SESAME Demonstrator: Ontologies, Services and Policies for Energy Efficiency

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ABSTRACT
The project SESAME uses semantic modeling and reasoning to support home owners and building managers in saving energy and in optimizing their energy costs while maintaining their preferred quality of living. We design a semantic layer for a technical solution that integrates smart metering, building automation and policy-based reasoning in order to offer an energy-optimization capability for the energy consumer and provider. Semantics plays a crucial role in binding information coming from the automation domain, energy management domain and in modeling user preferences and rules. Proposed concepts are implemented in an extensible demonstrator platform which provides a proof-of-concept for an innovative technical solution.

Categories and Subject Descriptors
H.4.4 [**Information Systems**]: Information Systems Application.

General Terms
Semantics.

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

1. INTRODUCTION
Climate change due to rising CO_2 emissions is one of the biggest environmental challenges of the 21st Century. Achieving 20% savings of energy consumption by 2020 through energy efficiency is one of the key measures to keep the CO_2 emissions under control. Systems for home and building automation can offer significant contribution to energy conservation - currently potential savings are estimated to 35%[1] - while also providing for an intrusion detection, pollution reduction and environment protection. The energy and cost saving potential of such systems could be further improved if automation actions could be made *energy-aware*, that is, aware of information such as consumption habits, power load, energy tariffs, etc. The smart (advanced) metering concept[2] (AMI) which is based on the new infrastructure of ubiquitously deployed energy meters, and devices that collect and process metering information, provides the basis for energy-awareness. In order to integrate a smart metering system with a building automation system, the requirements from two different domains need to be understood: (i) the customer domain, which hosts all the home appliances and devices and should be responsive to user needs and preferences, and (ii) the energy domain which is responsible to supply power to the user and define differing tariff models. According to the current practices the energy domain also includes the advanced energy meters which are under exclusive control of an external AMI operator. These two domains - the user domain and the energy domain - can interact in different ways. For example, the building automation system could receive metering data by subscribing to a remote AMI information provider (publisher), e.g., through a Web service. In the future, the energy suppliers may also offer dynamically changing energy-related information, such as tariff, to govern energy use. It can also be expected that a building automation system could in the future take over the reading of potentially multiple meters embedded within the house, hence becoming the source of metering information for the external use. Characteristic for all these scenarios is that we are dealing with an open system in which new devices and new information publishers/subscribers should be able to enter and integrate within the system. The requirement to realize a flexible open system motivates the SESAME project[3], which uses semantic web technology, in particular ontology-based and rule-based modeling, combined with the multi-objective reasoning and service-oriented design to capture and realize functionality of future energy-aware home management systems.

This paper describes the concepts which are implemented within the SESAME demonstrator. The paper is structured as follows: Section 2 describes related work on semantic research for smart homes; Section 3 presents the components of the SESAME approach – the system and service architecture, ontology and rule modeling; Section 4 concludes the paper also with an outlook on future work.

2. RELATED WORK
In the past years, research on modeling and implementation of pervasive environments and in particular smart homes has made significant advances. Some of the well researched topics include (i) the design of a context-aware, adaptable and flexible middleware, (ii) the service-oriented functional modeling, (iii) agent technology for implementing interactions in environments with high uncertainty, (iv) an ontology-based modeling for

[1] ICT EC Report, Impacts of ICT on Energy Efficiency, 2008, http://cordis.europa.eu/fp7/ict/sustainable-growth/studies_en.html.

[2] Smart Metering Industry Group, www.esmig.eu/smart-metering.

[3] SESAME project, sesame.ftw.at

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context-awareness and (v) an automated, policy-based decision making. A smart home is a heterogeneous dynamic system open for easy integration of many different devices offering different services to a variety of users. As users are often non-technical people, context aware or seamless operation on behalf of users is a critical usability requirement [1][2].

Two essential requirements for building context-aware systems are a suitable context model and a middleware level support. The middleware shall deal with acquiring context form physical sensors, databases and agents; and with context interpretation and timely dissemination, as well as orchestration of more complex context-aware services. The most prominent middleware platform in the smart home research is OSGI[4] [3][4]. The ontology-based modeling, as a central concept of the Semantic Web, has been established as a technology of choice for context-aware and smart home applications [5], due to its benefits including knowledge sharing, logic inference of a high-level, conceptual context from low-level, raw context, and existing domain knowledge reuse. At present, Web Ontology Language (OWL) [6] is often preferred for specification of ontologies because of its expressiveness, its capability to support semantic interoperability and context knowledge sharing, as well as because it enables automated reasoning. Protégé[5] and Jena[6] are tools well established for creation and processing of ontologies.

Efficient context modeling in the smart home requires separation between general information, focused on users, tasks and higher-layer situations, and specific information from the devices that can support these tasks. A frequent approach is to have a common core ontology to capture general context knowledge, while the lower level ontologies plug in depending on the used devices and the environment. Accordingly, the semantic context representation in the smart home commonly includes the basic concepts of person, location, computational entity, activity or function, and the properties and relationships between these concepts. [5][9][10]. Direct context is acquired from sensors or information servers or users. The higher-level context can be inferred from the lower-layer context by using inference rules. Therefore, the support for reasoning, in particular creation and management of user specified policies is of a central interest, as also supported by general studies on the policy-aware web approach [11][12]. Semantic Web Rule Language (SWRL) is increasingly gaining attention in the smart home research community, as it acts as an inference enabler for services that adapt to the needs of the home inhabitants, through its back chain and forward chain rules [13]. At present, for reasoning with policies the general purpose reasoning engines based on Euler[7], Pychinko[8] or Pellet[9] reasoners, can be used.

Integrated within the Service-Oriented Architecture (SOA), the use of ontologies facilitates intelligent service discovery and composition [7][8]. The concepts of SOA support dynamic discovery of available functions and their invocation in a loosely coupled manner. Several SOA approaches emerged for the embedded and automation domain including Universal Plug and Play (UPnP)[10], Devices Profile for Web Services (DPWS)[11], OPC Foundation[12], or Service-Oriented Architecture for Devices (SOA4D)[13].

[4] OSGi Service Platform, www.osgi.org.
[5] protege.stanford.edu
[6] jena.sourceforge.net/
[7] eulersharp.sourceforge.net
[8] www.mindswap.org/~katz/pychinko
[9] clarkparsia.com/pellet

3. SESAME APPROACH

The SESAME project extends the existing research focusing on the ontology-based modeling and rule-based reasoning for the smart home controlled by the user, by addressing new challenges coming from the required interactions between the user domain and other stakeholders in the energy market. Recently integration of these domains has also been addressed by the EU FP7 Projects Intelligent Self-describing Technical and Environmental Networks (S-TEN)[14] and SmartHouse/SmartGrid (SHSG)[15]. 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 ontology modeling, rule-based reasoning, and service-oriented interactions. In this context our goal is also to leverage on the semantic data for the energy domain within the Linked Open Data Initiative[16]. This Section describes system and service architecture, ontology, rules and user access.

3.1 System Architecture

The architecture of the system is illustrated in Figure 1. The core of the home system is a universal control box, or a home gateway on which the SESAME knowledgebase and service framework is deployed. This system integrates home devices, sensors, appliances, or display devices, through wireless or wired interfaces. The smart meter deployed in the home is controlled/ read through the Internet by the smart metering service provider that publishes metering information through a secure Web service.

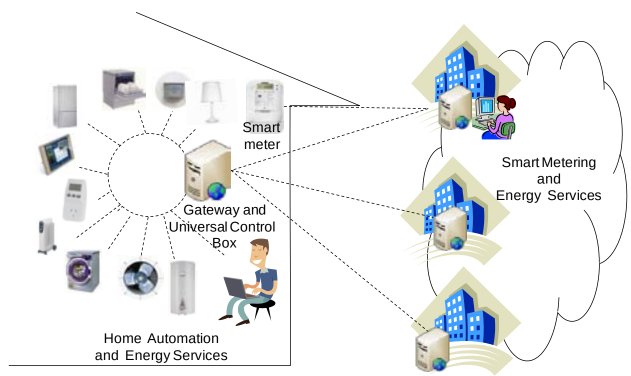

Figure 1. SESAME System Architecture

The SESAME approach assumes that the so-called *energy information service interface* will be established between the SESAME system and an energy supplier's systems. This interface offers access to relevant dynamically changing information such as tariff and updating of the knowledgebase. Changes in relevant information trigger automatic reasoning and automation actions at

[10] www.upnp.org.
[11] www.ws4d.org
[12] www.opcfoundation.org.
[13] forge.soa4d.org
[14] www.s-ten.eu
[15] www.smarthouse-smartgrid.eu.
[16] en.openei.org/wiki/Main_Page

the user side. At present, to get benefit of such information users must actively search for it through a web browser interface, and act on it by configuring their home devices or changing their behavior according to offered tariffs. The SESAME system takes the burden form the users by defining service-based machine-to-machine interfaces for a practical realization of a machine-optimized access to information of different providers. We also identify the need for the e*nergy optimization services* that should enable the users and energy suppliers to make joint control decisions. For example, a control action such as switching on/off of a device can be triggered from the remote supplier's side. On the user side these actions may be constrained by a special set of user-defined preferences in order to guaranty that user expectations are met.

3.2 Service Architecture

Service orientation is a central design principle in realization of the SESAME system. The SESAME service architecture is based on the OSGI Knopflerfish platform[17]. Services within the framework provide different functionality at different interfaces as illustrated in Figure 2. 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 knowledgebase. Sensors, appliances and displays are also implemented as service-based information publishers and consumers with published OSGI service interfaces. As a home automation system is inherently an event-based system each service interface implements also a notification passing capability. This is true also for the service-based interaction between the user and the energy providers or grid operators.

The ontology is the core of the knowledgebase, 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. For the implementation of the knowledgebase we used the Jena framework. The ontology is also the basis for the creation of rules. To implement the rule-based reasoning we integrated Pellet as a reasoning engine within the OSGI framework and SWRL and N3 format for specification of rules.

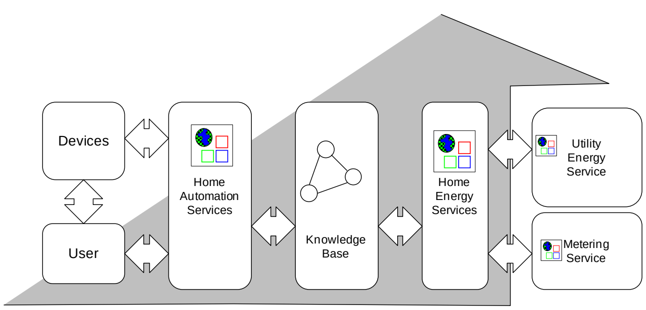

Figure 2. SESAME Service Architecture

3.3 Ontology

SESAME uses an ontology-based modeling approach to describe an energy-aware home and the relationships between the objects and actors within the control scenario. The SESAME ontologies are specified in OWL and N3 and provide a hierarchy of concepts to model the automation domain and the energy domain. The ontology includes a number of general concepts such as resident, location, and concepts in the automation and in the energy domain, such as Device, Tariff, energy usage Profile, Account. The Device class is further specified to model an Appliance, Sensor, or UI device. New properties in the device model are consumption per hour, peek power, the switch on/off status but also the required state "to be switched on/off". For an Appliance we also introduce the property "canBeStarted" which models the state of the devices which activation can be scheduled, e.g., a filled washing machine. The central function-level concept in the SESAME ontology it the Configuration class, which has two subclasses: Activity (automation activity) and EnergyPolicy. A Configuration connects Appliance, Sensor and UI Device into a joint task. The Configuration can provide regulation of different types, e.g. regulation on time, occupancy of location, threshold value. For this purpose Configuration includes properties including thresholds and scheduled times.

3.4 System-level Rules

System-level rules complement the definition of automation activities and energy policies in the ontology. System-level rule define *situation* and related *actions.* The situation is specified as a set of conditions on existence of specific triplets in the RDF store, the action defines consequent creation of new RDF triplets which potentially shall replace some of the existing data. A system-level rule which co-defines an activity that regulates on a Sensor reading and defined threshold values is used for illustration. The rule defines that the status of the Appliance is to change to "to be switched on" if the sensor reading of the sensor is *less than or equal* to the threshold value specified for switching on is defined as follows.

```
Activity(?a), Sensor(?s), regulatesOnThreshold(?a,?s),
usesAppliance(?a,?d), hasReading(?s,?r), isSwitchedOn(?d,false),
hasThresholdSwitchOn(?a,?t), lessThanOrEqual(?r,?t) ->
IsToBeSwitchedOn(?d, true)
```

A complementing rule for switching off can be defined in a similar way. An Activity that regulates on occupancy of the specific location can be customized by a specific rule, which states that if a location is occupied the appliance is to be switched on. An instance of the Activity that regulates on time is coupled with the rule that defines that during the specified period the Appliance should be switched off.

As described system-level rules specify how the information from the knowledgebase is used to reason about the changes on the appliances' state. Energy management rules are executed after automation rules to verify the automation decision based on energy constraints. For example, after the automation rule set the status on "is to be switched on" the energy management rule, which acts on the Tariff information can set up the activation parameter to "switch on". System-level rules would be created by a "power user" well acquainted with the model of the devices and activities. System vendors can also create such rules in which case they automatically come when the devices are installed in the environment. In the SESAME project for the creation of such rules we integrated a general domain tool [12]. "Normal users" are to use interfaces which we describe in the next Section.

[17] www.knopflerfish.org

3.5 User Policies and Preferences

User-friendliness is a critical requirement for the SESAME system, but the simplicity is difficult to achieve without constraining the functionality of the system. As already described, the functioning of the SESAME system, specifically in terms of energy saving, critically depends on the quality of the installed *rules*; however creation of rules may overwhelm an ordinary user. Therefore, in the SESAME system, the creation of rules is a two-stage process: (1) *system-level rules* are automatically created based on the current ontology and the knowledgebase, keeping the system flexible and open for changes, (2) through a user-friendly graphical interface the user is offered *just-enough* information so that he/she can specify his/her *policies/preferences* regarding the energy-aware environmental control; these preferences integrate system-level rules. More precisely, through a user-friendly interface a home owner can configure his/her home environment by setting specific properties of devices, e.g., the threshold values, working periods, etc., and select a subset of system-level rules creating a specific *user policy*. By being offered to just *select* from the set of *recommended* rules, the user is guarded from unintentional errors or wrong decisions. On the other hand, within the policy the user can customize, combine and weight system rules to achieve own personal objectives, sometimes prioritizing the quality of living to the energy saving, or sometimes vice versa.

As users select and customize existing system-level rules within their user-policies, it is easy to add monitoring of how the rules are used, e.g., how often they trigger some actions, are contradictory to the users' behavior, refer to non-responding devices, etc. Together with the time-stamped information about the energy use (as obtained through the smart meter), and environmental parameters (acquired through the environmental sensors) this monitoring function provides enough information for an internal recommendation component to identify which rules proved as energy effective, and to adaptively recommend them to the user. Further, complemented with mood tracking gadgets the system could also identify the *best mood* rules or policies.

4. CONCLUSIONS AND FURTHER WORK

SESAME project advances the concepts of energy-aware smart home by applying the ontology-based modeling and the service-oriented design, semantically intertwining the home automation and smart metering infrastructure. Such "semantic gluing" is not trivial task and it requires understanding of a number of specific issues in the energy and automation domains. With such system in place we expect better energy saving and convenience of living than today's home automation systems can offer through manual or scheduled activation of home appliances. Currently, the approaches similar to ours are not broadly explored, partially because of the proprietary developments in metering and automation data processing.

SESAME's semantic description of an energy-aware home includes models of devices, models of automation tasks and system-level automation rules, models of energy policies and system-level energy rules, and user preferences which customize the use of system-level rules. The SESAME demonstrator is a proof-of-concept implementation that integrates several relevant physical and virtual devices presenting a setup on which user interactions can be studied.

In the context of customer-provider interaction the issues related to the privacy and dependability of information, accountability for committed changes and actions, as well as the life-cycle management of ontologies and services are of high importance. Our future work will therefore address these problems and deal with possibly conflicting requirements and constraints of different stakeholders in the energy market.

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