PowerOnt: An Ontology-based Approach for Power Consumption Estimation in Smart Homes

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Summary. The impact of electricity consumption in buildings on the overall energy budget of European and North-American states is steadily growing and requires solutions for achieving a more sustainable development. Smart metering and energy management system can be hardly afforded by residential homes, for their cost and the required granularity. Empowering smart homes with suitable power consumption models allows to estimate, in real-time, the current home consumption on the basis of currently active devices. In this paper we introduce an ontology based power consumption model (PowerOnt) for smart homes, and we discuss some application use cases where the proposed approach may successfully be exploited. Results show that the modeling approach has the potential to support energy efficiency measures into residential homes with few or no metering devices.

Key words: Power Consumption, Ontology, Smart Home, Electricity

1 Introduction

According to statistics from both the US Department of Energy and the European Union Energy Commission, electricity consumption will increase in the next years, with residential and commercial buildings raising their aggregate figure up to 73% of the total yearly consumption. Smart homes can play a pivotal role by enabling users to better organize their daily activities in order to reduce the global home consumption, by suggesting and promoting new, more efficient behaviors and by preventing or postponing the activation of energy greedy appliances, possibly coordinating with local power sources. Fine grained metering is one of the key factor for these "energy positive" innovations in the homes although implied costs still prevent its application inside home environments. As a consequence, homes are still "locked" into a stale condition where only one meter (if any) is installed and almost no policy can be applied. To overcome this issue and start improving energy efficiency of residential habitations we propose to enrich smart homes with explicit, machine understandable information, in form of appliance-level power consumption data, either nominal or measured on the specific device. Such a detailed modeling allows to estimate the total power absorbed by a smart home by knowing device activations, only. If such a capability is complemented by the availability of one, or more, real meters, estimation can be improved and results may increase their accuracy scaling gracefully to the full metering case, where every device is connected to a dedicated meter. The PowerOnt ontology model presented in this paper is specifically designed to model nominal, typical and real power consumption of each device in a home and its modular design allows to plug the same model into different ontology-based modeling frameworks for smart homes.

2 Use Cases

To better exemplify how a relatively simple and abstract model of energy consumption such as PowerOnt can positively impact the energy consumption in habitations, we depict two different use cases, of increasing complexity, where power modeling assumes a crucial role for sustaining better consumption policies.

Meterless monitoring Many research contributions, in literature, show that householders can decrease their electricity absorption by 5%-15% by just being informed about their current energy consumption habits [1]. To make home inhabitants aware of their current energy habits, most approaches exploit In-Home energy Displays (IHDs) [2, 3] showing the amount of power currently consumed, the energy absorbed since a given start time and information to promote positive changes in the householders lifestyle. Metering is a functional requirement for IHDs, if no metering information is available in the home, no feedback can be given and no improvement can be achieved. By simply plugging PowerOnt device descriptions into an existing smart home, i.e., by inserting a proper software module into the existing smart home gateway, it is possible to estimate the current home consumption from the activation states of the connected devices, even if no meter is installed.

Better Practices Suggestion Given a smart home with one or more meters installed, PowerOnt may be used by the home gateway to implement advanced suggestion policies, stimulating positive changes of the home inhabitants behaviors. At every device activation, e.g., by means of a button, the home gateway intelligence may, in fact, check the alternative ways for achieving the same final state, and suggest to activate the one having the lowest impact on the home energy consumption. For example, imagine that the bathroom illumination can be obtained by either switching on the bathroom ceiling lamp, or by raising up the bathroom shutter. Every solution can be profiled under the electrical consumption point of view, using information encoded in PowerOnt, and the less consuming one can be identified. If the user does not select the best activation (energetically speaking),the smart home can exploit IHDs to inform the inhabitant of the existence of a better habit, e.g., raising the shutter instead of lighting the lamp.

3 PowerOnt

PowerOnt is a light-weight ontology designed to model power consumption of electrical devices and appliances in smart homes (see Figure 1), supporting the previously depicted use cases. A minimal approach is adopted, reducing model-

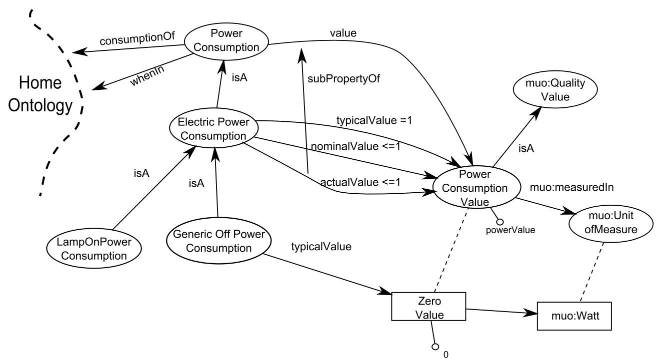

Fig. 1. PowerOnt, class hierarchy

ing primitives (classes and relations) to those strictly needed to support power consumption modeling. Relations to described devices and appliances are left "open," i.e., their descriptions shall be completely formalized depending on the ontology-based home/device model to which PowerOnt is connected.

3.1 Structure

Two main classes compose the ontology, namely `poweront:PowerConsumption` and `poweront:PowerConsumptionValue`. They respectively model the kind of power absorbed by a given device or appliance, e.g., electric power, and the amount (value) of consumed power in terms of International System units, e.g., Watt. The `poweront:PowerConsumption` concept is specialized into `poweront:ElectricPowerConsumption`, modeling electric power typically absorbed by home devices and appliances. Devices can be described by either instantiating the type of power they absorb or by further specializing the electric power consumption class and by instantiating the corresponding descendants, e.g., `poweront:LampOnPowerConsumption` that models power absorbed by switched-on lamps. Power values are referred to their unit of measure by means of the `muo:measuredIn` relation, defined in the standard MUO ontology[1], that relates a `poweront:PowerConsumptionValue` instance to a `muo:UnitOfMeasure` instance. Power consumption classes are related to (at least) one power consumption value by means of the `poweront:value` relation. Such a relation is further specialized to allow specifying typical, nominal and actual consumption values.

[1] `http://idi.fundacionctic.org/muo/`

Given an instance of a class descending from `poweront:PowerConsumption`, e.g., of `LampOnPowerConsumption`, such an instance can be connected to: (a) a *typical* power value derived from the consumption of a generic device of the same type, e.g., lamps in a home typically consume around 60/90 Watt; (b) an optional *nominal* power value declared by the device manufacturer, e.g., the living room lamp has a nominal power consumption of 30 Watt; (c) an optional *actual* power value measured on the real device, e.g., the living room lamp actually consumes 28,92 Watt.

Two "open" relations, respectively named `poweront:consumptionOf` and `dogP:whenIn`, model the power absorbed by a given device in a given operating condition. The former relates a device, expressed in whatever ontology (range unspecified) with its corresponding power consumption described in PowerOnt. The latter further specializes this relation by associating the power consumption with a specific device operating condition, e.g., state; also in this case the relation is left open to achieve maximum modeling flexibility (range unspecified).

3.2 Sample Integration with DogOnt

To better clarify power consumption modeling through PowerOnt we consider a specific integration sample, where PowerOnt is integrated with the DogOnt[2] ontology model for Smart Environments [4]. Integrating PowerOnt and DogOnt means exploiting DogOnt concepts as the ranges of `poweront:consumptionOf` and of `poweront:whenIn`. In DogOnt, devices that can be connected to a smart gateway, i.e., controlled, are modeled by the concept `dogont:Controllable`. Therefore, PowerOnt in DogOnt will specialize the `poweront:consumptionOf` range to `dogont:Controllable`. Moreover, since in DogOnt different device operating conditions are explicitly modeled by means of concepts belonging to the `dogont:StateValue` hierarchy, the PowerOnt `poweront:whenIn` relation range will be set at `dogont:StateValue`.

The resulting integration is reported in Figure 2 where DogOnt concepts are reported in bold while PowerOnt concepts are reported in italic font. The PowerOnt ontology integrated with DogOnt is available at `http://elite.polito.it/ontologies/poweront.owl`.

4 Example application

We can use the first use case presented in Section 2 (*Meterless energy monitoring*) as a practical example to exploit some PowerOnt functionalites. We can consider the devices present in a bathroom: a lamp on the top of the bathroom mirror, a shutter and the ceiling lamp. Only the shutter is metered. If we want to obtain the consumption of such home appliances (metered or not), in order to promote energy saving, we could use a SPARQL query, thus reporting either the typical, nominal, or measured value. As shown in Figure 3, SPARQL querying

[2] available at `http://elite.polito.it/ontologies/dogont.owl`

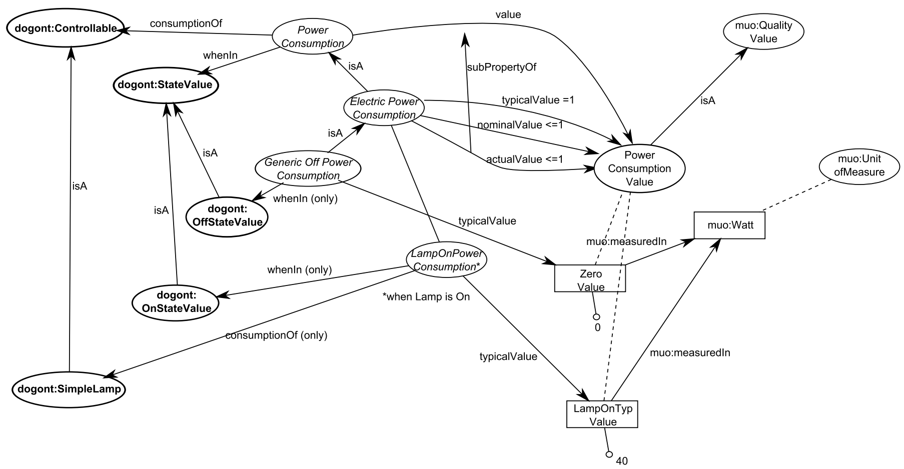

Fig. 2. Integration of PowerOnt and DogOnt

is exploited to extract, for each controlled device `?device` located in the bathroom, the list of its state values `?stateValue` and to further retrieve the power consumption values `?consumption` for each state value. Then, the typical consumption value (`?typicalConsumption`), the nominal (`?nominalConsumption`) and the measured one (`?actualConsumption`) are extracted, if available, from `?consumption`.

```
SELECT ?device, ?typicalConsumption, ?nominalConsumption, ?measuredConsumption
WHERE
{
?device a dogOnt:Controllable.
?device dogOnt:isIn <http://elite.polito.it/ontologies/samples/samplePower.owl#Bathroom>.
?consumption a powerOnt:ElectricPowerConsumption.
?device dogOnt:hasState ?state.
?state dogOnt:hasStateValue ?stateValue.
?consumption powerOnt:consumptionOf ?device.
?consumption powerOnt:whenIn ?stateValue.
OPTIONAL{?consumption powerOnt:typicalValue ?typicalConsumption}.
OPTIONAL{?consumption powerOnt:nominalValue ?nominalConsumption}.
OPTIONAL{?consumption powerOnt:actualValue ?measuredConsumption}
}
```

Fig. 3. SPARQL query for the “Monitoring” case

5 Related Works

Several ontologies for energy management in smart homes have been proposed in the literature. Most of them, differently from PowerOnt, are not modularand they do not use standard ontologies (such as MUO) to define units of measure. Example of such ontologies are the ontology part of DEHEMS, or the ontology used by the SESAME project. The ontology part of the European founded *Digital Environment Home Energy Management System* (DEHEMS) [5] project aims at being adopted by vendors and manufacturers of home appliances to create a uniform classification of devices that allows automated reasoning over their energy efficiency related characteristics. The DEHEMS ontology, in general, associates each appliance with: a a set of advice generated by the reasoning system as recommendation to users in specific case of abnormal energy consumption; b a "EU Energy Label Class" and a "Energy Star" rating for classifying the energy efficient of the device; c an indication about the "Wattage" used; d the value of the "Wattage on Standby" (if the specific appliance supports it); e the "Energy Consumed" in every possible state. The *SESAME* project [6], instead, uses an ontology-based approach to describe an energy-aware home. It does not provide appliances representation from the perspective of energy saving but it relies on overall energy consumption, peak power and various tariff information as they are provided by smart meter supplier.

6 Conclusions and future works

In this paper we introduce PowerOnt, an ontology based power consumption model for intelligent environments, able to provide, for each controlled home appliance, either a typical power consumption, a nominal or a measured consumption. Future work includes the usage of PowerOnt in the open source Dog gateway[3] and the realization of the proposed use cases.

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[3] see `http://dog-gateway.github.io` for further information