A Proposal for an Integrated Smart Home Service Platform

Robert Wehlitz[1], Theo Zschörnig[1] and Bogdan Franczyk[2,3]
[1]Institute for Applied Informatics (InfAI), Goerdelerring 9, 04109 Leipzig, Germany
[2]Information Systems Institute, Leipzig University, Grimmaische Str. 12, 04109 Leipzig, Germany
[3]Business Informatics Institute, Wrocław University of Economics, ul. Komandorska 118-120, 53-345 Wrocław, Poland

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Abstract: The growing popularity of Internet-connected smart devices in consumers' homes has led to a steady increase in the number of smart homes worldwide. In order to provide meaningful added value for consumers and businesses alike, smart devices need to be accompanied by services and applications which excel conventional devices' usages. However, integrated solutions to support the development and operation of smart home services for, and across, different devices and application scenarios are still missing in research as well as in industry. In this paper, we present the motivation, requirements and an initial concept for a fully integrated smart home service platform (SHSP), which may serve as a basis for further discussion.

1 INTRODUCTION

The number of Internet-connected smart devices equipped with sensors, actuators or tags is rapidly increasing (IHS Markit, 2018). It is estimated that worldwide about 136.4 million households will have smart devices in 2019 (Statista, 2018) and can therefore be referred to as smart homes. According to Aldrich (2003), "A 'smart home' can be defined as a residence equipped with computing and information technology which anticipates and responds to the needs of the occupants […]". The latter part of the citation refers to context awareness as a system property for enabling adaptive smart homes without explicit user interaction (Han and Lim, 2010). To accomplish this, the basic sensing and actuation capabilities of different smart devices have to be utilized in a way that allows for the creation of more intelligent smart home services and applications (Eom et al., 2013).

The smart home market in general offers great potential for both, businesses and customers. Traditional energy companies, for example, have the possibility to become smart home service providers, and thus open new sources of income. Moreover, the satisfaction and loyalty of energy customers can be improved by offering smart home services which, in addition to the provision of energy, yield added value. Therefore, customers may benefit in many different application scenarios, such as home energy management, entertainment, healthcare, security and comfort (Alaa et al., 2017).

However, an integrated platform that supports the development and operation of context-aware smart home services for, and across, different devices and application scenarios is still missing (Stojkoska and Trivodaliev, 2017).

Against this background, the main contribution of this paper is an initial concept for a fully integrated smart home service platform (SHSP) that aims to fill this gap. Our objective is to share and discuss first ideas with the scientific community and to present an initial overview of the platform architecture.

The remainder of this paper is organised as follows. First, we describe the motivation for our research (Sect. 2). We then discuss related work in this field (Sect. 3) and outline the requirements for our proposed platform solution (Sect. 4). Afterwards, we introduce our initial SHSP concept and describe its main components as well as their interactions (Sect. 5). Finally, the paper concludes with a short summary and outlook (Sect. 6).

2 MOTIVATION

In a nutshell, the Internet of Things (IoT) consists of heterogeneous smart devices that are capable of communicating with one another over the Internet (Han et al., 2016). However, smart devices, in

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comparison to conventional devices, do not offer added value to customers if the possibilities of their sensing and actuation capabilities are not fully exploited. Therefore, more intelligent services which are built on the aforementioned capabilities are required in order to create customer value around products like smart meters, smart lights, smart locks, etc. (Eom et al., 2013).

With regard to the smart home market, there are many devices available which produce data about their surroundings (e.g. brightness, motion, humidity, etc.) and some of them also enable the remote or automated control of actuators, e.g. smart thermostats for changing the room temperature (Bing et al., 2011).

However, most of these smart devices are proprietary solutions that have no or just little interoperability with other products (Gajewski et al., 2017). In consequence, they can usually only be used with the web or mobile applications of the respective vendor. This leads to lock-in effects and complicates the development of smart home services (Eom et al., 2013). Furthermore, current smart home solutions only allow for home automation based on predefined rules, requiring users to configure smart home services manually with regard to their individual needs and preferences (Xu et al., 2016). This contradicts with the statement in Sect. 1 that a smart home should be able to learn from the behaviour of its inhabitants in order to respond to their needs.

In this context, we see an integrated SHSP as an important building block to provide the infrastructure and software tools necessary to develop, offer and run context-aware services for, and across, different smart devices and application scenarios in adaptive smart home environments.

3 RELATED WORK

In scientific literature, publications dealing with service platforms dedicated to smart home environments are rare and they often focus primarily on security aspects (e.g. Gajewski et al., 2017; Fernandes et al., 2016) or specific application scenarios, such as energy management. Han and Lim (2010), for example, make a proposal for a smart home energy management system based on ZigBee networks. It relies on a sensing infrastructure for receiving and storing sensor data, an information extractor for converting sensor data into context information (e.g. the current location based on geodata) and a service extract engine for context reasoning. However, their concept addresses the context-based invocation of smart home services rather than real context-aware services. Al-Ali et al., (2017) also propose a smart home energy management system and combine IoT technologies, big data analytics as well as business intelligence tools in order to reduce energy consumption in households. Following the business intelligence approach, they primarily focus on data visualisation and reporting functions, also not addressing context-aware smart home services.

Additionally, there are also publications that deal with concepts for application-independent smart home solutions. Gu et al., (2011), for example, present the design of a cloud-based smart home platform that uses an intelligent gateway for protocol conversion and the abstraction of smart home networks, thus enabling inter-device communication. Ye and Huang (2011) propose a general framework for cloud-based smart homes and describe possible application scenarios. Bing et al., (2011) present a smart home system architecture that consists of a sensing and actuator layer, a gateway-based network layer and an application layer running on a remote management platform. Eom et al., (2013) describe a framework for an integrated platform which includes middleware functionality as well as data storage and ingestion capabilities in order to provide smart home services with real-time data processing on cloud platforms. Li et al. (2013) introduce a smart home service framework based on event matching. It consists of an IoT, data, event and service layer. The IoT layer uses a gateway to receive smart device data. The data layer stores and processes real-time sensor data. The event layer identifies and matches events based on data received from the data layer and invokes services accordingly.

In summary, the aforementioned approaches are primarily cloud-based, rely on gateway topologies and provide some sort of middleware functionality. They often allow for data processing as well as visualisation, the remote control of smart devices or simple home automation based on explicit user configuration. However, almost all of them lack advanced analytics capabilities and an integrated concept for the development and operation of real context-aware smart home services.

4 PLATFORM REQUIREMENTS

In this section, we describe the requirements for an integrated SHSP. These are partly derived from the previous work on general requirements for IoT platforms by Wehlitz et al., (2017) and extended using the results of workshops and expert interviews with stakeholders of the energy industry. The requirements are divided into functional and non-functional requirements. The functional ones are:

- **Interoperability:** Different hardware, operating systems, service interfaces, message protocols and data formats have led to a far-reaching heterogeneity in the IoT and smart home domain (Issarny et al., 2011). Hence, the SHSP is to provide appropriate means to simplify device integration and inter-device communication in order to overcome this heterogeneity (Wehlitz et al., 2017).
- **Event Detection and Insight Generation:** The full potential of smart device data is not yet exploited. Therefore, the SHSP is to provide the required infrastructure and powerful tools to identify events in data streams as well as to process and analyse real-time data. The main objective is to automatically generate insights that benefits users in many application scenarios.
- **Context-aware Device Control:** Current smart home solutions often only allow for the rule-based scheduling of device control tasks. In contrast, the SHSP is to orchestrate sensing and actuation services as well as advanced analytics services for an automated and context-aware control of smart devices (Wehlitz et al., 2017).
- **Cloud- and Fog-based Deployment:** Cloud-based smart home systems predominate the market. In the context of the SHSP, smart home services are to be deployed and run either in the cloud or on devices in the proximity of the users. Which option is selected depends on the respective application scenario, external regulations, user preferences or locally available computing resources.
- **Service Publication:** The SHSP is to offer various capabilities to publish user-generated artefacts. Both, customers and businesses, are to be enabled to share smart home services with other platform users. This aims to reach a critical mass of platform users faster, foster innovation based on previous work and to allow for new business models in the smart home domain (Wehlitz et al., 2017).

The non-functional requirements are:

- **Usability:** The SHSP is to provide suitable user interfaces in order to increase the acceptance of developers and users. In general, it is to be designed for making the development of smart home services more accessible to non-technical audiences.
- **Scalability:** The number of platform users and integrated smart devices as well as the amount of sensor data to be processed may vary from small to very large, depending on the application scenario. Hence, the architecture of the SHSP is to be flexible and scalable in order to meet the performance requirements of many different smart home applications (Wehlitz et al., 2017).
- **Privacy and Security:** Smart homes produce massive amounts of personal data. These as well as the control functions of smart devices need to be protected against unauthorized access and misuse. In this context, the SHSP is to enable data owners to define fine-grained security restrictions. This implies that users can decide which data is accessible by services, applications or other platform users (Wehlitz et al., 2017).

5 PROPOSAL

In this section, we introduce our initial concept for an integrated SHSP that was designed to meet the requirements we defined in Sect. 4. A schematic overview of it is given in Figure 1. The main components of the concept are: hybrid platform architecture, middleware, streaming analytics and machine learning, context-aware business processes, marketplace, and identity and access management. Following, we describe them and their interactions.

5.1 Hybrid Platform Architecture

The SHSP aims to deploy and run smart home services both, centrally in a data centre and decentrally in the proximity to the users.

The centralised approach addresses the cloud computing paradigm, in which local data is transferred via the Internet to a cloud platform for further processing by cloud services. Cloud computing has established itself as a disruptive concept for the scalable provision of IT resources (storage, network, computing power, etc.) over the Internet without having to operate and maintain them locally. However, this concept requires a high degree of robustness and availability of cloud platforms, a reliable Internet connection and a high level of user trust in cloud providers in terms of privacy and security.

The decentralised approach addresses the fog computing paradigm which extends cloud computing by making computing resources (fog nodes) available at different hierarchical levels between the cloud and end devices. The main idea of fog computing is to

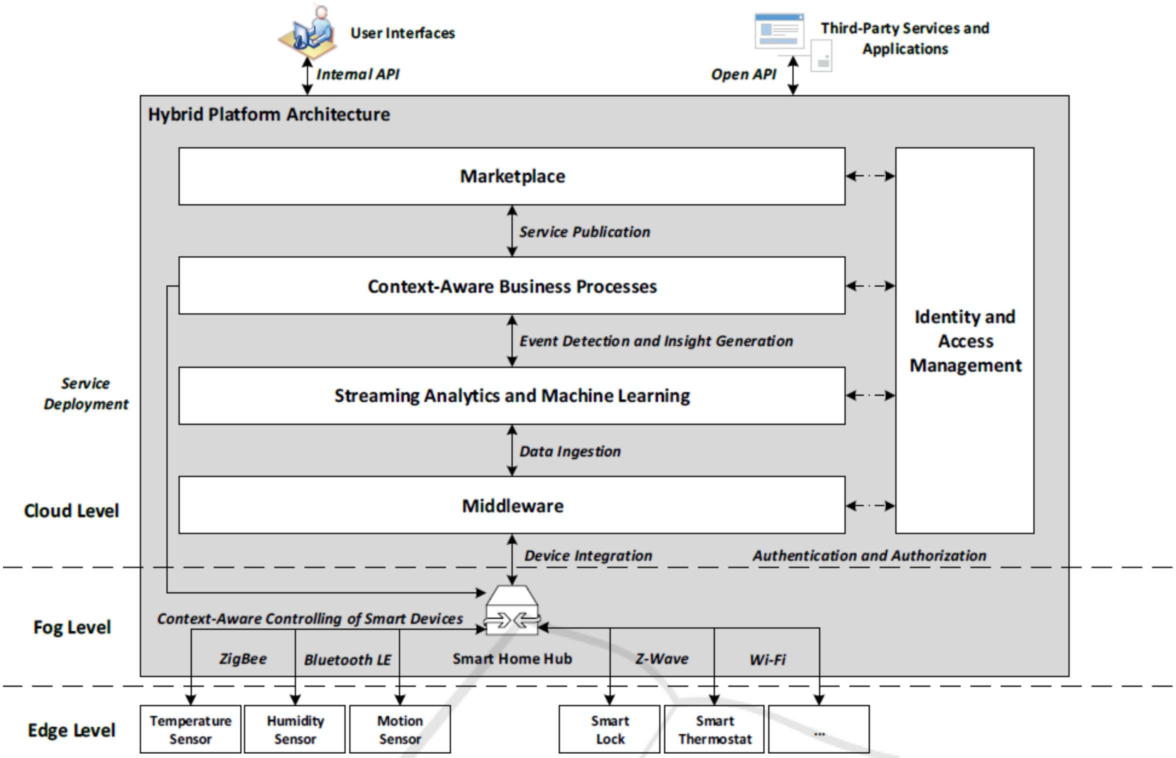

Figure 1: Overview of the SHSP concept.

move data processing closer to the "edge of the network". According to (Byers, 2017), this may result in significant benefits such as higher degree of data privacy and security, lower latency and network traffic, as well as greater fault-tolerance, which are important requirements in certain application scenarios, e.g. healthcare or home security. However, smart devices often prove to have limited computing resources, making them unsuitable for more complex computing tasks. Further challenges in the field of fog computing include, among others, the design of suitable interfaces for the provision of services on distributed IT resources as well as the deployment and synchronisation of cloud- and fog-based operations (Shanhe et al., 2015).

Against this background, our SHSP concept flexibly combines the advantages of both, cloud computing and fog computing, within a hybrid platform architecture.

5.2 Middleware

The middleware manages the registration and administration of smart devices as well as the communication between the fog and the cloud level of the SHSP architecture. In the context of smart home, smart devices are often connected to local smart home hubs or gateways which provide higher-level interfaces for accessing sensing and actuation services (Stojkoska and Trivodaliev, 2017). The middleware acts as the central point of integration for smart home hubs and uses a data abstraction model to handle heterogenous data streams. It translates incoming messages (e.g. sensor data) into a unified platform-internal message format and makes the data available to the streaming analytics and machine learning component. The middleware also retranslates outgoing messages (e.g. control commands to smart devices) into device-specific requests that are handled by smart home hubs.

In addition to ensuring the aforementioned syntactic interoperability between smart devices, the middleware also supports their semantic integration. This includes the enrichment of smart device data with metadata which allows to automatically deduce their meaning. In order to achieve this, suitable description languages (e.g. RDF), efficient storage solutions (e.g. Triplestore) and query languages (e.g. SPARQL) are used. Due to the linking of semantic aspects, ontologies as representations of knowledge are created and context information based on them can be inferenced. Hereby, the management, processing and analysis of data, as well as the context-aware control of smart devices are to be supported.

5.3 Streaming Analytics and Machine Learning

In smart home application scenarios, data usually arrives in data streams and is characterized as time series data, thus creating the need for real-time processing (Pawar and Attar, 2016). While the batch processing of historical data combined with the application of prediction models on this data is already established, real-time processing of smart device data, while enabling the detection of causable relationships between the devices themselves and their surroundings, is not. Nonetheless, this is the basis for the autonomous adaption to new situations (Stolpe et al., 2016).

Regarding the SHSP, the application of streaming analytics and machine learning technologies is the basis for developing context-aware smart home services. Hence, it is to provide the infrastructure and tools for sophisticated data manipulation, efficient persistence, event processing functionalities and the process of insight generation. The SHSP aims to enable predictive and prescriptive analytics based on machine learning so that the value of information gained from historical or real-time data is increased and thus also the benefits for smart home users. Furthermore, tools for the automated configuration of smart home services with regard to individual customer needs and preferences are to be provided.

Considering the technical implementation, we propose an approach based on the Kappa architectural concept at the cloud level extended by the fog computing paradigm, thus offering data processing close to the source of data. Streaming analytics and machine learning capabilities are encapsulated by so-called analytics operators. These represent microservices which, as single processing steps, can be combined to analytics pipelines in order to solve more complex analytics tasks. Analytics pipelines are designed by power users with a background in data science via a graphical composition tool and their results can be accessed by context-aware business processes. In order to achieve this, a key aspect of the streaming analytics and machine learning component is the orchestration of analytics operators in the overall platform architecture. Since the processing of smart home data may be subject to different external regulations and conditions (Byers 2017; Mouradian et al., 2018), it is necessary to only allow for analytics operator deployment at the fog or cloud level if predefined deployment rules are met. These rules, for example, could be based on hardware constraints at the fog level and compliance regulations for the cloud level.

5.4 Context-aware Business Processes

Within the SHSP concept, the service logic of smart home services is defined by the notion of business processes. Business processes primarily include tasks, events and decisions by which sensing and actuation services as well as services for accessing analytics pipelines are being orchestrated. The SHSP is to enable the modelling, implementation, execution and monitoring of context-aware business processes. Based on the results provided by analytics pipelines, the control flow of business processes can be affected at runtime, thus allowing them to adapt to new situations. The modelling of business processes provides the basis for the composition, reuse and sharing of smart home services as well as their instantiation for different smart home environments and application scenarios. Additionally, there are numerous tools by which they can be modelled graphically making the development of them more accessible to non-technical audiences. Regarding the deployment of context-aware business processes, the SHSP allows for both, running them at cloud as well as at fog level. Moreover, an application programming interface is provided which supports the development of third-party applications, e.g. dashboards or mobile applications.

5.5 Marketplace

The major feature of the marketplace is to allow platform users (customers and businesses) of the SHSP to easily share and subscribe to user-generated artefacts which include data, analytics operators and pipelines, as well as business process models. In this regard, users may decide if their artefacts are published directly on the marketplace or only be shared with single users or user groups. This is to render the platform attractive to developers and to foster innovative smart home services as a result of reusing and adapting already existing components. Furthermore, the marketplace has the potential to encourage new innovative business models in the smart home domain.

5.6 Identity and Access Management

The identity and access management system are an important building block for registering smart devices and managing platform users and access rights across the different levels of the platform architecture. They govern the authentication and authorization of users and enable fine-grained access control for smart devices, data, analytics as well as context-aware business processes. In this context, the identity and access management system can also be seen as the basis for publishing smart home services on the marketplace or sharing them with other platform users.

6 CONCLUSIONS

In this paper, the motivation, requirements and initial concept for an integrated SHSP, which offers tools to develop and run context-aware smart home services are presented. The concept is based on a hybrid platform architecture extending cloud computing with the fog computing paradigm. A middleware ensures the syntactic and semantic interoperability of smart devices. Streaming analytics and machine learning capabilities in the form of analytics operators and pipelines are used to provide meaningful insights into smart device data. The service logic of smart home services is defined by the means of context-aware business processes, whereby the SHSP provides tools for their modelling, implementation, execution and monitoring. A marketplace offers the possibility to share user-generated artefacts. The definition and application of fine-grained access control policies to preserve privacy and security is enabled by the identity and access management system.

In the near future, the individual areas of the SHSP need to be investigated deeper in terms of their detailed design and technical implementation as well as focusing on the interaction between them. It is essential that all subsystems of the platform are designed in such a manner that it is easy to use also for non-technical audiences. Finally, the proposed hybrid platform architecture approach needs to be investigated further and, if feasible, evaluated in terms of performance compared to similar approaches.

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