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Requirements and Architecture Concept for a Data Processing System in Local Area Smart Grid

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Abstract: WINNER, a German research project, integrates local photovoltaic systems, charging infrastructure for electric vehicles and tenant households, focusing devices with and without smart grid abilities. The project's goal is to manage the local power grid operations in a way that allows locally produced energy to be consumed locally. This local optimised consumption is done by using currently available devices. Further, we want to analyse accruing data streams and optimise the usage of local devices to manage this time-base shifted consumption scenario by implementing a non-hard real-time processing system. In this paper, we outline the project's primary objectives from a technical point of view. First, we present "Wohnungswirtschaftlich integrierte netzneutrale Elektromobilitat in Quartier und Region" (WINNER) and some related research projects. We describe the integration tasks, the data sources, and sinks. So, a project overview can be given. Afterwards, we compare our approach and already developed technologies. Requirements are derived from the system overview. According to them, we can outline an architectural view of the core component of data stream processing within this scenario. Finally, the results are discussed, and consequences are drawn.

Key words: System architecture, local smart grid, requirements analysis, renewable energy, controlled charging.

1. Introduction

A primary source of renewable energy is PV (photovoltaic) systems. Installed as small to medium-sized plants on the roofs of apartment buildings these systems provide locally generated power to tenant households, which should be consumed locally as well. Unfortunately, solar energy production and consumption of households, at least if we consider individual electric mobility, are time-based shifted [1].

Our research project WINNER [2] aims to integrate and coordinate electromobility, the energy consumption of tenant households and the local production of electricity, e.g., by integrating photovoltaic systems into a smart local energy grid. Our primary goal with this project is to implement a "power grid neutral" behaviour, i.e., avoiding feeding electricity into higher grid levels. Within the project, EVs (electric vehicles) are used via the car-sharing approach which allows gaining booking data. Knowing the intended begin and end time of usages we can schedule the charging or discharging process and create forecasts on it. If the EVs are not used within the next hours, you could take the electric energy from their batteries and supply it to the local power grid.

However, within the research project WINNER, multiple installations of such smart local grids are intended. Further, we want to learn from our installations, analyse them, create forecasts based on this knowledge and optimize local consumption. WINNER does not develop new protocols for information exchange between components of such installations. Our goal is a prototype, implementing an ICT infrastructure and the analysis of measurement data within these prototypes. We consider existing components and currently existing potentials of optimisation without making modifications at any device.

The facts imply an information flow, managed

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within a non-hard real-time system which integrates a heterogeneous landscape of actors. Within this paper, we want to focus on system requirements and overall architecture of such scenarios. Furthermore, we want to deduce an architecture for our WDL (WINNER DataLab), which handles the information flows. This centralised part has to interact with the grid components within a tenant household to balance the consumption and production of electric energy.

The requirements and architecture concept discussion start in Section II with related work about similar projects and publications. Further, Section III presents the goals and central challenges of our use case. As a result of that, a set of requirements we impose on data processing units within those use cases, as well as the resulting WDL, is shown in Section V. Finally, we discuss the results in Section VI.

2. Related Work

First, we have to mention CEN [3] where a reference architecture model for smart grid applications was developed. Fig. 1 shows the so-called SGAM (smart grids architecture model) framework which sketches five different layers. Starting with the lower one, the level of abstraction increased up to the business layer. The component layer covers the physical representation like generators or electric appliances,

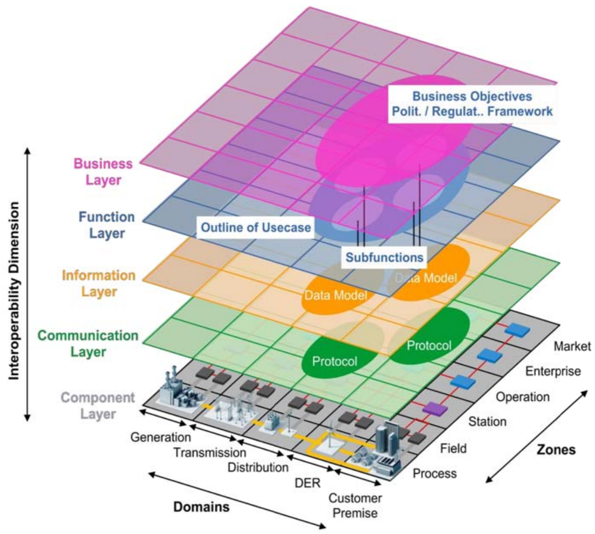

Fig. 1 SGAM framework [3].

whereas the upper layer of business describes which regulations and market mechanisms affect the system. The domains represent the path of the electric current and the interaction of the included components. The dimension of zones tries to build a "hierarchical model" [3] of power system management. That means, on the one hand, you could influence the power system by energy trading or pricing (upper hierarchy, focus on the market). On the other hand, there is the possibility of producing lots of electric energy or lowering the own consumption (lower hierarchy, focus on process).

Second, there are two research projects to mention—RegModHarz project [4] and Modellstadt Mannheim project [5]. The former focuses on selling the produced electric energy. The aspect of EV is not part of this research project. An exciting approach to this project is the calculation of prices for electric current based on the supply of locally generated energy and the demand of the inhabitants. Out of that, a virtual power plant is used to control the energy supply. Consumers or producers sign up with it. The WINNER project covers similar aspects but focuses on electromobility and intelligent charging and discharging additionally. Thus, the topic of temporary electricity storage is more important in WINNER. The project Modellstadt Mannheim [5] from 2013 tried to solve similar problems. Within this project, the so-called Energiebutler was developed. This physical device controls household appliances and turns devices like washing machines on or off at scheduled time. In this way, the demand side management is feasible in a very detailed way. The WINNER project does not aim such influence on households. Within our setup, it is necessary to collect the consumption data of households to generate load forecasts and to use them to schedule the electricity distribution between EVs, households and other consumers. The lower impact on tenants (no hidden forces control their household appliances) helps to increase the acceptance of our research project and new technologies in general.

The OpenADR (open automated demand response) project [6] pursues a similar goal. The focus is on the demand response mechanism and the (partially) compensation of load peaks. Depending on the amount of necessary electricity various devices send requests. A common language is used, and messages are sent via existing technologies like HTTP (Hypertext Transfer Protocol) over the internet. Ghatikar et al. [6] present a certification scheme for transmitted messages to ensure that only specific and secure devices can communicate with each other. As mentioned, the WINNER project pursues a similar target, but there are more things to think about. We do not assume that we have access to all devices within the local power grid or network. So, we may integrate various protocols and message transmitting technologies. Furthermore, there are more goals than compensation of load peaks. The pricing of electricity and the demand for charging have to be focused. Out of that, we can gain information by the devices within the local grid, but we are not necessarily able to control them.

The EEBUS initiative [7] tries to specify a harmonic data model for communication between smart devices. One of the main goals is to provide so-called power sequences. These represent timelines of electricity consumption of specific devices. By interchanging these load curves, local load peaks can be avoided, because flexible devices like washing machines can wait for others before they start their tasks. But if you want to enable all devices to communicate with each other, you have to make them use the same protocol. So each device has to implement the EEBUS standard and provide controlling options. The contrast to WINNER is a view on devices as they are, even without the ability to communicate with each other. We try to gain information on electricity consumption by measurements of current or evaluating booking data. There is no need for cross-device communication even a cross-device protocol.

Besides, related to practice projects there is fundamental research on smart grids as well. Basic principles for designing data management architectures are described, e.g., by Chervenak et al. in Ref. [8]. Tierney et al. [9] introduce concepts on monitoring such grids. Further, Appelrath et al. describe in Ref. [10] the process of developing IT architecture for smart grids as a result of a German research project, and Rusitschka et al. [11] present a computing model for managing real-time data streams of smart grids within the scope of the energy market. Unfortunately, these approaches are not directly applicable to our use case. Either they are large-scale, or focusing on data storing and mining. However, they can be considered within our approach, which has to bridge the gaps between smart grids, data storing, and possibilities for data mining as well as non-hard real-time event processing.

3. Project WINNER

The WINNER project aims to integrate electromobility, the energy consumption of tenant households and infrastructure as well as the local production of electricity visualized in Fig. 2. Until now, it is possible to install setups like this based on available devices. Unfortunately, each device acts for itself, i.e., local production of electricity is injected into the power grid, and a local consumer uses energy from the power grid. Each of them is mostly cleared independently or considered when making up the balance.

However, the WINNER project focuses on three objectives. The first objective addresses the already mentioned power grid neutrality. Thus, the target is to consume the locally produced energy to charge EVs, and provide energy for tenant or infrastructure devices,

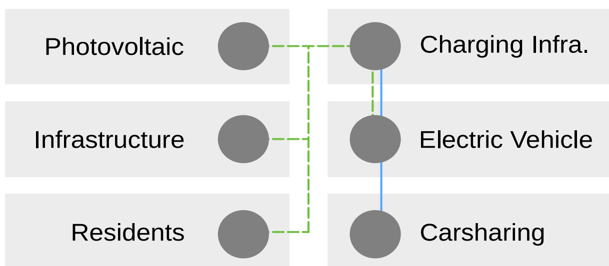

Fig. 2 Overview of the installations in the Project WINNER. Dashed line shows energy connectivity and straight line shows information exchange.

e.g., installations like a public light. The second objective addresses the possibility of controllable charging processes of EVs and utilises forecasts on EV bookings. So, charging them should be possible just before the next scheduled, or predictable, usage. Furthermore, it might be possible to use bi-directional charging of EVs to compensate load peaks. Finally, the third objective addresses the avoidance of load peaks. Multiple arriving vehicles in combination with peak times in tenant consumptions have to be managed to stabilise the local power grid. Based on these aims within the WINNER project, three problems can be derived and have to be considered:

(1) Competing load requirements

As illustrated in Fig. 3 PV produces energy while the sun is shining; typical load profiles of residents show peaks in the morning and the evening; EVs want to get charged when they are plugged-in right after coming home from work.

(2) Missing demand site management in residential areas, especially in tenant households

Unfortunately, most local grids do not have the opportunity to manage controllable devices.

(3) Lack of communication and exchange standards

There are different types of charging ports in case of the EVs and a wide range of communication standards between devices.

Based on our objectives and the exposed three problems, we need to capture the requirements which

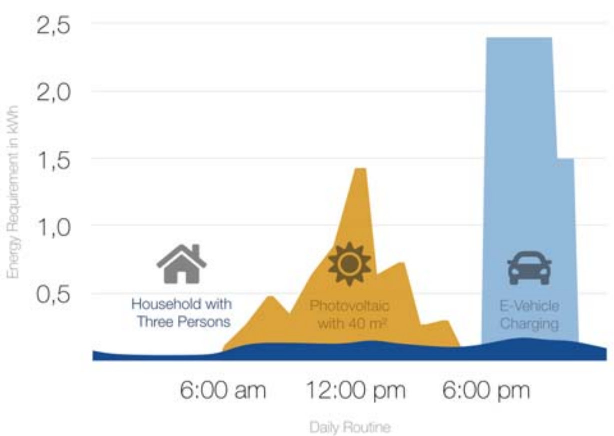

Fig. 3 Production vs. consumption in daily routine for common three-person household with 40 m^2 and one EV.

have to be considered when implementing our WINNER project. The primary requirements are listed below and focus on elements which have to be combined, as well as data sources which are required to create the smart grid under these circumstances.

(1) The scenario contains four main devices: PV, EV, charging station and metering from tenants as well as public installations.

(2) Real-time analyses require data from PV, EV and charging stations, as well as current consumption data from meters. Meters might be smart or the electrical installation has to be improved by some non-invasive measurement units.

(3) Analyses have to consider and integrate external services like weather and energy price forecasts.

(4) The charging process has to be controllable; the station itself as well as the EV.

(5) Local energy storages to overcome peak-times and time-shifts are optional. They are not a major concern in WINNER, but optimisation algorithms should be able to consider them.

(6) Access to events from car-sharing booking systems as well as the possibility to gain information on vehicle availabilities must be provided, e.g., in the case of few remaining energy within the car to prevent bookings at the moment.

(7) Data bus within the residential area is required to capture measurements from various data sources and required devices.

Putting together the objectives, the problems and the requirements result in Fig. 4. This figure visualises all discussed devices (EV, PV, charging infrastructure, car-sharing and residents as well as public installations). Furthermore, this figure shows additional elements measuring the current state of devices (Clamps, e.g., Rogowski coils, and Signal Converter) and their connections. The dashed line describes the local power grid; the dashed and dotted line describes the local network connections; the straight line represents the data streams. Additionally, this figure shows analogue connections as well as unspecified connections between

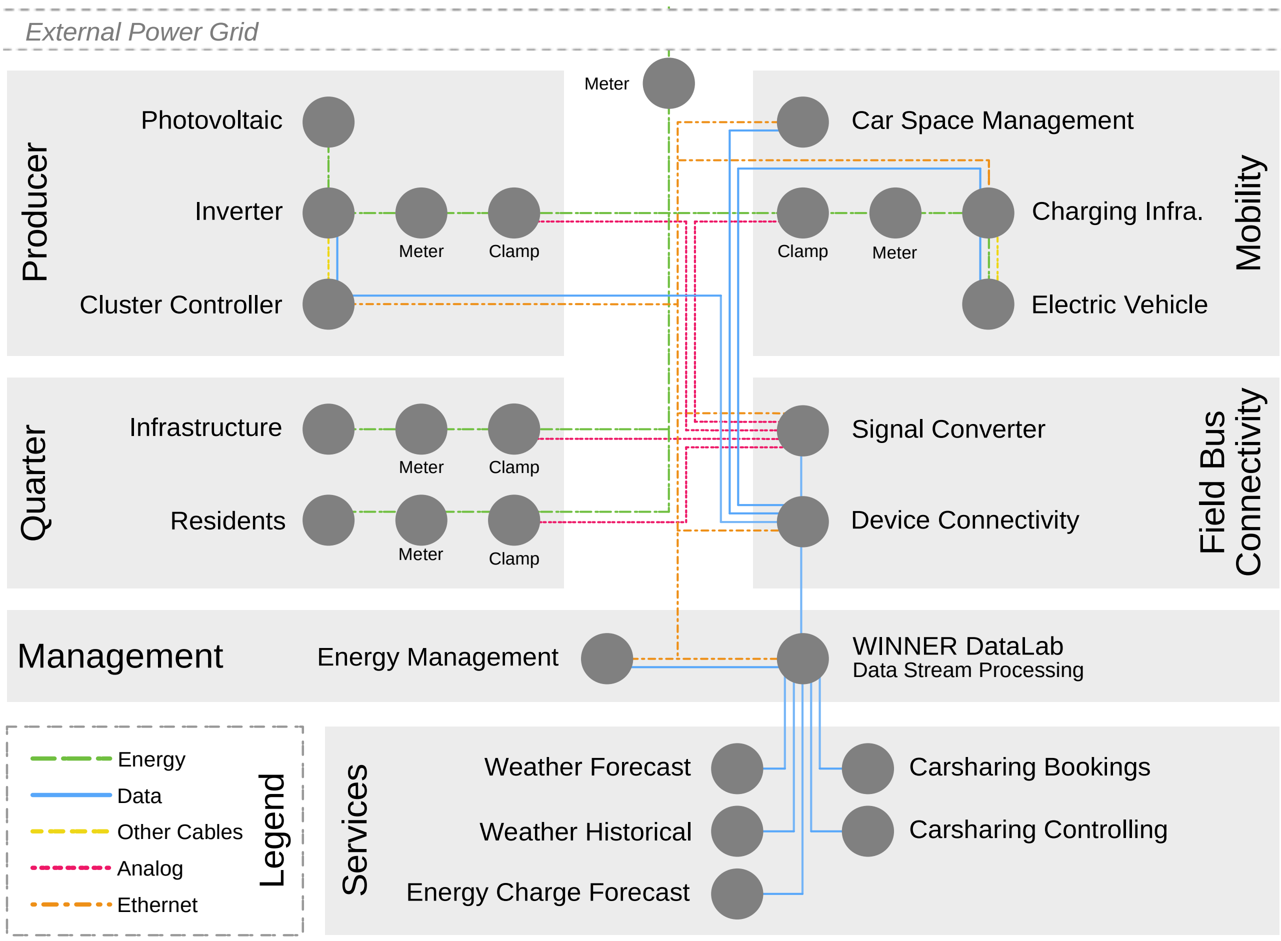

Fig. 4 Abstract WINNER system overview visualizes main devices and its energy, network and data connections.

devices, labelled with "Other Cables". Finally, this setup requires a computational unit to handle local device connectivity tasks as well as a data stream processing component and an energy management component for further gathering, analysis, forecasts, and optimisations.

4. Comparison and Classification

The first step is to classify our tasks using the SGAM framework to get a comparison base. Referring to Fig. 1, we can state that our position lays in the corner of customer premise and process. On the one hand, electricity is produced locally and not distributed in broad areas. On the other hand, we do not focus the zones of market or enterprises, but the consuming and producing processes. Watching the interoperability dimension, we have to work with protocols, data models, and subfunctions. So, we cover nearly any layer of the SGAM framework, and we are not able to state clearly, what we are doing within this context.

Another way of description is used by Ref. [12], which classifies different layers within grids. Unfortunately, a layer within buildings and households is missing and added by us. Watching Fig. 5, we can state, that WINNER covers the Levels 7, 8 and 9. Out of that, we do not expect devices to communicate using standard protocols. E.g., Level 7 (Fig. 5) shows electric vehicles and their charging infrastructure as well as PV systems. Each of them uses a particular protocol and a specific communication technology, e.g., the SMA (System, Mess- und Anlagentechnik) (German solar energy equipment supplier) protocol for PV systems or OCPP (open charge point protocol) for charging infrastructure. We collect information within the local network and control devices, if possible.

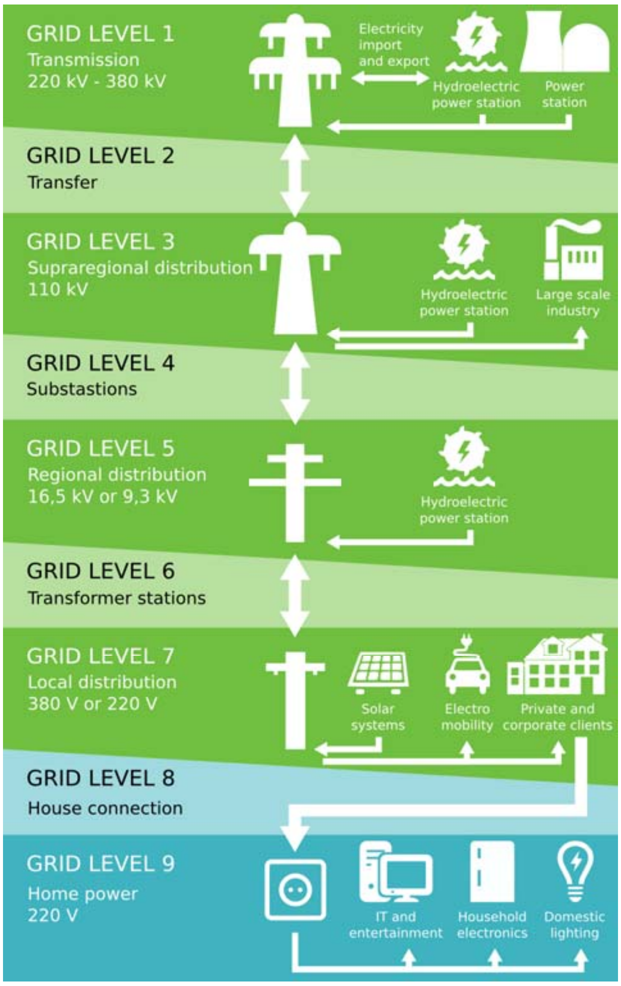

Fig. 5 Grid levels (based on Ref. [12]).

Using this layer visualization, EEBUS [7] covers the ninth level in our opinion. There are possibilities to add data structures, so that other levels may touch, but this is not the central fact of EEBUS. The OpenADR project [6] represents a technology stack reaching grid Level 9 and the above ones. The communication between home device and electricity provider is a primary goal. Out of that, requests for energy can be made. Finally, none of the formerly mentioned technologies suits our needs. EEBUS [7] requires access to all devices, but we are not able to reach all of them. OpenADR [6] is a technology developed to enable the communication between provider and consumer, what does not fit to our requirements too.

5. WINNER DataLab

OpenADR and EEBus do not focus precisely on the objectives of WINNER and mainly describe data structure and communication protocols. Within WINNER all components should remain in their state. If a device can communicate through OpenADR or EEBus like protocols, then we need to integrate them. However, if they do not provide suchlike protocols, we need to integrate them as well.

The WDL has to be an integration platform which has to manage a heterogenous landscape of components, which produces real-time measurement values, consumes forecasts from external services and provides optimised operating schedules for devices.

According to the objectives of the WINNER project in general and the system overview in detail, some requirements can be concluded. These refer to the core component, the WDL, itself. Out of that, we developed a concept for the core components of our WDL. This section describes the process starting with the requirements, followed by a matching concept.

5.1 Requirements

Before creating the architectural concept, we need to outline requirements the WDL has to take into consideration.

(1) Functional aspects: Some general requirements are referring to the whole system. Components like interfaces and services within the WDL require broadcastor to listen for particular events. Furthermore, some events have to be provided for external devices, e.g., about upcoming control tasks. Out of that, a monitoring interface providing the system status is needed. We have to monitor the WDL and the peripheral systems, i.e., the interfaces connected to them, to ensure orderly and correct operations of the system. Because of the integration of external services, there must be a mechanism to store credentials in case of required authentications safely. It has to suit the needs of the WDL and the available protocols provided by external systems.

A more specific aspect covers the data structures. Possible data sources, derived from Section III, are PV installations, power consumption measurement devices or actual weather data. Thinking of them shows that the ability to process time series data is required. Out of that, the system must handle forecast data as well, e.g., weather and energy market forecasts. Finally, another group of information, which has to be handled, covers master data without time dependencies. Booking information or general data on devices and services belong to this group. This data may be very unstructured like text-only entries.

Corresponding to various data structures, we have to pay attention to different data formats each component may provide. Focusing on technical details, the WDL needs to be able to process JSON (JavaScript Object Notation), XML (Extensible Markup Language) or other well-known formats. Further, specific serial data streams are also possible.

Keeping the interfaces in mind, one has to think of the necessary contact points to other services or the environment in general. The interfaces of the WDL have to accept and send HTTP requests, especially while communicating with REST (representational state transfer) services. Similarly, FTP (file transfer protocol) servers must be communicated with. The WDL must receive and process e-mails as well. Likewise, a file-based data transfer is needed. Finally, there are interfaces to external services using proprietary communication formats transported via TCP (transmission control protocol) or UDP (user datagram protocol). The system to be developed has to be able to receive this kind of messages. Besides, the message producing components of the WDL primarily need to communicate via HTTP. Particularly, the interface to a database can be made up of REST client services sending HTTP-based messages.

After paying attention to input and output components, the internal processes of routing and filtering shall be characterised. Asynchronous processing describes the most important requirement. Message queues or small buffer databases may decouple various components, so they can work without waiting for each other to terminate. All incoming messages caused by occurring events have to be converted into an internal format. To achieve this, the WDL has to transform and extend these messages into internal data packages with typical structure and additional information. Further, after information processing and right before providing information for external services, unneeded contents must be removed, and data packages have to be transformed into external data formats as well. Alongside, external descriptors have to be mapped to internal descriptors and vice versa.

The WDL itself does not need a graphical user interface for managing data stored in databases or data streams. We do not focus on a visualisation in the WDL.

(2) Non-Functional aspects: Central non-functional requirements are maintainability, scalability, and reliability. The latter refers to interfaces receiving data from external services and devices. On occurring errors incoming and shortly arrived messages should not get lost. Keeping this in mind, we can conclude that the data storage must be redundant. The loss of data is not acceptable.

Another aspect refers to security, e.g., the use of transport protocols like FTP without using TLS (transport layer security) should be avoided. But this approach can only be used if the peripheral systems support the necessary protocols, so these options and decisions depend on the external services which have to be integrated.

5.2 Concept

WDL has to integrate various inputs and provide information for a wide range of outputs. Based on our requirements we have decided to use the micro-service architecture and utilize enterprise integration pattern EIP for each component within the WDL. An overview of this architecture is shown in Fig. 6. This figure indicates already mentioned inputs on the left side and outlines required interface implementations to integrate each input. Further, the processing and routing of messages between interfaces and services are shown.

(1) Inputs: As shown in Fig. 6, the WDL has to integrate interfaces for incoming data and services providing information to external systems. These peripheral components should be described at first. We target the coordinated charging processes of EVs, so we have to integrate status and booking information of the car-sharing service platform. The booking data refers to the availability of cars at a specific station and the beginning or end of a booking period. In contrary, status issues apply to a single booking. Maybe there is a modification of start time or an EV breaks down. This information needs to be gathered as well.

The term of “Device Connectivity” (Fig. 6) summarises the values of actual electricity consumption within the tenant households. There are classic electric meters and other digital measurement devices, e.g., the interfaces of charging units or insolation.

The “Energy Charge Forecast” watches prices of electricity to manage the supply. So, the WDL integrates forecasts of price data referring to the actual and the following day.

The prognosis of energy production requires information on the weather. These data are gathered from web services like “OpenWeatherMap” [13] and “Deutscher Wetterdienst” [14], which provides a weather forecast for a requested geographical region and period.

(2) Outputs: Fig. 6 shows various information targets on the right side. There is an interface connected to a charging infrastructure which controls the charging process of EVs.

Out of that, all occurring data are collected within a database. We distinguish runtime data and master data. The runtime data describe measurements in time series as well as forecasts. The master data are used to store metadata for each installation and documents, e.g., booking information.

(3) Internal components: The data sources on the left (Fig. 6) provide information, which is collected by internal interfaces. This transfer of information is based on messages, which are requested or received (pull or push). The messages get enriched with additional information, e.g., identification numbers. Out of that, the transformation to an internal format is enforced.

Within the WDL information is distributed by data streams and asynchronous message queues as well as loosely coupled services. Thus, every component can work independently of the others.

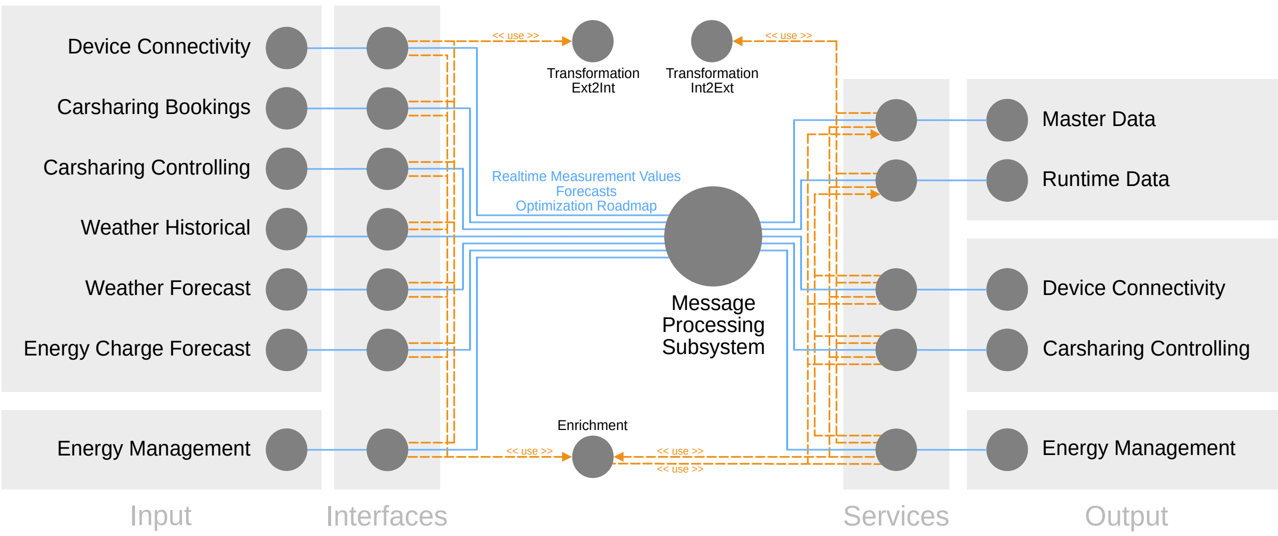

Fig. 6 Level 1 view of WDL.

6. Discussion

At this moment all listed requirements are quite generic. We can only name a few interface specifications in detail. So, the shown system design is at a very high abstraction level.

Nevertheless, some aspects can be discussed. The provided architectural design for the WINNER DataLab implicates technological software challenges. Some left open questions cannot be answered in before, such as:

- How easily can new external systems or internal components be integrated?
- Can a proprietary communication protocol be implemented and integrated well into the systems technical design?
- Are there some new standard protocols, e.g., out of the Internet of Things domain, we have missed at the moment, and how do these protocols fit into our architecture?

A decisive aspect in architectural design is the requirement of implementing the WDL in a loosely coupled way so that the components can work independently of each other. This requirement is quite common in distributed environments and systems, but it results in technically more complex implementations.

While loosely coupled components are not interfering each other that much while working, systems overall latencies and inner delays will be increased. Currently, there are no time limits within our WINNER system requirements. Thus, no maximal round-trip delays have been set or refresh rates for forecast updates are specified. We will have to clarify this and keep an eye on our system's behaviour.

The system's behaviour will also be much influenced by the update and refresh rates of each source or sink. E.g., if we use a very high refresh rate at some interface, which has to be polled, we would stress the polled system as well as ours even if there is no change to the processed data. On the other side, if we choose a lower refresh rate to reduce systems load, we might miss some state changes. The optimal balance of refresh rates has to be figured out interface by interface.

Beside these overall and external questions, each described inner component has to be refined to clarify its internal structure. At the same time, the WDL internal interfaces have to be specified in detail.

7. Conclusion

This paper illustrates the architectural design of our main data processing component WDL. This design was created based on functional and non-functional requirements, which were derived from the primary technical objectives of our research project WINNER. Out of that, we classified our approach and related research using a grid hierarchy. The need for further research referring to the local smart grid could be shown in this way. The unique characteristics of WINNER were outlined as well. EVs are included as well as electrical devices as they are without adding further communication technology etc. Our next steps are the refinement of this architecture and, afterward, the implementation of main aspects of the WDL. This will be done in an iterative process. However, we have to re-evaluate our architectural design in an ongoing process within the development as well as productive operation. Further, we have to countercheck that the shown requirements and the derived system design will hold the real-world requirements.

Acknowledgements

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