User Created Machine-readable Policies for Energy Efficiency in Smart Homes

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Abstract

The project SESAME[1] utilizes smart metering, building automation and policy-based reasoning to support home owners and building managers in saving energy and in optimizing their energy costs while maintaining their preferred quality of living. In this paper, we present how user-created policies are being applied to develop a system of least interference that supports the user in gaining awareness about energy consumption habits and saving potentials. Proposed concepts are currently being implemented and validated in an extensible demonstrator platform which provides a proof-of-concept for an innovative technical solution.

Keywords

Smart Metering, Building Automation, Energy Efficiency, Sensor Networks, Ontologies, Policy Based Reasoning, Knowledge Capture, Knowledge Management.

[1] http://sesame.ftw.at

ACM Classification Keywords

H.4.4 [**Information Systems**]: Information Systems Application.

General Terms

Semantics.

Introduction

The SESAME project uses ontology-based modeling and rule-based reasoning to address challenges beyond the smart home control [1, 2], focusing on the new types of interactions between the user domain and the stakeholders in the deregulated energy market, a topic which receives increasing interest at the EU level[2,3]. To realize energy-efficient smart home that has the ability to interact with the external information and control systems of energy suppliers, AMI information providers, etc., SESAME approach is strongly based on rule-based reasoning and service-oriented architecture.

Services within the SESAME framework provide different functionality at different interfaces as illustrated in Figure 1.

For example, the smart-meter data is published by the smart metering provider through an external SOAP-based Web service. On the SESAME system side the Web service client invokes this service and updates the knowledge base. Sensors, appliances and displays are implemented as service-based information publishers and consumers with published service interfaces. Each service interface implements a notification passing capability. This is true also for the service-based interaction between the user and the energy providers or grid operators.

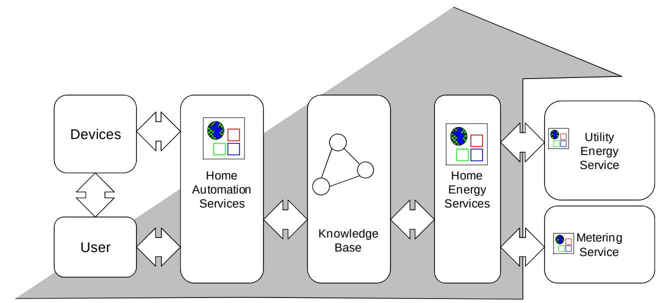

Figure 1. SESAME Service Architecture

The SESAME ontology model [3] is the core of the knowledge base, which is an RDF store that hosts the instances of the model, and is populated with real data from different information sources, e.g., sensors, appliances, the user profile, energy supplier profile, etc.

The ontology is also the basis for the creation of rules. For the implementation of the knowledge base we use the Jena, JESS and Pellet frameworks.

In the SESAME concept, the ontology model of the environment is complemented with the system-level user specific policies. System-level policies define different lower-level *situations* and related *actions.* For example a system-level rule may specify threshold values for a specific sensor and states that a specific appliance is to be switched on if the sensor reading is *less than or equal* to the threshold value. We assume that system-level rules would be created by a "power user" well acquainted with the semantics of the devices and activities, or they may automatically come with the devices installed in the environment. In the SESAME project, for the creation of such rules we integrated a

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[2] EU FP7 Project Intelligent Self-describing Technical and Environmental Networks (S-TEN www.s-ten.eu).

[3] EU FP7 ProjectSmartHouse/SmartGrid (SHSG)3. www.smarthouse-smartgrid.eu.

general domain tool [4]. System level policies are described in more details in the coming sections.

By customizing the system-level policies, users can further specify their preferences. Creation of such user specific policies will happen at the system installation time or occasionally after the system feedback to the user, so the user can adjust his/her preferences.

In order to understand the potentials for energy saving, and how to provide the best support to the user to create policies, we conducted a diary experiment presented in the following section.

The Diary Experiment

To gain an insight into behavioral patterns within the home, four in-depth interviews were conducted with two men and two women living in individual households. The sample was not meant to be in any way representative for a certain kind of cohort, social class or target group, but was intended to identify occupancy patterns, device types and their corresponding usage. Therefore, two time frames have been analyzed. The interviewees were asked to describe in detail their appliance usage during morning time from getting up to leaving for work – a time frame which is in so far crucial, as morning hours generate peak loads at the energy providers' side. Additionally, participants were asked to describe a typical week in their lives which was necessary to capture occupancy and sleeping patterns during workdays and weekends.

From this information we modeled a normalized seven day period in a single resident household representing the devices in use, occupancy and sleeping patterns. The average energy consumption per device-type was calculated and differentiated by active and passive use. By applying tariff schemes from the Austrian Energy Exchange[4] we also calculated the average energy costs for a single household per day and per week. These calculations were crucial as simple scenarios showed that a change in behavior might lead to a reduction of energy consumption, but not necessarily to a cost reduction and vice versa if the prices of the energy market would be used by the end customer. These effects have to be observed closely as cost-efficiency and energy-efficiency do not necessarily correlate positively.

System-level Policies

Using the findings of the diary experiment, we investigated in creating system-level polices that are directed towards achieving the goal of reducing the costs and overall carbon footprint of the user without compromising on his/her standard of living. These can be described under following broad categories: (i) tariff dependent policies, (ii) device dependent policies, and (iii) threshold dependent policies. This classification is not exhaustive, and there are some additional policies that we define which do not lie in the scope of this classification.

Tariff dependent policies

Tariff dependent policies take into account the information on various current and future pricing schemes published by utilities and available to the system through its smart meter. A schedulable device, for example, may be configured by a policy to operate during low tariff periods of the day.

[4] http://www.exaa.at/

Device dependent policies

Device-dependent policies distinguish between certain device types based on technical specificities and user behavior. These can be categorized as (i) permanent devices, which should never be turned off e.g. a fridge, (ii) stand-by devices, which can be turned off, when nobody is at home or everybody is asleep e.g. TV set, and (iii) ad-hoc devices, which are needed spontaneously e.g. lights. These device specific policies take into account special characteristics of individual devices that can be harnessed in a way to achieve user goals of convenience, cost reduction and reduction of greenhouse emissions. For example, a stand-by device may be turned off by a policy after 15 minutes of staying idle.

Threshold dependent policies

These policies are based primarily on the limits put on certain environmental conditions in and around the location where the appliances are installed. While on one hand they provide a better user experience by enforcing the most preferred environmental conditions to the user, on the other, they ensure optimal use of energy resources by the appliances. For example, a heater could automatically switch on by applying a policy if temperature falls below 18°C.

User Interaction

To obtain user preferences during the initial setup of the system, the users will be guided through a set of questions streamlined with the policy types described above. The aim is to collect primarily behavioral and device-specific information, as well as information on preferences concerning room climate, tariffs and energy types. Typical question sets could be divided under the following categories which again do not necessarily represent an exhaustive classification of possible questions:

Behavioral questions

Queries seeking policy related information about normal user behavior fall under this category. Such questions would seek information like (i) the user's waking up times on weekdays, weekends, holidays, etc., (ii) times for going to bed, (iii) times for leaving and returning home from work on various days of the week, (iv) frequency of using dishwasher, washing machine, iron, cooking plates, etc.

Environment-related questions

These questions gather information about resident's choices with respect to various environmental conditions like (i) desired temperature limits (higher and lower) in various rooms for various seasons, (ii) desired humidity limits (higher and lower) in various rooms for various seasons, (iii) preferred lighting intensity in various locations, etc.

Tariff dependent questions

These questions gather information about resident's choices with respect to (i) preferred type of tariff by a) provider, b) pricing scheme, c) energy mix, and (ii) preferred type of energy: a) green energy b) cheap energy, etc.

Device specific questions

These questions gather information about resident's choices with respect to (i) inclusion of schedulable appliances under the intelligent planning by the system, (ii) predefined usage of certain devices while out of home or asleep (i.e. washing machine), (iii) order of preference of tools for cooling the bedroom , (iv) turn off time frame of standby devices after *x* minutes of being idle, etc.

The output of the questionnaire automatically maps into a set of partially predefined system-specific rules. The Policy Acquisition Tool (PAT) is a policy editor and engine that will assist a user in modifying the default policies generated and in creating new policies according to his/her own habits and preferences [4]. After the user feeds in his/her preferences via the questionnaire, the default policies of the system are instantiated and presented in the PAT editor enabling further modification and/or approval. The PAT tool is a web application with JSON based front end for policy construction, editing and saving and a backend reasoning based on the Python version of Euler reasoner. It uses the N3 native knowledge representation format.

Evaluation

The empirical modeling of usage patterns performed in the diary experiment lead to the conclusion that a policy based energy control could result in energy savings by simply applying automated turn-off rules to stand-by devices (saving up to 22%)[5] and ad-hoc devices alone when streamlined with the behavioral patterns of the user. But to fulfill the requirement of keeping up the resident's standard of living an "approach of least interference" with the normal user behavior has to be followed. This means that spontaneous changes in predefined settings (triggered by the user) should override policies in place and execute the desired action without delay or pervasive notification. In addition, regular reports shall help the resident to discover interdependencies between usage patterns, energy consumption and costs, so that future decisions can be made on an informed basis.

Estimation of the savings achieved in terms of cost and energy is the primary tool that evaluates the effectiveness of SESAME system. A simple formula for calculation of savings achieved by turning off the stand-by devices can be used:

$$S = \sum_{i=0}^{n} d_i \times (h_i - k_i), \text{ where}$$

S= savings in Euro (per day), i = index of the stand-by device, n = total number of stand-by devices in house, d_i = cost (in Euro) per hour consumed by device 'i' in standby mode, h_i = number of hours (per day) device 'i' normally stays in standby mode and k_i = number of hours (per day) device 'i' stays in standby mode after interference from the smart home. Similar formulae are used for estimating savings of individual policies that save energy by switching off unnecessary appliances.

To test these concepts in a controlled environment, an experimental prototype integrated within a box is created. As shown in Figure 2, it consists of some real devices, two temperature sensors, a movement sensor, two electric heaters, a switch, a plug and it has a capability to integrate simulated and real devices such as a washing machine, cooking plates, refrigerator, etc. An integrated smart meter collects real time data from these in the appropriate scale. System actions on various appliances pertaining to the default and user created policies are implemented through a central UCB controller. The UCB is a universal IP-based control box which acts as a central control device in connecting and controlling the operation of various devices.

[5] http://en.wikipedia.org/wiki/Standby_power

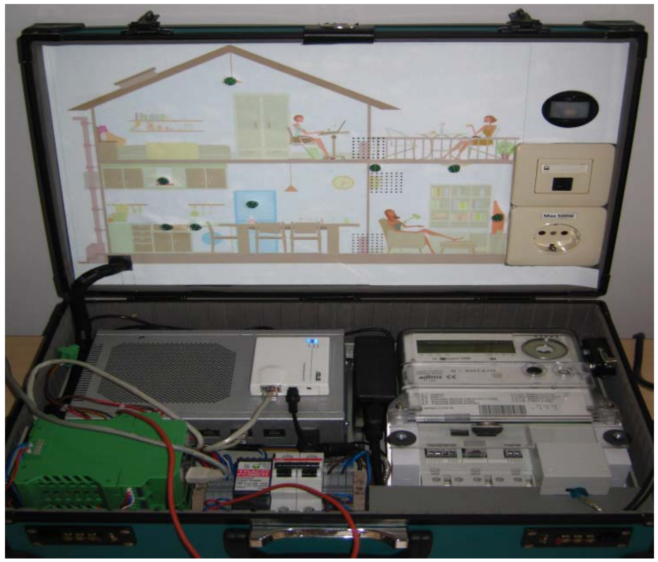

Figure 2. SESAME Demonstrator

Conclusion

The project SESAME uses semantic technology in creating a technical solution that integrates smart metering and demand management, building automation and policy-based reasoning and offers an energy-optimization capability for the energy consumer and provider. The information used is coming from sensors from multiple domains, including the physical sensors (e.g., temperature, light, presence) and the information sensors from the energy management domain services, or other sources, such as weather services, etc. This information is crucial in modeling user preferences and rules. In this paper, we discussed policies which users create to specify their preferences regarding the comfort of living and energy saving goals. These policies are created by customizing system-level rules and are used for reasoning in the SESAME system. Work is underway on assessing savings achieved by policies that attain their goal by different techniques including scheduling of appliances under a variable tariff regime. Special focus is also on user friendly enhancement to the current interface to help non-expert users in easily creating, modifying, deleting and saving their own policies.

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