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In Search of a Comprehensive Solution to Energy and Mobility-Related Issues

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Abstract

However, there is a potential trade-off between storing excess energy from renewable energy sources in electric cars and ensuring that drivers have access to and usage of their vehicles. DAI-Lavor has worked on a wide variety of projects, both completed and, in the works, that address the energy and mobility challenges associated with managing electric vehicles. We created standardized domain models characterizing the many facets of the e-mobility domain to standardize and streamline advances across these initiatives. In several of our applications, we make use of such domain models to optimize charging schedules and guarantee user mobility.

Introduction:

The fields of energy and mobility may not appear to be related. The recent resurgence of interest in electric vehicles, however, has made it clear that innovations in either industry may benefit the other. Examples of power grid infrastructure issues that have been addressed by focusing on electric cars include peak load reduction, increased use of renewable energysources, and compliance with energy regulations. Electric vehicle charging and feeding operations located strategically may help alleviate the problems. The demands of unconstrained EV use, such as fixed charging levels during times of vehicle need, may not be easily met here. However, smart grid designs are being used in many different initiatives with the aim of improving EV efficiency in areas such as lowering effective emissions, expanding EV accessibility, and decreasing TCO. Currently available options entail supplying the power demands of EVs with electricity produced on-site at energy production plants. In contrast, other approaches take advantage of established and innovative business models, such as those that share electric vehicles. These methods may increase the number of EVs on the road, but they typically decrease the efficiency of the power grid as a whole in the process. Despite the intertwined nature of energy and mobility, there have been relatively few attempts to address both at once. (e.g.,Rue lens et al.1). Although the precise explanation is unknown, a lack of practical experience with EVs and smart grid topologies may be a contributing factor. The objective of this study is to provide an approach that balances energy efficiency and mobility needs. Only through amassing information could we have come up with this answer, and that's exactly what we did. Here, therefore, are some examples of completed initiatives concerned with energy (see Section 2.1) and transportation. (See Section 2.2). The requirements of our current initiatives are then presented, with an emphasis on the rising interdependence of energy and transportation concerns. (See Section 3). In Section 4, we describe our developed domain-specific solutions and how they contribute to the requirements of a larger strategy. The requirements are discussed in depth in Section 5.

Previous Work

We have so far devised answers to issues relating to both energy and transportation. In what follows, we highlight these works and highlight the developing relationship between the two fields.Over the last two decades, there have been extensive changes to the markets for energy production, distribution, and consumption in terms of their general infrastructure, the technological features of control and communication methods, and legal and regulatory considerations. Improving energy efficiency across the board—from generation to distribution to consumption to metering to control—remains a pressing concern. Both journey time and environmental effect may be minimized with the help of e-mobility and driver aid systems, such as those that provide traffic information and services for locating and reserving parking spots and charging stations. Transportation in the industrial sector may benefit from the same strategy. Both scenarios need novel approaches to doing business since they include savearl parties with competing interests. Large battery storage systems, as opposed to end-user owned assets like car batteries, can supply the few megawatts to hundreds of megawatts of capacity needed for most generating and transmission services. But with the right IT-infrastructure in place, many entities may work together to deploy multiple capacities, such as a fleet of vehicles sharing a battery bank. For this method to operate, a certain amount of centralized authority is needed so that a distribution network operator may be given the authority to regulate the charging and discharging of a fleet of cars. (cf.2p. 2). Energy storage systems can be used in a decentralized manner for a variety of end-user applications, including the storage of renewable DG production, the postponement of demand in order to avoid peak prices, the arbitrage of prices in real-time pricing scenarios, the integration of plug-in hybrid vehicles via off-peak charging, utility control for targeted enhancement, demand-response/load-management integration, demand-response/load-management integration with renewable resources, and the improvement of reliability. Beginning with residential energy management, DAI-Lab has launched savearl Smart Grid research projects over the last few years. (see3,4).

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 Mia. 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 Day planner was realised, which allows planning of routes by using public transport, station-based782 Marco Lautenberg et al. / Procedia Computer Science 32 (2014) 780 – 787 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 CO2 emissions. Within the projects Mini E 1.0 and Gestures Laden V2.0 we developed an approach5,6,7,8 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 approach3 was developed within the Berlin Electromobility 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.

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 IMA9, 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 extendibility 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 Mehrs chicoterie und NachleeringmetelectriseNutzfarceuse (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. Marco Lautenberget al. / Procedia Computer Science 32 (2014) 780 – 787 783 ElectriseFlattenfour Berlin-Brandenburg. In this project, car sharing fleets with varying configurations are tested. The DAI-Lavor 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 Electromobility 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.rate 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. Firsching campus EUREF. The aim of the FroschNg campus EUREF project is twofold. The first aim is to extend the existing infrastructure to facilitate its electrical autarchy. This infrastructure is the EuropeanisesEnergyOrum, 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 cannot be considered individually.

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.

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.

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 Redeveloped 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.

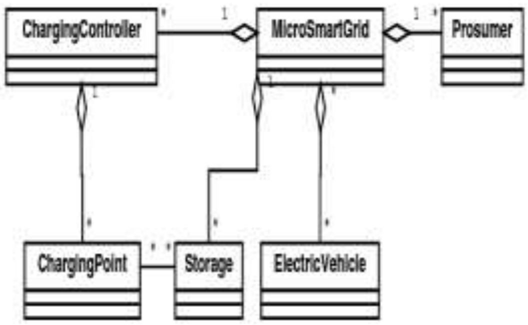

Fig. 1. Draft of architecture of the common domain model.

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 Smart Grid 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.

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, peddles 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 to assist the user throughout the trip end detail 5. Events: as routing requests are always time-related, results need to have more information than 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 driver's 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

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.

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 Electromobility 2.0 project, we created such a scheduling system based on a generic optimisation framework developed in an earlier project, EnEffCo4. 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 detail3. 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 strategy10, 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 f first pass the optimization algorithm distributes the previously allocated amounts of energy to the respective vehicle786 Marco Lutzenbergeret al. / Procedia Computer Science 32 (2014) 780 – 787 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.

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, which 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.

Combining Energy and Mobility services

In the ImaadEMDprojects servicesare composedofalpineservices 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 descriptions11. 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 as 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 egg, 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 Marco Lautenberg et al. / Procedia Computer Science 32 (2014) 780 – 787 787 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.

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 several 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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