, we created a domain model specifically for electric vehicles in micro smart grids.

While similar to the new consolidated domain model, that model was in some aspects more restricted, which was in accordance with the requirements, but not with those of our new projects. The optimisation used a variant of evolution strategy[10], in which charging schedules are randomly mutated and recombined until an optimal schedule is found.

Regarding our future projects we have to allow additional degrees of freedom in the domain model, considerably increasing the complexity of the optimisation. Thus, we are planning to restructure the scheduling process, splitting it up into several distinct phases, namely:

First, simple heuristic algorithms are used to select what vehicles and/or batteries to use and to determine by what amount and in what time interval they have to be charged in order that the bookings can be fulfilled. Then, in a first pass the optimization algorithm distributes the previously allocated amounts of energy to the respective vehicle batteries, while at the same time avoiding load peaks due to concurrent charging. Finally, surplus energy from local production is fed into the remaining vehicles and local storages to dampen load peaks.

This way, 'hard' constraints, such as ensuring that each of the bookings is fulfilled, can be handled deterministically. 'Soft' goals on the other hand, such as scheduling the charging intervals to provide load balancing and make best use of available renewable energy, are still handled using stochastic multi-objective optimisation where the different quality criteria can be freely weighted against each other.

4.2.2. Intermodal Trip Planning Component

The demand for trip planning in urban areas is growing due to the increasing amount of transportation options. Urban inhabitants are becoming more and more flexible according to the mobility requirements of a specific day. For example, when the weather is good and there are no external appointments, the bike is being taken to work. On other days the vehicle is being used in order to bring the children to school and in other situations the public transport is appropriate. Further, in some situations it also makes sense to combine these various modes of transportation for one trip, in order to have some workout (bike sharing), but not getting too late to work (public transport for the second part of the trip).

Therefore we started implementing an intermodal trip planning component within the IMA project that considers the user requirements and various mobility and information services in order to propose a solution that is tailor-made to suit the individual user. Since the intermodal trip planner is included in a distributed system where services can appear and disappear it is important to have an unique model for the description of mobility services, as shown in the model chapter. Every mobility service that shall be accessible to the intermodal trip planner, must implement a standardised service interface according to the type of service (scheduled service, flexible station service, fixed station service, etc.). Further, the services can be enhanced with a semantic service description that contains preconditions and effects and describes the attributes using the mobility model in an OWL representation.

The intermodal trip planning component searches the distributed platform for services and uses a semantic service matchmaking component to evaluate whether the services are appropriate for the user's attributes and preferences. E.g. if the user has no driver's license, the planner must not include car-sharing services as a routing option, which he can already filter according to the preconditions of a car-sharing services. After the matching procedure all locations or stations of possible mobility services are integrated as nodes into a graph, which are in turn assembled to clusters indicating potential changing locations between modes of transportation. In a next step, the costs are being estimated by an objective function considering the user's preferences, such as time, monetary costs, ecological footprint and other limitations. In order to be able to set the preferences into relation with each other, each of them is normalized according to the worst estimation for the respective route. With this heuristic, we are able to annotate the edges between the nodes and can search for an optimal intermodal solution on the graph with the A* search algorithm.

To sum up, it is important, especially for distributed systems with multiple stakeholders, to have a common domain model, that considers all relevant entities. For the mobility domain these are in first place the types of transportation including energy related information, such as electric vehicles, batteries and charging stations.

4.2.3. Combining Energy and Mobility services

In the IMA and EMD projects services are composed to create a plan or service composition to shape more complex service out of a set of available services. Using a combination of the mobility and energy domain model, service are semantically described, which allows *service matcher* or *agent planner* to reason upon those descriptions [11]. To ease the matching of descriptions to a request, the domain model is enriched with semantic descriptions formulating more details about the domain objects. Additionally the domain model is structured in concepts describing the language of the given domains, a *context model* representing the dynamic and relevant aspects of the domain model to one service using it and a *state model* describing the dynamic contextual (the state of the world) information during run-time of a service.

The *context model* contains all the entities which the service might adapt to as well ass restrictions of the general entities of the domain model to a certain context. E.g. a service might be able to find charging stations given a location, but the location should be located in and around Berlin. The *state model* on the other hand describes the context at run-time, specifying the concrete instances of the service parameters e,g, including profile information of the user.

Two of the on-going research projects (IMA and EMD) aim to developing software components which compose such semantically described service to forge plans (semi-) artificially, allowing to adapt the service selection to the context of use and availability of the services. Here the models are dynamic and need to grow with the services. Thus additional requirements regarding the domain model arise: The models need to be extensible, by new service which might bring in new domain objects. This entails a certain abstraction level and a constant manual realignment of the models.

To conclude, the challenge in EMD and IMA is to use a domain model in other models like the context model or the formulation of precondition and effects of service model.

5. Challenges

The aim of this paper was to create an awareness for the ever increasing convergence of two domains that are commonly considered in separation: energy and mobility. We observed this trend in first generation projects already, though, when looking at on-going work, this connection becomes even more apparent. We presented domain-specific solutions with emphasis on our superior objective: the development of an integrated, holistic solution. We continue by discussing the most significant challenges along this path.

There have been a number of challenges arising from the e-mobility projects. The similar nature of the several projects demands for a common solution, instead of implementing large parts for each project anew. At the same time, while the projects are in many aspects very similar, they have some subtle but important differences, that have to be captured in the common parts, particularly in the common domain models.

NaNu, for instance, comprises vehicles with multiple, exchangeable batteries. Other projects support single, integrated batteries, only. We solved this by allowing multiple batteries in the meta model. To make the complexity manageable, we kept the assignment of those batteries to actual vehicles out of the main part of the optimisation.

Finally, both, the common domain model for energy and mobility, are joined together when it comes to developing mobility services using the energy domain model. It is planned to model each of the phases in the energy optimisation as a distinct service, that can then be orchestrated to comprehensive scheduling service and integrated into the user's mobility planning services.

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