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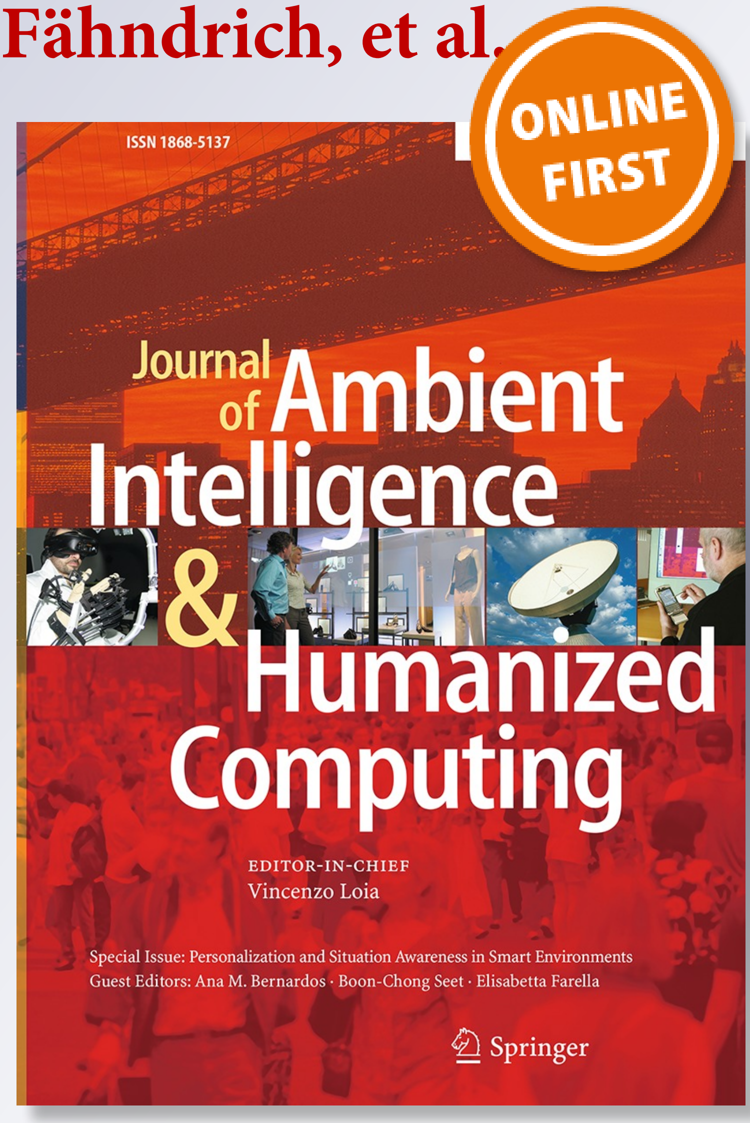

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ORIGINAL RESEARCH

A common approach to intelligent energy and mobility services in a smart city environment

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Abstract Due to the fact that electric vehicles have not broadly entered the vehicle market there are many attempts to convince producers to integrate technologies that utilise embedded batteries for purposes different from driving. The vehicle-to-grid technology, for instance, literally turns electric vehicles into a mobile battery, enabling new areas of applications (e.g., to provide regulatory energy, to do grid-load balancing, or to buffer surpluses of energy) and business perspectives. Utilising a vehicle's battery, however is not without a price—in this case: the driver's mobility. Given this dependency, it is interesting that most available works consider the application of electric vehicles for energy and grid-related problems in isolation, that is, detached from mobility-related issues. The *distributed artificial intelligence laboratory*, or *DAI-Lab*, is a third-party funded research lab at Technische Universität Berlin and integrates the chair for *agent technologies in business applications and telecommunication*. The DAI-Lab has engaged in a large number of both, past and upcoming projects concerned with two aspects of managing electric vehicles, namely: energy and mobility. This article aims to summarise experiences that were collected during the last years and to present developed solutions which consider energy and mobility-related problems jointly.

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 having a positive effect on mobility may affect the overall system's energy balance in a negative way. Contrary, solutions that aim to optimise energy aspects may be poisonous for the mobility of electric vehicles.

As an example, consider the many attempts to use electric vehicles for challenges that are confined to power grid infrastructures, e.g., avoiding peak loads, increasing the utilisation of renewable energy, or providing regulatory energy. Most of these challenges can be solved by a well-directed arrangement of charging and feeding processes of electric vehicles. Examples for such approaches were presented by Aabrandt et al. (2012), Gray and Francfort (2012), Kamboj et al. (2010), Markel et al. (2009), and Sundström and Binding (2010).

The 'energy-optimised' arrangement of charging processes, however, does not necessarily further the unconditional usage of electric vehicles (e.g., ensuring a certain energy level in the battery of the car). In fact, using vehicles with an electric powertrain is not as easy as using conventional vehicles. Smaller ranges as well as long charging intervals require drivers to carefully plan their trips. As a consequence, several approaches have been developed, aiming to make the use of electric vehicles more comfortable or more efficient. Available approaches range from decreasing the effective emissions of electric vehicles, via improving their availability, throughout to lowering their cost of ownership. As an example, consider the works of Freund et al. (2012) or Keiser et al. (2011, 2012), which aim to tackle such problems. Most available solutions integrate electric vehicles into energy-producing

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facilities and use locally produced energy to cover their demand. Other approaches implement next generation business models, such as presented by Masuch et al. (2011). Summing up, these approaches aim 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. 2012). The reasons for that are not entirely clear, though, little practical experience with electric vehicles and smart grid architectures might be a factor.

This article aims to outline a solution, which 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 Sect. 2.1) and mobility projects (see Sect. 2.2). Subsequently, we emphasise the increasing symbiosis of energy and mobility-related problems by presenting requirements of our current projects (see Sect. 3). In Sect. 4, we present our domain-specific solutions from which we derive requirements for a more comprehensive approach. We discuss these requirements in Sect. 5. This article revises and extends previous work by Lützenberger et al. (2014).

2 Previous work

The DAI-Lab has developed solutions for both, energy and mobility-related problems. In this section, these works are presented with particular emphasis on 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,[1] 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, 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 centralisation, such that distribution network operator could be granted tools and permissions to control charging and discharging of a fleet of vehicles (cf. Tomić and Kempton 2007, p. 2).

In a more decentralised approach, for end-user applications, energy storage systems can serve, e.g., for storing renewable 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 or load management integration, renewable demand response or load management, and reliability enhancement.

The DAI-Lab has successfully completed a number of research projects (Freund et al. 2012; Küster et al. 2013) in the Smart Grid domain within the past years. The list of projects comprises various aspects and applications in the multi-facetted field of energy management, reaching from building operations and battery storage management in homes over electric transportation to power management in industrial production plants and electricity grid security simulation.

As a part of the *service-centric home project* (*SerCHo*), the *smart home energy assistant*, or *SHEA*, laid the foundation for building energy management research applications at the DAI-Lab. The main goal of the SerCHo project was the development of an open service platform to increase life quality at home. The platform was intended to support the quick and easy delivery of new context sensitive services into the home environment. The services developed within the project also comprised applications for cost and resource efficient provision of power and heat as households account for more than one fourth of end energy consumption.[2] To reduce primary energy consumption, the SHEA monitors the energy consumers and records their consumption data. On demand of the inhabitants, these data are provided in graphical form spanning freely scalable time intervals. In this way the user can reproduce and analyse clearly arranged load profiles, serving as basis of

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[1] It is important to mention that some of the services that are discussed and used in this paper are not yet available. Today, for instance, it is not possible to 'book' charging stations by using public-available services. The ever-increasing advance of technology, however, indicates that such services will be available in the near future. In fact, it is already possible to make reservations for parking lots via internet.

[2] http://www.solarify.eu/2014/02/20/743-ageb-warme-ist-wichtigste-nutzenergie/.

decision-making process and for subsequent attitude change with respect to antiquated and energy-hungry equipment.[3]

Further possibilities to enhance energy efficiency and ease of use for home operations have been developed within the projects *system for the optimization of in-home energy consumption* (*SOE*) and *Intelligent building energy management* (*IGEMS*). Contrary to attempting to improve the energy related physics of buildings and appliances, the core idea of IGEMS is to make energy consumption more transparent to the user and to enhance energy relevant in-house processes in an integrated, intelligent and as far as desirable automated way, with respect to interdependencies between the different electrical appliances, heating, and airing. The IGEMS provides an intuitive multimodal user interface with a high degree of front end ergonomics. There is a special focus on natural ways of interaction. It is embedded into the home environment and supports the user across different devices such as television, PC or audio devices. Also mobile devices like PDA and mobile phone are used to interact with the application. Because of its ubiquity availableness and easy interaction, the IGEMS copes with the title of a personal assistant. Objective of the SOE project was to use machine learning approaches to recognize situations and behaviour of residents based on high-resolution smart meter consumption data (Spiegel and Albayrak 2014). The collected data is used to deduce alternatives in building operations, which lead primary energy savings. Observation results are presented to the residents as recommendations but could also be integrated in any automation application. To increase acceptance and ease of use, the system is provided with context adaptive user interfaces.

In the project *service-oriented home automation platform for increased energy efficiency* (*SHAPE*), a distributed energy management system has been developed. SHAPE facilitates the optimisation of heating energy in private households beyond the visualisation of energy consumption and tariff information in apartments. The system is particularly applicable in multi-story buildings with varying heating demand. The convenient control of heating output allows visual display, tracking, and comparison of household energy consumption and costs. A demand-driven optimisation of the heating output, based on the input of heating profiles for each individual room, allows savings of up to 30 % heating energy (Beucker et al. 2012). The system can also synchronise the household electricity consumption with future variable electricity tariffs. Thus, for example, targeted use of renewable energy is possible in households, alongside shifting electricity consumption to low-rate times. With the ‘Wind-to-Home’ service that was developed in SHAPE, hot water storage tanks can be operated on excess wind power instead of fossil fuels. Furthermore, a key component of the project was the development of business models from which various stakeholders of energy management can benefit, e.g., consumers, the housing industry, energy producers and distributors.

Approaches to integrate battery energy storage by means of intelligent charging and discharging of electric vehicles have been investigated in the projects *DEASYS* and *He-Lion*. Other than the various e-mobility projects presented in the remainder of this article, research was pointed at the connection of one vehicle with one household, leaving aside the many regulatory requirements concerning the participation of e-vehicles in energy markets. The energy management system in both projects is based on a distributed *multi-agent system*, or *MAS*, which controls and regulates the energy consumption of all components. If the system recognises a planned or unplanned peak load and a car is connected, additional energy source can be used to reduce the load of the public electrical network and flatten the personal electricity consumption curve. The external energy storage can also be used to store energy following a variable power price tariff to account for variations in power production from renewable energy sources.

While the projects described so far focus on applications for cost and energy efficiency in the distribution grid, the project *energy efficiency controlling* (*EnEffCo*) (Küster et al. 2013) was conducted at DAI-Lab to identify load management potentials in the context of industrial production. More precisely, it pursues the goal to develop and implement a novel hard and software concept (Küster et al. 2013) that facilitates the reduction of energy consumption and energy costs in the automotive industry. The software serves as a tool for decision-makers in manufacturing, to whom it offers the identification and evaluation of strategies and tactics for establishing cost and energy efficient production and building operations. Efficient production planning is determined on the basis of energy and production specific input data, such as production rates or energy costs that can be specified by the production manager. Specific input data could for example be to produce a certain number of items within a specified time period without exceeding a maximum aggregate electricity grid load. Energy parameters can e.g., be the overall amount of energy, a maximum load level or load shape transformations. For the realisation of the simulation, software paradigms from the artificial intelligence domain are used as well as rule based optimisation systems. Domain modelling is done in an ontology-based approach to establish a generic data model as a basis for adaptation and interoperability beyond the scope of this specific project.

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[3] http://energy.dai-labor.de/index.php?id=14.

Due to the increasing frequencies of natural disasters as well as potential terrorist attacks, the protection of critical infrastructures from natural and man-made catastrophic events is a central challenge which was focussed in the project *intelligent solutions for protecting interdependent critical infrastructures* (*ILIas*) (Konnerth et al. 2012). The volatile critical infrastructures are getting even more challenging to manage since their scale as well as complexity and mutual interdependence grows. Furthermore, new technology paradigms such as All-IP networks and Smart Grid functionality are blurring the classical domain boundaries and facilitate novel attack types. The latter aspect in particular can lead to cascading failure effects where the malfunction of neuralgic infrastructure elements brings down entire systems through hidden or explicit dependencies. In ILIas, intelligent solutions for protecting critical infrastructures, which provide electricity and telecommunication services to the general public were developed (Konnerth et al. 2012). A service-oriented multi-agent architecture is employed as a flexible peer-to-peer-based distributed management system to provide a robust and fault-tolerant foundation for the network analysis and administration functionalities, ensuring data availability and system control in case of different network failures. Isolated nodes locally ensure minimum system stability until overall control can be re-established. The DAI-Lab developed a software solution for simulating attack scenarios and evaluating protection mechanism efficiencies in large-scale networks. The simulation models are supplemented by a hardware test laboratory where exemplary symbiotic energy and telecommunication infrastructures are set up. Both environments were used for cross-validation to ensure the validity as well as real world applicability of our proposed solutions.

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*. MiFA 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. The Dayplanner plans routes by using public transport, station-based car sharing and bike sharing as modes of transportation. 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. In the projects *Mini E 1.0* and *Gesteuertes Laden V2.0* we developed an approach, which 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 (Keiser et al. 2012; Krems et al. 2013; Lützenberger et al. 2012; Masuch et al. 2012b). 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 (Freund et al. 2012) 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.

We selected an agent-based approach for most of the presented projects and implemented our solution as a distributed multi-agent system by means of the agent framework *JIAC*, the *Java-based intelligent agent componentware* (Lützenberger et al. 2013). The applicability of the agent metaphor for problems related to smart grid infrastructures or electric vehicles is commonly agreed (see e.g., Formato et al. 2014). Yet, we decided to apply an agent-oriented view because both domains—the energy domain as well as the traffic and transport domain—comprise a number of loosely coupled devices (e.g., vehicles, charging stations, cell phones, batteries, laptops, backend servers, desktop computers, to name but a few), which frequently have to act autonomously, that is, without any human interaction.

The agent-based approach worked fine for the mentioned projects, yet, when developing our applications, we recognised that we neglected the impact of mobility-related aspects on energy-related aspects and vice versa. Due to the advanced stage of these 'first generation' projects, it was not possible to account for this dependency anymore. For our second generation projects, however, we aimed to solve this problem. We continue by presenting these second generation projects in more detail.

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.

3.1 Intermodal mobility assistance for megacities

The aim of the *Intermodal mobility assistance for megacities* project (*IMA*) (Acar et al. 2015; Keiser et al. 2014; Masuch et al. 2013), is to increase the quality of life in megacities by providing an open mobility platform with intermodal trip planning, monitoring and trip-assistance functionality. The platform integrates different types of mobility and infrastructure providers, such as car-sharing, bike-sharing, public transportation and traffic surveillance, which can dynamically be included at run-time by using semantic description mechanisms. The users can request (intermodal) trip advices via a mobile application at pre-trip time according to their profile (which includes preferences for aspects like time, costs, or CO_2 emissions) and context information, like traffic jams or drop out of means of transportation. Furthermore, IMA provides an on-trip time assistance system, that monitors the current status of the trip (including GPS-tracking and modality recognition of the user at trip time) and relevant changes in the environment. If delays are expected, the system suggests alternative trip options. As traffic conditions play an important role for dynamic trip assistance systems, IMA is researching in the field of traffic surveillance data analysis in order to recognise traffic disturbances. The research is split into two parts, the single camera analysis (SCA) and the multi camera analysis (MCA), which clusters single camera results to a broader evaluation of traffic situations. Due to the expendability 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.

3.2 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. Due to the much quieter electric drive engines, the use of these batteries allows to implement a multi-shift operation mode for electric vehicles in residential areas, which doubles their utilisation. The system is aware of all routes in advance, thus, energy requirements are know as well. This information makes it possible to exploit the available storage capacity and to maximise the batteries' profitability. In Germany, it is required by the law that energy providers account for a certain amount of additional energy, namely regulatory energy. Providing this 'ancillary service' is extremely expensive, however, using the NaNu approach, it becomes possible to use exchangeable batteries to do grid load balancing and to actively support energy providers, ensuring a smooth grid operation. The optimisation problem in NaNu is aggravated by some additional constraints, e.g., exchangeable batteries must be loaded in pairs into the truck in order to guarantee the weight symmetry of the vehicle, or all SOC levels have to be equal in order to ensure electrical stability of the power flow that supports the vehicle's powertrain.

The problem's complexity required us to design a system able to deal in real-time with all imaginable conditions of the grid, the vehicles, the batteries, and the routes. Furthermore, the system has to adapt to changes quickly, always ensuring a high-quality delivery service.

3.3 Smart e-user

Smart e-user aims to cover some of the existing voids present in the electric mobility picture. The objective is to implement existing business models by using fleets of electric-drive vehicles, instead of vehicles with internal combustion engines. The cases under study are both, transport of goods and private transport services. In relation with the first one, there is a package delivery company involved and in the second one, three companies implementing private transport for business services as well as for medical care ones are participating.

Although their requirements may be different when comparing the route patterns and the service times, in order to reach a good level of performance in both, energy consumption as well as routes have to be optimised. Therefore a dynamic routing assistant as well as an energy management system are being designed and implemented for this project including the mechanisms necessary to coordinate both.

On the one hand, the dynamic routing assistant must plan the routes taking into account aspects such as the traffic congestion and weather conditions. On the other hand the energy management system has to calculate optimised charging schedules while paying attention to several variables. For instance, the current state of charge of the vehicles, charging speed, energy requirements and costs or the power constrains imposed by the grid configuration on each location at any time.

3.4 Extendable and adaptive e-mobility services (EMD)

The EMD project focuses on the development of software tools and models which facilitate 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 using annotations and OWL-S descriptions. As most of these services are intended to be developed and published by third parties, the envisioned models for the e-mobility domain need to be extendable and adhere to current industry standards. The second contribution are software tools that 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. Retrieving user input, either because certain information is unexpectedly not available or because it is deliberately designed as user input, poses a particular challenge in this context as simply decomposing the model's concepts into their primitive parts and obtaining the corresponding values from the user may be inappropriate in many cases; e.g., the user should not be required to manually provide latitude and longitude when being asked for their current location. Moreover, the representation of concepts needs to be adjusted to the current context for both retrieving input from the user as well as presenting objects. For instance, when the user is looking for a charging station, presenting its location is usually of paramount importance while in other situations different aspects such as its maximum charging power might be more important.

To evaluate the advances in the developed software tools one goal of this project is to develop so-called *basic services*, such as a billing service, and enrich them using the created model to finally compose complex value added services based on these basic services, e.g., an intermodal routing service.

3.5 Elektrische Flotten für Berlin-Brandenburg

In this project, car sharing fleets with varying configurations are tested. The DAI-Lab focuses on supporting the user in finding and executing an intermodal route involving these fleets 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 project focuses on the mobility of the user. The energy management of car sharing fleets is usually handled by the operator of the fleet and hidden from the user to reduce complexity. However, the mobility of the user is indirectly influenced by the energy management since the energy in the vehicle has a direct influence on the mobility of the user. The application takes this into account by proposing vehicles for a route whose charging state is appropriate and providing the user with information about the charging state and estimated range. Focusing this information is especially critical in spontaneous cases where the application does not know the route or destination of the user. In addition, the energy management depends on the user to connect the vehicle to a charging station to make it available for charging and optimisation purposes. Fleet operators try to incentivise this behaviour. The application also is used to test whether a mini-job concept (e.g., connect an almost empty vehicle to a charging station for 30 min free car sharing) can help with this issue. Thus, energy management aspects are supported indirectly in this project by providing the relevant information to the user. This application is developed using model-based user interface development.

3.6 Micro smart grid EUREF

The project Micro smart grid EUREF focuses 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 (Küster et al. 2014) will be extended with further and more diverse vehicle fleets and generation and storage equipment, such as additional electrical storage, a combined heat and power plant, a super-capacitor and additional charging stations. The project will comprise multiple competing car sharing operators as well as private electric vehicles using the same micro smart grid. 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. The project deals with a complex environment with multi-operator fleets, known and unknown users as well as different existing car sharing business models. Therefore, it is necessary to handle not available or non-existing car bookings. In particular, floating car sharing services do not have valid booking information, because they are booked on demand. Sometimes these services have reservation bookings, but only for a small time range like 30 min in advance, which is not suitable for a long-term scheduling. For this reason it is required to model or learn the usage behaviour of electric vehicle sharing users in a specific environment. The considered solution is using supervised machine learning techniques. The model training for booking predictions draws on historical data about the power consumption of the charging stations. Training data from 16 months with 3 min resolution was collected before the scheduling system was deployed on the charging stations. This allows to determine whether a car was available at a time slot or not based on a minimal consumption threshold. The ends of such periods with available cars are interpreted as bookings. At the moment we are using an artificial neural network with two hidden layers to learn a model of car bookings. Other machine learning challenges within the project include the improvement upon the mid-term forecast of energy production through photovoltaic with *deep learning* approaches, as well as forecast of energy consumption of buildings. Given the aforementioned forecasts, the planning component of the implemented energy management system conducts a multi-goal optimisation using a meta-heuristic algorithm, namely *evolution strategies* (Küster et al. 2014). The weights of different goals are configured in operation scenarios, such as the maximisation of locally generated energy, an economic optimisation, long time peak shaving, or islanding mode of the micro-grid. The optimised plan is passed to a supervisory control and data acquisition system (SCADA) that distributes the control signals to the controllable grid components. A feedback loop from the SCADA system updates the planning component with deviations from the plan or newly available data. A new planning calculation is triggered, when configured thresholds are passed. The learning and optimisation phases are implemented in a multi-agent system, which allows for a flexible orchestration of the system behaviour and the reconfiguration or exchange of algorithms at runtime.

3.7 ProSHAPE

The goal within the research project ProSHAPE is to increase the energy efficiency in residential buildings through the deployment of an intelligent building energy management system (BEMS). In particular the interaction between *smart homes* and the building energy management, combined with an open service platform, is considered. The project builds on the preceding project SHAPE. Within SHAPE a home service platform with a connected service provider platform was successfully developed. It offers added value services to the user, e.g., presenting information regarding dynamic electricity prices in order to achieve changes in the user's behaviour and to decrease energy costs. Within ProSHAPE this platform is now extended beyond the boundaries of the smart home to a *microgrid-service platform* including energy-relevant components in a residential building, such as decentralised generation, controllable and non-controllable consumers, and storage. This open service platform allows to extend the system with services for tasks such as forecasts of non-controllable consumption, variable energy prices and decentralised energy generation, as well as optimisation and planning tasks. Optimisation tasks incorporate the energy co-generation through a combined heat and power plant, while considering thermal storage capacities, decentralised electric generation through for instance photovoltaic and variable energy prices. In addition to water tanks as thermal storage, also the thermal storage capacities of the building mass are considered and evaluated for demand response capabilities in respect to user preferences. The system is evaluated in a field test in a quarter, which combines five residential buildings with over 200 apartments. It is further evaluated in a microgrid test-bed, where a smart home test-bed and demonstrator is combined with local electricity generation and storage.

3.8 Forschungscampus EUREF

The aim of the *Forschungscampus EUREF Mobility2Grid* project is twofold. The first objective is to extend the existing infrastructure (photovoltaic panels, wind turbines, combined heat and power plant, P2H, P2G, and batteries) to facilitate its electrical autarchy. Thermal energy must be considered as well. 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 objective is to develop and implement car sharing and fleet concepts based on V2G-enabled vehicles that increase the usage of locally generated energy and 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.

3.9 Similarities and differences

When looking at goals and major problem domains of our current projects, we can distinguish between three main categories: energy, mobility, and a combination of both (see Table 1).

The first category focuses on energy aspects and comprises factors like sustainability, autarchy and charging management. Amongst others, the second category addresses: intermodal trip planning, dynamic assistance at trip time, and traffic analysis based on different sensor sources. Finally, there are projects where both issues, energy and mobility are considered. Considering our most common application problem domains, we are facing challenges in the area of charging optimisation and intermodal trip planning. Even trip planning seems to be a particular problem of the mobility domain, it has a strong impact on energy problems in combined scenarios, as for instance in the IMA project.

A look into second generation project shows that it becomes more and more difficult to consider energy and mobility-related problems in isolation. Especially in the case of electric vehicles (and their applications), both domains seem to converge. In order to support this convergence, it is necessary to bring domain-specific solutions together. In the following, we present our approach to do that.

Table 1 Project domain categorisation and applications

Project	Domain		Application area	
	Energy	Mobility	Charging optimisation	Intermodal trip planning
IMA	○	×	–	×
NaNu	×	–	×	–
Smart-e-user	×	×	×	×
Extendable and adaptive e-mobility services	○	×	–	–
Elektrische Flotten für Berlin-Brandenburg	○	×	–	×
Micro smart grid EUREF	×	–	×	–
ProSHAPE	×	–	×	–
Forschungscampus EUREF	×	–	×	–

Domain and domain model or application problem are × = included; ○ = touched; – = not included

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 approach to merge both 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

Our approach to represent these projects through information systems, in order to provide for intelligent energy distribution management, includes a common domain model. This facilitates the reuse of software components—most notably the planning component described in Sect. 4.2.1—and further provides a common ground for communication (both inter-program and inter-personal) across the projects.

The analysis of similarities in Sect. 3.9 supports our objective as requirements are generally similar. Yet, there are also distinct differences, plus, an increasing complexity. Both factors may significantly challenge the development of a common model. However, collected experiences from previous work significantly support our idea to design a common model.

Based on the analysis of on-going 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* Usually, a car battery is assigned to (i.e., permanently installed in) one vehicle only. The NaNu project, however, requires the concept of multiple exchangeable batteries per vehicle.
- *Increasing complexity* Energy producers and consumers, or *prosumers*, were presented as uncontrollable demand or availability forecasts. Yet, novel concepts, such as hydrogen electrolysers, combined heat and power plants, and electrical warm water heaters with storage, require a more flexible representation.
- *Multi-operator fleets* Previous work considered individual, bookable fleets, only. On-going projects, however, cover 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.

The architecture of our common domain model, incorporating some of the challenges and lessons learned, is shown in Fig. 1.

The model is made up of two parts: The static architecture of the micro smart grid, and the information concerning a specific scheduling order and the resulting schedule.

Consequently, the elements in the MSG part contain only the information that does not change over time. Particularly, there are no clear 1:1 relations of storages to charging points, or even of vehicles to storages, but only lists of 'compatible' storages and charging stations. The actual assignment of storages to vehicles and charging points to storages is determined in the optimisation process (see Sect. 4.2.1). This additional flexibility is required in particular by the NaNu project, where batteries are

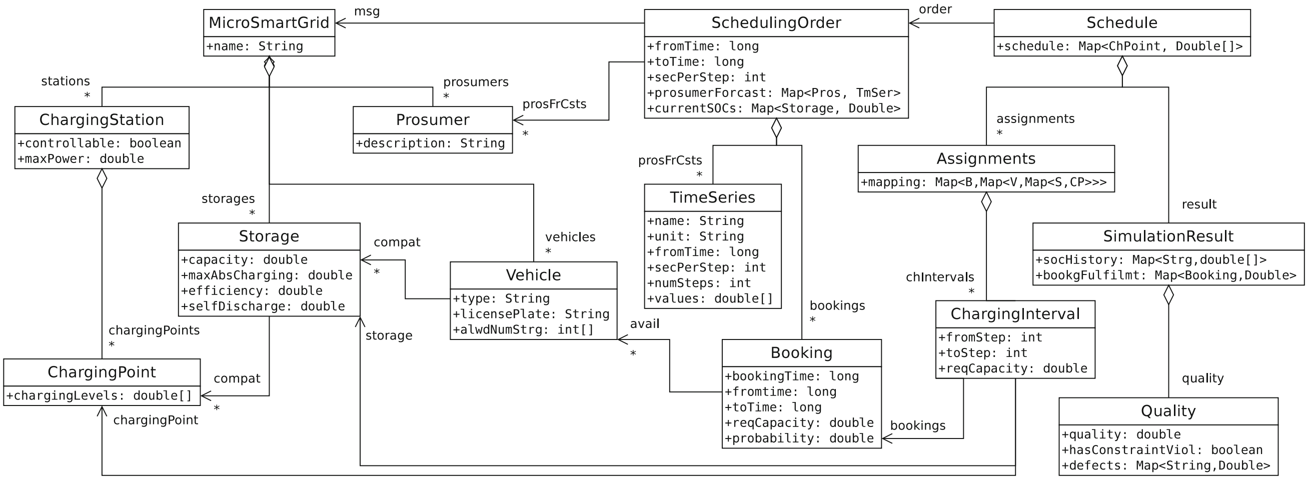

Fig. 1 Class diagram of the common domain model architecture (slightly simplified)

interchangeable, and by MSG EUREF, where a flexible association of storages to charging stations is needed to account for multi-operator fleets. The introduction of charging points (connectors to a charging station) was required, since the overall current capacity of the charging station induces a limit on the current at each of its charging points. Also, 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.

Booking information as well as forecasts for energy prices and the consumption of individual prosumers are specific to the scheduling order and have been aggregated accordingly. Similar to the relation between vehicles, storages and charging points, a booking has a reference to 'compatible' cars (e.g., cars of one type, in one location, or of one car sharing provider), while the actual assignment of a concrete vehicle to use for that booking is part of the schedule, i.e., the result of the optimisation process.

Besides the classes shown in Fig. 1, the domain model also includes a number of utility classes, first and foremost an interpreter for simulating and assessing the behaviour of a given micro smart grid over time. Given a charging schedule, the interpreter will iteratively simulate each of the discrete time steps, calculating the state of charge in each of the storages, the total energy consumption by prosumers and charging, and how well each of the bookings could be fulfilled by the schedule. All this information is aggregated in a simulation result object and returned for further analysis, and to serve as a quality function in the optimisation of the schedules.

4.1.2 *Mobility domain model*

The idea to capture the concept of human mobiliy in a formal representation is not entirely new (see e.g., Vastardis and Yang 2014). Originally, we developed such model for the IMA project, however, we recognised that a formal representation of human mobility behavior is useful for other projects as well. The IMA project has a strong focus on mobility and transportation issues, rather than on energy aspects. We therefore decided to develop a domain model, which covers the different aspects of intermodal travel assistance systems. These are listed below:

1. *Mobility service* In order to find intelligent intermodal routes the data of different mobility providers is needed. Therefore we defined a Mobility Service representation within the model that contains all relevant information about the offer of the provider. Amongst others, this includes data about the service provider, the type of service, the mode of transportation, the costs and billing details and its ecological footprint.
2. *Modes of transportation* For a comprehensive mobility domain model the different modes of transportation in an urban environment have to be represented. Currently, our model covers descriptions for cars (combustion and electric cars), bikes, pedelecs and public transportation vehicles, such as metro, bus and suburban train. Electric vehicles, for example, have a relation to a Battery class which specifies the capacity while the combustion car defines the size of the tank.
3. *Infrastructure* Mobility assistance is only applicable with respective infrastructure. Our model therefore represents infrastructural entities, such as roads, traffic information, charging stations and parking spots. By

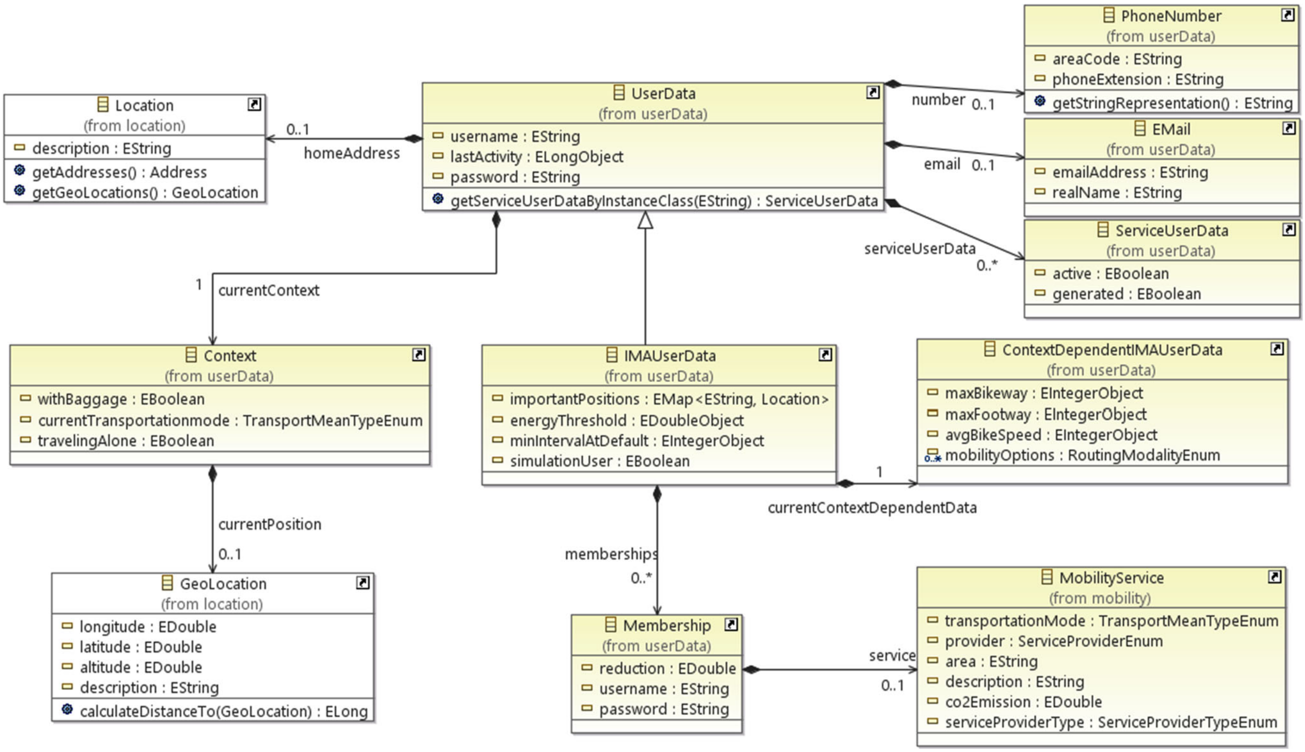

Fig. 2 Overview of the user data package in the mobility domain model (simplified)

doing so, the model enables the developer to work on solutions for traffic-aware routing, pre-selection and potentially booking of parking spots and control systems for the availability of charging stations, amongst others.

4. *Routing* Besides a definition of the infrastructure, there is a need to define the route that is evaluated upon it. Therefore the model comes up with a route representation that can be recursively segmented into smaller route parts with different modes of transportation which finally are described as atomic waypoints.
5. *Events* As every travel assistance system is related to time, there is a need about temporal information in requests as well as in routing results. In our model a route is wrapped in a *JourneyEvent* object that additionally contains information about departure, transfer and arrival times. Furthermore, the model also considers information about parking, charging and appointment events.
6. *User data* User-centric travel assistance systems largely depend on the amount and the quality of user-related data they can access. Therefore, we defined a comprehensive user representation, which can be seen in extracts in Fig. 2. It is basically built in a hierarchical structure, as we defined a basic *UserData* Class which is then refined in project-related user date classes (in the Figure *IMAUserData*). Furthermore we distinguish between (almost) static data, such as user name or email address and dynamic, context dependent data, such as the current position or the mode of transportation the user is currently using. The latter is especially relevant for monitoring and re-planning purposes.

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 led 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: a charging optimisation component, an intermodal trip planning component, and the practical attempt to merge both 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, optimising 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 (Küster et al. 2013). 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 process model was not suited for modelling the system in an adequate level of detail (Freund et al. 2012). 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 project's requirements, but not with those of our new projects. The optimisation uses a variant of evolution strategy (Rechenberg 1973), in which charging schedules are randomly mutated and recombined until an optimal schedule is found (Küster et al. 2014).

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

1. Use of any kind of machine learning techniques to allow for the prediction of bookings.
2. Assignment of vehicles to bookings, storages to vehicles (where applicable) and charging points to storages, based on heuristics.
3. Optimisation of the charging schedules for the electric vehicles w.r.t. each booking, focusing on those bookings being fulfilled while at the same time tuning the schedules for the individual vehicles in order to avoid load peaks.
4. Using local storages and unused vehicle capacities to redistribute temporal surpluses in electric energy.

In the first phase, the list of bookings given in the scheduling order is reviewed and extended with more information or additional bookings. In particular if there is a large number of *ad-hoc* bookings, this step is essential for providing a useful schedule. Next, 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. This assignment is then assumed as fixed for the upcoming optimisation of charging times. Then, in a first pass the optimisation 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.

As an example, consider an employee in a city that has a home to work distance of 10 km. In this scenario, there are a lot of different options available. For example, when the weather is good and there are no external appointments, the person might choose the bike. On other days the vehicle is being used in order to bring the children to school and in other situations the public transport or car sharing vehicles are 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 (e.g., by using bike sharing), but not getting too late to work (public transport for the second part of the trip). However, right now the person has to check a variety of different sources (weather, traffic, availability of resources, personal appointments) to come to a decision. A comprehensive platform, integrating all these different aspects and coming up with a transparent overview about the options is needed.

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 tailored to the particular user. Since the intermodal trip planner is included in a distributed system where services can appear and disappear it is important to have a unique model for the description of mobility services, as presented above (see Sect. 4.1.2). Accessible mobility services have to implement a standardised service interface in order to be considered by the intermodal trip planner. The concrete interface type depends on the particular nature of the service, e.g., scheduled service, flexible station service, fixed station service, to name but a few. Services can also be enhanced by means of semantic service descriptions. These contain preconditions and effects and describe the service's 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 (Masuch et al. 2012a); 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 service. 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 normalised according to the worst estimation for the respective route. Based on this heuristic, we are able to annotate the edges connecting nodes and thus can search for an optimal intermodal solution on the graph with the A-star search algorithm.

Furthermore, the component is being extended to not just give a recommendation before the trip is happening, but also offering assistance throughout the whole trip. Therefore we are developing a monitoring component. On the one hand, this component checks user information (GPS position, current mode of transportation) at a regular interval, on the other hand, context information, e.g., traffic jams or weather, are observed. If the forecast deviates from reality, the system proposes new routing suggestions. This is done by means of a mobile applciation, namely the *Intermodal Routing Assistant*, or *IRA*.

To sum up, it is important, especially for distributed systems with multiple stakeholders, to have a common domain model that covers all relevant entities. For the mobility domain, these entities are first and foremost the particular 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 services out of a set of available services. Using a combination of the mobility and energy domain model, services are semantically described, which allows *service matcher* or *agent planner* applications to use these descriptions for reasoning operations (Fähndrich et al. 2013). To ease the matching of descriptions to a request, the domain model facilitates semantic descriptions of instantiated objects.

Several steps were done in order to increase the performance of the domain model. First, a 'reduced representation', namely the *context model* was introduced. The context model describes only dynamic and relevant aspects for the given service. Secondly, the *state model* was introduced. The state model describes a service at runtime and is required in order to facilitate a reliable service composition procedure.

The context model contains all the entities that the service might adapt to, as well as specifies restrictions of the domain model to a certain context. As an example, a service might be able to find charging stations based on a given location. This, however, applies only when the location is within (or close to) the city of 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. Figure 3 illustrates this relationship of the different models and gives an example.

Within two of our on-going research projects, namely IMA and EMD, we aim to develop software components that compose such semantically described services to generate plans (semi) automatically. This mechanism allows to adapt the service selection to the context and the availability of the services.

With the introduction of the context model as an subset of the domain model, we postulate that every entity used in the context is modelled before it can be used by a service during runtime. Additionally the use of a state model

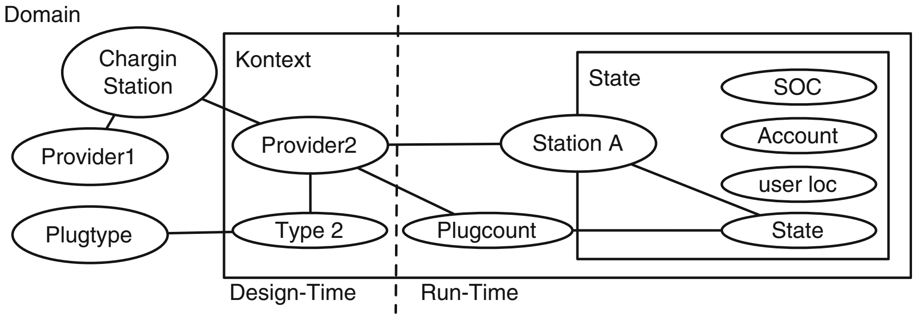

Fig. 3 Illustration of the relationship of domain, context and state model

allows us to help the service orchestration developer to specify rules or bindings regarding specific state variables, which are used in a service-overarching manner automatically since a fitting service can be found regarding instance information. Through the continuous change in the service environment the models are dynamic and need to grow with the services. Thus, additional requirements regarding the domain model arise: It has to be possible to extend the models with new services, which may entail new domain objects. This situation requires the model to be rather high level and makes it necessary to constantly revise the model, manually.

Wrapping up, the challenge in EMD and IMA is to design a domain model in a way so that it can be used in other models (e.g., the context model), or for the formulation of precondition and effects of the service model. formulation of precondition and effects of the service model.

5 Challenges

The objective of this article was to create an awareness for the ever-increasing convergence of two domains that are frequently considered in separation, namely: energy and mobility.

The necessity for a joint approach was observed in ‘first generation’ projects, already (see Sect. 2), yet, when looking at on-going work, this requirement becomes even more apparent. In this article, domain-specific solutions were presented. In doing so, particular emphasis was laid on identifying the connections between both domains.

The aim was to show benefits of a joint consideration and to outline an integrated, holistic solution. Such integrated solution, however, is aggravated by several factors.

There have been a number of challenges arising from the electric 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. This problem was solved by allowing multiple batteries in the meta model. To make the complexity manageable, the assignment of those batteries to actual vehicles was kept out of the main part of the optimisation.

Finally, both models are used together for developing mobility services referring to the energy domain model. It is planned to model each of the phases in the energy optimisation as distinct services, that can then be orchestrated to one comprehensive scheduling service and integrated into the user’s mobility planning. Nevertheless, collected experiences convinced us that, in the near future, solutions for energy-related issues and solutions for mobility-related issues must go hand in hand.

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