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Enabling Machine Understandable Exchange of Energy Consumption Information in Smart Environments

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Abstract

In the 21st century, all major countries around the world are coming together reduce the impact of energy generation and consumption on the global environment. Energy conservation through its efficient usage has become a top agenda on the desks of many governments. In the last decade, the drive to make homes automated and to deliver a better assisted living picked pace and the research into home automation systems accelerated, usually based on a centralized residential gateway. However most of the devised solutions lack to provide users with information about power consumption of different house appliances. The ability to collect power consumption information can pave the way for a more energy efficient society. The goal tackled in this paper is to enable residential gateways to provide energy consumption information, in a machine understandable format, to support third party applications and services. To reach the goal, we propose a Semantic Energy Information Publishing Framework which publishes, for different appliances in the house, their energy consumption information and other properties, in a machine understandable format. Appliance properties are exposed according to the existing semantic modeling supported by residential gateways, while Power consumption is modeled through a new modular Energy Profile ontology.

Keywords: Energy Conservation, Machine Understandable Power Consumption Information, RDF, Semantic Energy Information Publishing, Energy Profile ontology

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1. Introduction

Energy Conservation is a rising concern for many countries around the world. The resources used to generate energy, their scarcity and the rising impact of those resources on the global environment have made energy conservation a top agenda on the tables of high government officials around the world. In USA, the Department of Energy (DOE) launched a Weatherization Assistance Program that enables low-income families to permanently reduce their energy bills by making their homes more energy efficient¹. The US Environmental Protection Agency defined an Energy Conservation Action Plan which addresses the opportunities for energy conservation in homes, schools, offices and industrial environments through the use of energy-saving innovation². China introduced a medium and long term energy conservation plan to push the whole society towards energy conservation and energy intensity reduction, to remove energy bottlenecks, to build an energy saving society, and to promote sustainable social and economic development³. The International Energy Association published statistics of energy consumption by sector [1], according to which China uses 38.2% and 40% of its total energy on the residential and industrial sectors respectively. Europe uses 26.6% and 32.2% of its total energy on the residential and industrial sectors. Currently, a trend can be seen that developing countries with growing population use a major portion of their energy in the residential and industrial sectors.

Ambient, Ubiquitous and Intelligent computing have provided stimulus to the research of a number of residential gateways [2] [3] [4] [5] which provide control of the appliances in the house and access to the general appliance properties. Access to this information can be provided locally through a software application or remotely over the web. If energy consumption information is provided by the residential gateway, the energy provider or the gateway itself could provide applications to increase the awareness among the consumers for more efficient energy usage. Most of these residential gateways [2] [3] [4] [5] [6] do not provide energy consumption information about the different appliances in the house. To support different type of applications and services the consumption information should be exposed in an open and machine understandable format, so that different application can use the data according to their own diverse goals.

¹<http://apps1.eere.energy.gov/weatherization/>

²<http://www.epa.gov/>

³<http://www.chinaenvironmentallaw.com/wp-content/uploads/2008/04/china-medium-and-long-term-energy-conservation-plan.doc>

The goal of this paper is to enable residential gateways to expose power consumed by different appliances installed in a house, in a machine understandable format, to support the development of external applications. Such applications can provide visualization of energy information (either locally or on the web), can provide statistics and analysis of the energy data, and in the next future may aim at achieving intelligent negotiation and consumption coordination. Exposing energy consumption in a neutral and machine understandable format will allow multiple services to use the energy and power consumption information according to their own application goals.

To achieve the aforementioned goal, this paper proposes a Semantic Energy Information Publishing Framework (SEIPF) which publishes, for different appliances in the house, their power consumption information and other appliance properties, in a machine understandable format. Data is published according to Semantic Web standards and best practices, to ensure application neutrality and intelligent machine processing. While appliance properties are exposed according to the existing semantic modeling supported by home gateways, power consumption is modeled by introducing a new modular Energy Profile (E.P) ontology.

The proposed framework is consistent with publication of information at different granularity levels (e.g., by aggregating over device groups) and respecting different authorization levels. Depending on the type of application, different complexity levels require different complexity in data representation, so that the SEIPF framework is able to expose data both as simple RDF triples (according to Linked Data requirements) and as full ontology instances, for the benefits of applications needing intelligent processing.

Today the ability to collect and share power consumed by different devices in a house can give rise to many applications that pave way for energy efficient society. These applications include making consumers aware of their power consumption through Power meters, sharing of data over the web to create mesh up application, consulting service to provide feedback on different appliances power requirements. In Future, Intelligent negotiation and consumption coordination will allow third-party service providers to build intelligent and automated services that use energy consumption information to build dynamic services. For example, automatic load transfer, intelligent energy grids. A basic requirement to fulfill the scope of aforementioned applications is a standard, open and semantic representation of a device's power requirement is needed, so that the applications may use the energy information according to their own goals.

The remainder of this paper is divided into eight sections. Section 1 provides the target sce-

narios from which needs and requirements driving the approach are derived. In Section 2, the main issues to achieve target scenarios are outlined. Section 3 explains the basic principles on which the envisioned solution is founded. In Section 4 a possible solution is presented, which is further detailed in Section 5. Section 6 provides implementation details of the proposed framework along with the experimental results by showing samples applications built to prove the feasibility of the solution. Section 7 present related works portion and the section 8 concludes the paper and discusses possible extension.

2. Scenarios and Motivation

2.1. Scenario 1: Home Energy Management System

Consider an energy provider, which decides to provide its residential consumers with a Home Energy Management System. The system is connected through a home network to a smart utility meter and electrical appliances. To reach the goals of energy aware and energy efficient society, the system provides different applications to track the power consumption of different appliances inside the house. It provides tools to monitor current energy needs, to provide analysis on the power consumed over time, to provide suggestions on better energy management plan. The System is a plug and play management system in which third-party applications can be installed to provide consulting services that suggest vendors that provide more energy efficient devices, plans to save money by saving energy etc. Shifting the use of major appliances such as dishwashers and clothes dryers to hours with lower overall electricity usage can help utilities meet demand and help consumers save energy under demand-based pricing plans. Providing real-time information linked to such dynamic pricing may be a winning combination for consumers who want to cut energy costs.

To support the system, issues of gathering information related power consumed by the devices, publishing this information. Providing an open and standard format for the information will allow different applications to use the information according to their own goals. It will act as a baseline for more applications that could be plugged in the system.

2.2. Scenario 2: 2020 Intelligent Energy Grids

Consider the energy delivery and consumption landscape in 2020 (or even before). In 2020 the world energy demand has grown by 76% with respect to 2007, requiring 4 800 GW of capacity additions, almost five times the 2009 capacity of the US [7]. In this scenario, energy

production and delivery dramatically relies on smart grid solutions to effectively distribute the available energy (mostly electrical) and to coordinate with consumption demands to avoid peaks and abnormalities that today require oversizing of distribution and production systems.

One of the main contributions to the future ability to cope with such a high energy demand is the improved and automated cooperation between consumption centers, be they residential houses (around 30% of the current consumption) or industrial and commercial facilities. The Internet growth and the take off of Information and Communication technology and Artificial Intelligence based techniques has driven the energy distribution scenario to the current state where consumers and producers continuously and autonomously negotiate the best trade-off between energy needs and availability. Take 2020 homes as an example, they are automatically communicating and coordinating their energy needs. In every city district, single homes interact and communicate with neighbors to shape the global district consumption, to activate home level energy transformation and to coordinate local energy production, thus reducing the cumulative amount of energy required from the main electric distribution network and almost eliminating consumption peaks. This amazing capability of coordinating different homes together can be observed every day: at each day hour some houses are producing energy thanks to solar cells installed on their roofs or to thermal co-generation of their heating systems. The homes that are not generating, or that require additional energy, negotiate with neighbors energy transfers, minimizing the need of 'external supplies' through the main power delivery line.

Even countries are coordinating and collaborating in the same way, while one hemisphere of the world is sleeping, energy production is mainly routed on the illuminated side of the earth, supporting the higher day-light consumption request. Everything happens seamlessly, and if observed from a distant energy point of view the whole globe is traversed by a steady wave of energy, that regularly feeds human activities, 24/7.

This futuristic, but still realizable, scenario involves many subtle issues, that need to be unveiled in order to guide research on the technology infrastructure needed to support it. At basis of the depicted scenario, the Internet acts as a connective tissue, flowing energy related information between different involved entities such as the homes, industries, offices, power delivery and power production plants. On top of this connection network, data exchange needs common, machine understandable formats to enable all the above intelligent negotiations and consumption coordinations. We do not go further in the analysis of the issues raised by the 2020 scenario,

instead we focus on this information exchange infrastructure on which every advanced consumption policy is rooted.

3. Design Issues

The core requirement of the defined scenarios is the ability to gather power consumption information of an appliance or a group of appliances in a house and showing it over the Internet. To accomplish the scenarios mentioned in Section 2 three main issues need to be addressed. As explained previously, they are gathering energy consumption information, publishing this information, and making the information usable by machines. Gathering energy consumption information means measuring the current consumption of home devices, such a measure is greatly facilitated if a smart or home automation plant is available in the homes. Publishing information means deciding, and most importantly, let the household decide which information to expose and at what granularity. Finally, distributing machine understandable information implies the adoption of an open and effective data format that enables machines to interpret them; the Semantic Web and Linked Data communities have already paved the way in this direction. By going a little further on these three main issues, we can identify the following, related needs.

3.1. Energy Consumption Information

The power consumption of an appliance or group of appliances is the information exchanged between smart homes. energy providers or any third-party applications is Homes will be equipped with appliances ranging from a lamp to a fully automated heating control system. An appliance during its operation can have different operating states like on, off, stand-by, up, down etc. Then in different states, the appliance can have different power consumption levels. We need a mechanism to encode this power consumption information about the appliance in different states and the residential gateway should provide the power consumption of an appliance or of a group of appliances according to their current state. The availability of a house automation system, coupled with the knowledge of device characteristics, allows us to estimate and couple power consumption information at a much finer level, with less expensive means compared to the installing power meters.

3.2. Energy Information Publishing in a Machine Understandable format

The power consumption information should be distributed in an open, machine understandable, semantic enabled and effective data format, so that a single information point can act as

input for multiple and diverse third-party applications, services and potentially automated agents as well.

3.3. Information Publishing Control

Residential gateways are designed to provide automated control to the house and thus they have information about every appliance in the house. The information may comprise appliance properties, energy consumption and procedures to control the appliance automatically. This information if utilized by third party applications, services or automated agents has the potential to provide the consumer better services. However, this information sharing should be governed by a sound access control mechanism so that the basic consumer rights and privacy issues are addressed. Privacy is a subjective issue, and different consumers or even people living in a single home might perceive it differently from others. Several case studies in relation to the issue of privacy have been carried out [8] [9] and the research is still on going.

4. Basic Principles

The web today is witnessing a paradigm shift from a displayed data era to a new era of well understood meaningful information over the web. This is the vision of the future web, better known as Semantic Web. W3C ⁴ describes Semantic Web as the web of data. It creates a universal medium for the exchange of data [10]. The Semantic Web vision will enable automated negotiation and retrieval of machine understandable information among web applications, services and agents. The basic components that forms the basis of semantic web and the necessary ingredients needed for the solution of the issues mentioned in Section 3 are explained below.

4.1. Resource Description Framework (RDF), Linked Data and Ontology

RDF [11] is the framework presented by W3C for representing machine understandable information on the web. It is a simple data model to describe the resources over the web. RDF has been designed for situations in which information needs to be processed by applications, rather than being only displayed to people. The basic structure of any expression in RDF is a collection of triples, each consisting of a subject, a predicate and an object. A set of such triples is called an RDF graph.

⁴<http://www.w3.org/>

According to Tim Berner's Lee web architecture note [12], the Semantic web is not just about exposing machine understandable information over the Internet but making links between different exposed information sets, so that a machine, an application, a service or a person can find related information. The availability of data from different sources in a universal format and linked together is known as 'Linked Data'. Linked Data⁵ (LD) assumes the availability of information in RDF format. Formally, Linked Data is a term used to describe recommended best practices for exposing, sharing, and connecting pieces of data, information, and knowledge on the Semantic Web using URIs and RDF. To capture domain knowledge in a generic way, and provide a commonly agreed understanding of a domain, which may be reused and shared across applications and groups, the concept of *Ontology* is used. An ontology is a formal specification of a shared conceptualization [13]. W3C provides the Ontology web Language (OWL) to describe ontologies about a particular domain [14]. OWL has three increasingly-expressive sub languages: *OWL Lite*, *OWL DL*, and *OWL Full*.

4.2. DogOnt

DogOnt [15] is an ontology able to model the domotic system of a house with focus on supporting the intelligent operations in a domotic environment. DogOnt has been designed along 7 main hierarchical trees, corresponding to the *Building Thing*, *Building Environment*, *Functionality*, *Command*, *DomoticNetworkComponent*, *State*, *StateValue*. *Building Environment* and *Building Things* are used to describe the environment of the house. DogOnt provides the ability to model different devices that exist in a house through the *Building Thing* concept and DogOnt has a clear separation between the Controllable and Not Controllable devices through *Controllable* and *UnControllable* subclasses respectively. The *Functionality* class is related to the different functionalities of the device. The *Command* and *Notification* concepts are linked to a specific functionality instances. Networking modeling is achieved through *DomoticNetworkComponent*. *State* and *StateValue* are used to model the different states of a device. A very basic device model is shown in Figure 1. It illustrates a device *sample_lamp* which has two inherited functionalities named *OnOffFunctionality* and *Queryfunctionality*. The *sample_lamp* has a state *OnOffState* and it is in *sample_living_room*. The interested readers are referred to [15] or to the DogOnt website⁶ for more details and examples about DogOnt.

⁵<http://linkeddata.org/>

⁶<http://elite.polito.it/dogont-tools-80>

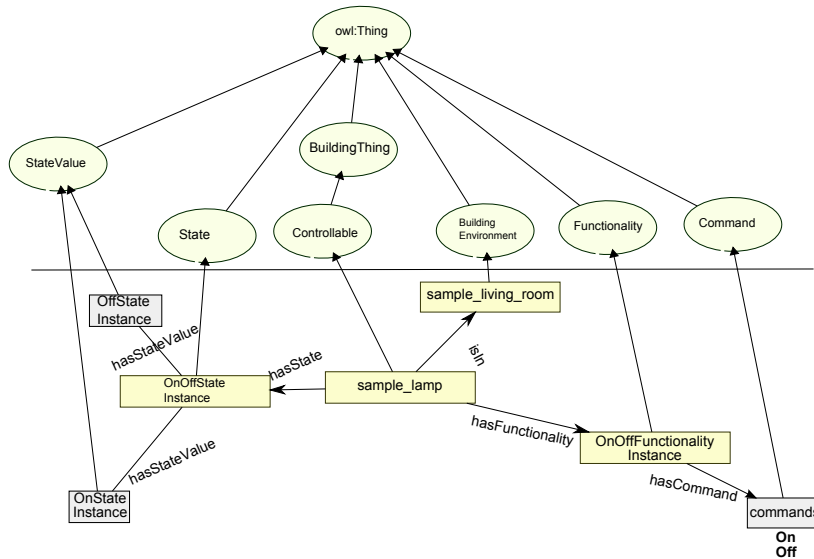


Figure 1: A sample Device Model in DogOnt

4.3. Dog

Dog [16] is an ontology-powered Domotic OSGi Gateway (Dog) that is able to expose different domotic networks as a single, technology neutral, home automation system. It is versatile as it is built on top of the OSGi framework and the adaption of semantic modeling techniques allows Dog to support intelligent operations inside the home environment. Dog uses the DogOnt ontology to model a house environment. Dog provides ability to control different devices installed in a house and to query different device properties ranging from location to current operating state.

4.4. Web Of Domotics (WoD)

WoD [17] is derived by combining the components of three concepts namely: Internet of Things, Ubiquitous Computing and Domotics. It is an Internet architecture enabling mobile users to access device information and operate them in a ubiquitous manner, independent of network-specific location dependence. WoD addresses issues like proximity-based device identification (e.g., visual tags), network independent detection of service access points (through DNS-based device de-referencing), user identification through OpenID, open data exchange, service/device description through Linked Data formats and device operation through REST-based interaction. WoD extends Dog to include a new WoD layer (Figure 2), that comprises a HttpAccess unit and an Authentication and Authorization unit. The HttpAccess unit provides the ability to get

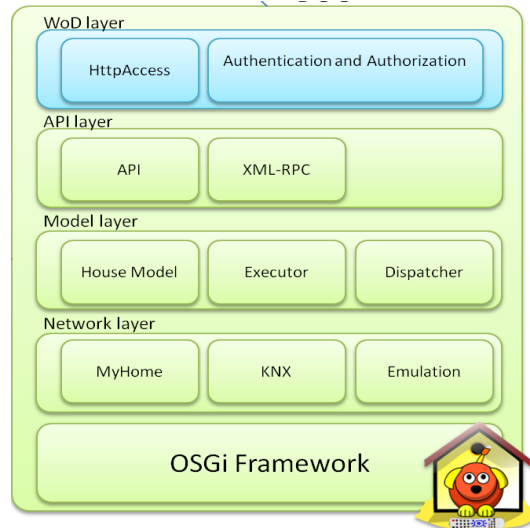


Figure 2: WoD Layer inside Dog

information and to control devices in a domotic system over the Internet. The Authentication and Authorization unit provides a authentication stub that forwards the incoming request to third-party authentication services like OpenID and OAuth⁷. The Authorization portion is used to authorize the incoming requests according to local policies.

5. Solution

To provide residential gateways the ability to expose power consumption information about an appliance or a set of appliances in a house and also do so by addressing the issues raised in Section 3, this paper proposes a Semantic Energy Information Publishing Framework (SEIPF) based on RDF applicable to a residential home managed by a residential gateway. The SEIPF exposes the energy consumption information of appliances along with different appliance properties in RDF format over the web. SEIPF addresses the issues defined in section 3. The *Energy Consumption Information* modeling issue is addressed by defining a new Energy Profile (E.P) ontology (defined in section 5.1). This ontology is based on the modularity pattern and models the energy consumption information about the appliance, modeled through the underlying domotic ontology, i.e., DogOnt. The modularity pattern provides separation to model different

⁷<http://oauth.net/>

aspects of a system through separate ontologies and provides the ontology ability to be plugged with various ontology. The *Machine Understandable Format* issue is addressed by adopting RDF as the standard format to expose information because it provides meaningful representation of information which can be semantically post processed, as explained in section 4. The complete approach is defined in section 5.3. The *Information Publishing Control* issue is currently addressed by using the Authentication and Authorization unit of the WoD architecture. However, in future we intend to incorporate an ontology based access control policy. It is further explained in section 5.2.

5.1. Energy Profile Ontology (E.P)

To model the energy consumption information, an Energy Profile (E.P) ontology was developed. It models the energy consumption information about different appliances in the house. The E.P ontology is developed according to the modularity pattern, so that it can be attached to ontology that can describe the domotic environment of a building (DogOnt is out case). The basic concepts of the E.P Ontology are DeviceProfile and Consumption (as shown in figure 3).

1. *Consumption*: This class encodes the power consumed by an appliance in a given state.
 - *nominalValue*: This property shows the nominal power consumption of an appliance state. It gives the estimated power consumption of a device in a state.
 - *realValue*: This property is the measured power consumption of an appliance in a given state.
 - *associatedState*: This property relates the instances of the Consumption class to a given state of an appliance.
 - *hasUnit*: This property defines the unit of power for the power consumed by the appliance, expressed as one pre-defined instance of the *MetricUnit* class in the Measurement Units Ontology⁸.
2. *DeviceProfile*: This class describes the energy profiles of all the major device categories in the house. The energy profile information can be related to lamp, coffemaker, dishwasher etc. The class has three properties.

⁸<http://idi.fundacionctic.org/muo/muo-vocab.html>

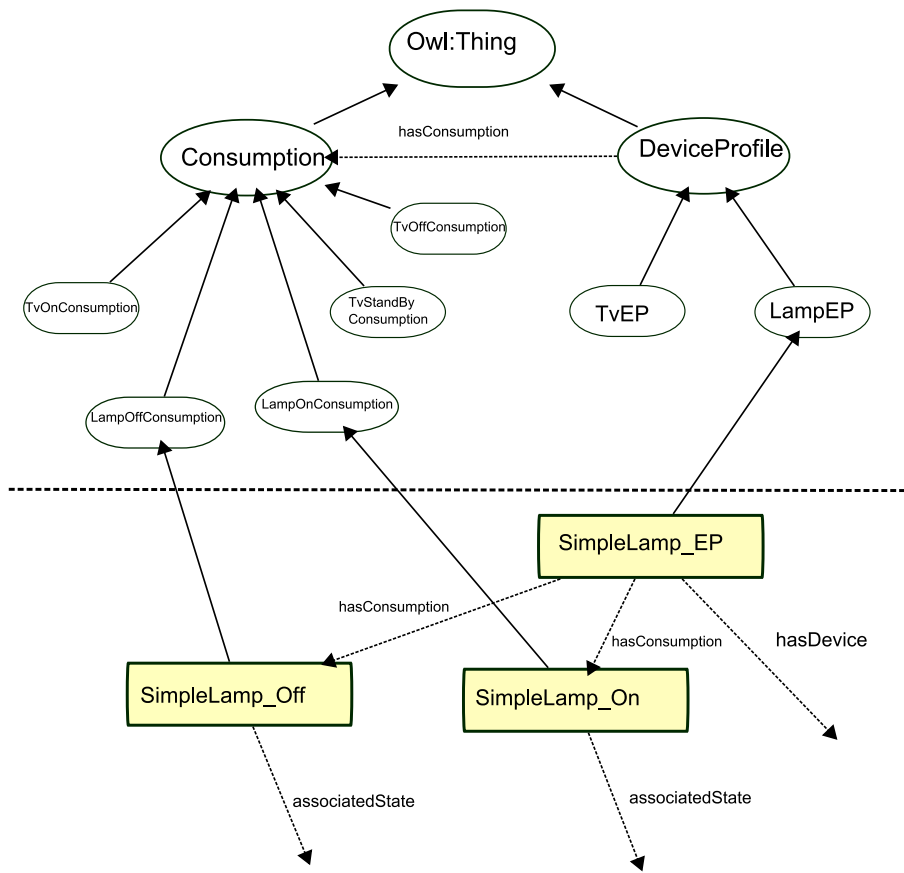


Figure 3: Energy Profile Ontology

```

<LampOffConsumption rdf:ID="SimpleLamp_Off"/>

<LampOnConsumption rdf:ID="SimpleLamp_On">
  <hasUnit rdf:resource="http://purl.oclc.org/NET/muo/ucum/unit/power/Watt"/>
  <realValue>35</realValue>
</LampOnConsumption>

<LampEP rdf:ID="SimpleLamp_EP">
  <hasConsumption rdf:resource="#SimpleLamp_On"/>
  <hasConsumption rdf:resource="#SimpleLamp_Off"/>
</LampEP>

```

Figure 4: An excerpt of the Energy consumption information about a device

- *hasConsumption*: This property relates the DeviceProfile instances to Consumption instances. An appliance can have multiple consumption levels corresponding to the given state of the appliance and this property stores this information.
- *hasDevice*: This property relates an instance of device energy profile to a particular device.

The E.P ontology defines two extension points through which DogOnt ontology defining the domotic system can be attached. The first is the *hasDevice* property of DeviceProfile class, which attaches a energy consumption information structure with a device or an appliance. For example, in DogOnt it relates to instances of Controllable concept. The second is the *associatedState* property of the Consumption class, which relates a given state of the appliance or device to its consumption level. For example, in DogOnt it relates to the instances of StateValue concept.

A fragment of E.P can be defined as shown in Figure 4 where we define a single Device Profile instance named SimpleLamp_EP. SimpleLamp_EP is attached to two consumption instances SimpleLamp_On and SimpleLamp_Off, which are instances of LampOnConsumption and LampOffConsumption classes respectively.

5.2. Information Access Control

The residential gateway houses different chunks of data about a home ranging from appliance properties and operations to sensing the presence of people and their choices. Some of this information can be utilized to provide a better standard of living to the people living inside the house, e.g., informing the people about their current energy consumption can help them to be more energy efficient. Related approaches to provide semantic access control to a system may be found in the literature. Chi-Chun et al. [18] proposed a Semantic Access Control Enabler

(SACE), a middle ware-based system that has been designed and implemented to enable Semantic Access Control on the Web. Toninelli et al. [19] proposed a semantic context aware policy model that adopts ontologies and rules to express context and context-aware access control policies and supports policy adaptation. Ionita et al. [20] proposed a model that regulates access control on ontologies defined in the Semantic Web.

Since the main issue of this paper is on power consumption information sharing, we present here a very basic solution for our SEIPF implementation. Currently the SEIPF uses the Authentication and Authorization mechanism provided by WoD layer inside Dog to control the access to information.

5.3. *Machine Understandable format*

Exposing power consumption information in an open, neutral and semantic format will allow multiple services to use the information according to their application goals and, in the future, will allow intelligent negotiation between automated software agents. To achieve the aforementioned task, RDF was adopted as an open format that has embedded semantic information which allows the information to be machine understandable. SEIPF publishes all the information pertaining to an appliance, including its operating states, related current power consumption and general properties, as a pure RDF structure.

To provide reasoning support over the RDF response received from the SEIPF, a basic set of general concepts were defined through a vocabulary. The vocabulary is encoded in the SimpleDomoticData ontology, which is very similar to E.P ontology but it was created separately for following reasons:

1. The E.P ontology was developed to model only the power consumption of an appliance or group of appliances. The actual appliance modeling is provided through DogOnt ontology. Whereas, in SimpleDomoticData we model the device and its power consumption. It can be extended to include other appliance properties.
2. Providing the response based on DogOnt and E.P ontology would have required external applications to understand the complex structure of DogOnt with additional information about the domotic system, which in this case is not always needed. Therefore, to provide easy and simple integration a simplified SimpleDomoticData vocabulary is preferred to encode the response.

The ontology and its general concepts are explained below:

1. *Device* This class indicates the device or the appliance for which power consumption is inquired.
 - *hasConsumption*: This property relates the instances of Device class to the Consumption class (defined later) instances.
 - *hasState*: This property relates the instances of Device class to the State class (defined later) instances.
2. *State* The 'State' concept related to the current state of the device.
 - *hasStateValue*: Defines the actual state value of the instance of State class.
3. *Consumption*: This class encodes the energy consumption information about an appliance in a given state.
 - *hasUnit*: This property defines the unit of power for the power consumed by the appliance, according to the Measurement Units Ontology.
 - *value*: This property shows the power consumption of a device.

6. Semantic Energy Information Publishing Framework (SEIPF) Architecture

The SEIPF can be installed on any centralized residential gateway that uses the DogOnt ontology to model the domotic structure of an environment. It comprises a core Publishing Unit that provides the power consumption details pertaining to different appliances in the house and other appliance properties and is explained more in section 6.1.

SEIPF is integrated with WoD. WoD provides an interface over the web based on the REST over HTTP interaction pattern to access the domotic system of an environment. The interface is implemented through an OSGi bundle named HttpAccess. The HttpAccess bundle was extended to add new functionalities to query SEIPF. The advantage of integrating SEIPF with WoD is to provide functions that enable a requesting entity to acquire information in Linked Data format about the general domotic structure of the environment and the identification of different devices installed in an environment. The requesting entity could be a third-party application, a service or an automated agent etc.

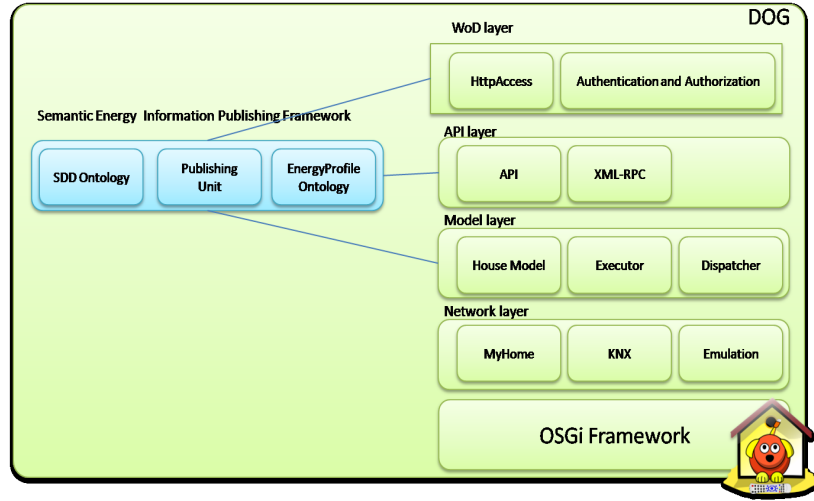


Figure 5: Publishing Framework Architecture

The request can be made with certain parameters (using the HTTP GET method) to retrieve the power consumption information from the SEIPF. The parameters and their possible values are shown in Table 1.

Table 1: List of Parameters

| Parameter | Values | Example | Detail |
|----------------|---------------------|------------|--|
| command | info | info | To request an appliance power consumption |
| device | <i>device id</i> | lamp9 | The identifier of the device |
| room | <i>room id</i> | livingroom | To request information about all devices in the livingroom |
| devicecategory | <i>device type</i> | Lamp | To ask the power consumption of Lamp-type devices. |
| query | <i>SPARQL query</i> | - | To query the DogOnt and E.P ontologies directly. |

The access control to information is provided through the Authentication and Authorization Bundle of WoD. To provide an authentication which is scalable and has a web wide scope, WoD adopts the Open ID [21] as an authentication mechanism for the requesting entity. Open ID is a decentralized standard to authenticate the requesting entity. Currently, the Authorization is provided through a type-based policy but as stated earlier, we are working on providing a separate ontology based publishing policy that will be independent of WoD.

```

<rdf:RDF
  xmlns:sdd="http://elite.polito.it/ontologies/SimpleDomoticData.owl#"
  ... other namespaces ... >

  <rdf:Description rdf:about="#&sdd;ComputerOffConsumption_faisal">
    <hasUnit>http://purl.oclc.org/NET/muo/ucum/unit/power/Watt</hasUnit>
    <value>0</value>
    <rdf:type rdf:resource="&sdd;#Device"/>
  </rdf:Description>

  <rdf:Description rdf:about="#&sdd;#Computer_faisal">
    <hasConsumption rdf:resource="&sdd;#ComputerOffConsumption_faisal"/>
    <rdf:type rdf:resource="&sdd;#Device"/>
  </rdf:Description>

</rdf:RDF>

```

Figure 6: An excerpt of the Energy consumption information about a device

6.1. Publishing Unit

The Publishing unit is the core logic unit of the SEIPF. It consists of many entities as shown in Figure 5. It accepts the request through the HttpAccess bundle. Based on the request, it queries the XML-RPC bundle of Dog to determine the current state of an appliance or set of appliances. Then it determines the power consumption of appliances by quering the E.P ontology and DogOnt ontology (present in the HouseModel Bundle of Dog). The publishing unit then sends a pure RDF response (based on SDD ontology) to the requesting entity.

It has three methods, which can be accessed through the HttpAccess bundle by providing different parameters depicted in Table 1:

1. **getEnergyInfo:** This function provides the current power consumption level of a device in a house based on the current state of the device. It takes the device identifier and returns the power consumption information about the device based on SimpleDomoticData ontology. The device identifier is mentioned through the **device** parameter and it assumes that the **command** parameter is set to value **info**. An excerpt of the response is shown in Figure 6
2. **getRoomEnergyInfo:** This function provides the power consumption of all the appliances present in a given room. The room is mentioned through the **room** parameter.
3. **getDeviceTypeEnergyInfo:** This function provides the power consumption of all the appliances belonging to a single device category. The name of device category is passed as a **devicecategory** parameter.

6.1.1. SPARQL endpoint

The SPARQL endpoint provides the ontological level access to the requesting entity. To ensure safety, its access is granted to the highest levels of authorization, only. SPARQL queries are forwarded to query DogOnt and E.P ontologies directly, for extracting general device properties and power consumption details. As defined in Table 1, the query parameter can be used to access SPARQL end-point.

7. Implementation and Experiments

The core publishing unit of SEIPF is implemented as a separate OSGi bundle inside Dog. We adopted the Eclipse Equinox⁹ OSGi framework to implement the bundle. As stated earlier, SEIPF uses the HttpAccess bundle of WoD to provide access over the web. The HttpAccess bundle uses the jetty web server¹⁰ to expose its services. Access Control is provided through the Authentication and Authorization bundle of WoD. It uses the OpenID4Java¹¹ library to forward the authentication credentials to the appropriate external OpenID server. Requesting entities are authorized according to different levels, based on the type of entity accessing the framework.

The goal of SEIPF is to provide the residential gateway ability to expose the power consumption of different devices in an open, effective and semantic format to enable external applications to consume information according to their own application goals. The applications can be standalone providing the feedback on the current power consumption of devices or it could be mash-up applications that consume data from different data sharing sources to provide feedback. As a proof , we have implemented two experimental applications. We integrated SEIPF with Dog and ran the tests in our department Lab, using two demo cases equipped (shown in Figure 7), respectively with a BTicino MyOpen and a KNX domotic plant. We marked different buttons to emulate the functioning of three devices for our experiment namely: a computer, a coffee maker and a lamp.

The first application is a standalone application that provides the current power consumption of the emulated devices. The testing application was built as a separate Java application that queries the SEIPF to acquire the current power consumption of emulated devices and uses

⁹<http://www.eclipse.org/equinox/>

¹⁰<http://www.mortbay.org/jetty/>

¹¹<http://code.google.com/p/openid4java/>



Figure 7: BTicino and KNX Domotic demo cases

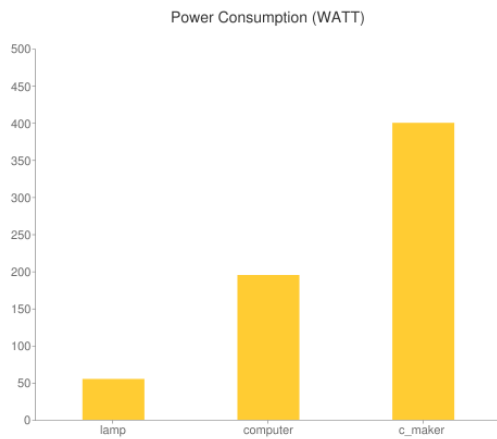


Figure 8: Current Power Consumption of Emulated Devices

the Google Chart Tools¹² to provide graphical feedback on the current power consumption of appliances. A snapshot of the response of the application is shown in Figure 8.

The second application acts as a data sharing application and it accumulates power consumption of individual emulated device over time. The application shares the data with the Pachube¹³ service. Pachube is a convenient, secure and scalable platform that helps applications and services connect to and build the Internet of Things. It store, shares and discovers realtime sensor, energy and environment data from objects, devices and buildings around the world. Pachube provides most of its functionality through a REST based API and can be used to send real time

¹²<http://code.google.com/intl/it-IT/apis/charttools/>

¹³<http://www.pachube.com/>

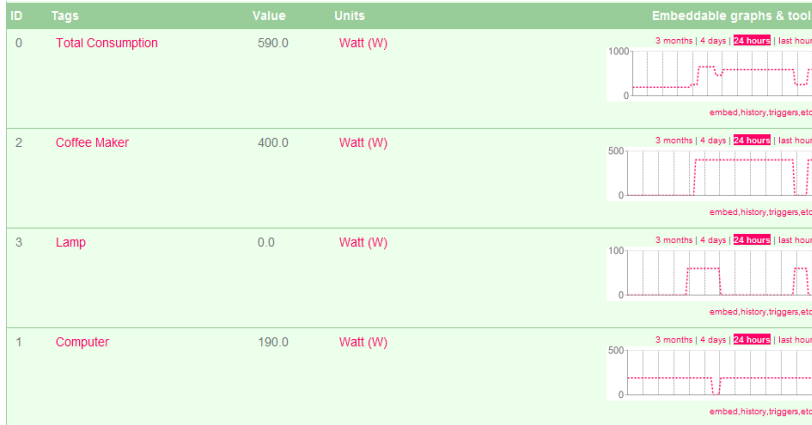


Figure 9: A snapshot of the graph obtained on Pachube by posting Power Consumption Information

sensor, energy and environment data from anywhere around the globe. We built a Java application that periodically queries the SEIPF for power consumption of appliances over time. The application uses polling to acquire data over time and then sends the power consumption data to the Pachube server. A snapshot of the power consumption data accumulated over time on Pachube is shown in Figure 9.

The two experimental applications prove the feasibility of the framework as well as provides a step towards defining an open, standard and semantic powered format that will allows different applications to use power consumption data according to their own application specific goals.

8. Related Works

Google PowerMeter [22] is a free energy monitoring tool that allows you to view your home's energy consumption from anywhere online. It assumes that the device must make an SSL-secured outbound TCP/IP connection to Google so that it can periodically transmit data to Google via HTTPS. Typically, a device should use the device owner's home Internet connection to transmit data. Our approach is different from that of Google Powermeter. The basic assumption is that all the devices in the house are controlled by a centralized residential gateway. The publishing framework exposes the information in a machine understandable RDF format, which can be semantically post-processed by any third party applications, services or automated agents. The information is exposed through a proper authentication mechanism and the resident of the house is provided the complete control over the information that is exposed through the

framework.

Weiss et al. [23] proposed an interactive feedback system that uses a smart electricity meter to provide consumption feedback for different household devices. It also provides a set of API to communicate with the smart electricity meters. The SEIPF approach is different as it can be installed on any residential gateway that uses DogOnt to define the domotic structure of a house. SEIPF also has the ability to expose different information related to devices. Moreover, the SEIPF exposes the information in pure RDF format which allows any application to consume power consumption information according to its own application requirements. By contrast, [23] provides a predefined custom format, and exposes consumption information, only.

Sheth et al. [24] proposed that the sensor data retrieved from sensor networks is annotated with semantic metadata to increase interoperability as well as provide contextual information essential for situational knowledge. In particular, annotating sensor data with spatial, temporal, and thematic semantic meta data. The SEIPF publishing framework exposes the information in a pure RDF along with the option to view ontologies to understand the whole structure of information instead of annotating the information. The framework also provide a mechanism to authenticate and authorize the third party applications, services or automated agents, and provides the consumer information in a restricted manner.

9. Conclusion and Future Works

This paper presents a Semantic Energy Information Publishing Framework (SEIPF) that can be installed on a Dog residential gateway to publish power consumption information of different appliances in a house environment. A new modular E.P ontology to model the power consumption of different appliances in the house is proposed. Modularity allows the E.P ontology to be plugged in the DogOnt ontology that models the domotic plant in a house. SEIPF exposes the power consumed by different appliance and different appliance properties in a pure RDF format. The goal of our approach is to make power consumption information machine understandable to support intelligent negotiation. This will enable today any third-party application, services or agents given authorization to access power consumption details of a house or a building and help build standalone or data sharing application to evolve a energy aware and energy efficient society. In future, the SEIPF could also help us build systems where energy consumption can be co-ordinated between different consumers. The semantic nature of the exposed data will help

build application where automated intelligent negotiation and consumption coordination can take place, evolving in to intelligent energy grids.

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