SWEEB: Semantic Web-enabled Energy Efficient Buildings

Niccolò De Caro
Dept. ETRO
Vrije Universiteit Brussel
Pleinlaan, 2 – 1050, Brussels, Belgium

ndecaro@etro.vub.ac.be

ABSTRACT

Energy efficiency and CO_2 reduction in buildings can be achieved by adopting Wireless Sensor and Actuator Networks (WSANs) to perform monitoring and control activities. The advent of embedded Internet and Web technologies eases the integration of the WSANs with the Web, improves interoperability between different devices and applications, and eases the implementation of Semantic Web technologies. This work proposes SWEEB (Semantic Web-enabled Energy Efficient Buildings), a framework based on open Internet and Web standards and Semantic Web technologies, aiming to combine local and remote data to enrich the context information related to the building itself and the deployed WSAN. SWEEB can hence be used to pursue the twofold objective of improving the energy efficiency through smart control, while optimizing the performance of the WSAN deployed within the building.

Keywords: Semantic Web, Wireless Sensor Networks, Web of Things, Energy Efficiency, Building Automation.

1. THESIS STATEMENT

Environmental control and comfort monitoring in buildings have become essential tasks which are linked to health, safety and ergonomics, but also to energy-efficiency and CO_2 reduction. In such context Wireless Sensor and Actuator Networks (WSANs) play an outstanding role in the area of remote monitoring and control. Sensors normally monitor the functioning and the health of building devices, gauge CO_2 levels, monitor temperature and brightness, detect room occupancy, and so on. These data are generally gathered by a central controller, which then controls the proper actuators.

Typically, in today's building automation systems, services are provided by several autonomous application specific subsystems (e.g., lighting, security, fire safety, elevators, building access). Hence, a Building Management System (BMS) has to interact with these subsystems in order to provide global management functionalities. As a result, a main issue for BMS developers concerns interoperability between these subsystems, since each subsystem has different ways to communicate and represent information. As a result, sensor/actuator data are often locked into closed systems and the information they hold cannot be easily shared.

The proposed approach leverages on the support of open standards based on Internet and Web technologies (i.e., 6LoWPAN[1], RPL[2], CoAP[3]) on embedded sensors and actuators. This allows to overcome the protocol fragmentation issue, to improve interoperability, flexibility and scalability, and to ease the integration of the WSANs with the Internet and the Web while avoiding the introduction of complex protocol translation gateways. However, the issue of translating between different data representations still remains.

In SWEEB, to this end, WSANs are enhanced with the support of Semantic Web technologies, which extend the current Web by describing information and its meaning in a machine-understandable way. In the building automation domain, this enables:

- to collect and combine building information from different data sources (i.e., sensors, actuators), and to enrich context information with semantic information available on the Web (e.g., calendar/weather web services, open datasets…);
- to reason on top of this aggregated information, allowing for efficient searches and query, and for energy saving decision making.

In particular, this work puts a strong accent on the management of the WSAN deployed within the building. Indeed, information related to the WSAN performance (e.g., in terms of latency, packet loss, throughput) can also be collected, semantically enriched, linked with context information, and reasoned on. As a result, the WSAN can be dynamically configured with proper network settings, with the aim of enhancing its performance, while reducing

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[1] IPv6 for Low-power Wireless Personal Area Networks

[2] IPv6 Routing Protocol for Low-Power and Lossy Networks

[3] Constrained Application Protocol

the need of human intervention required for commissioning and maintenance of the WSAN.

2. RELATED WORK

The approach of reusing the standard principles of the modern Web architecture to integrate physical objects to the Web has already been followed in [1] and [2], where sensor/actuator platforms include a Web server offering sensing, control and internal functionalities as Representation State Transfer (REST) resources. Both contributions focus on the smart home application domain. In [3], the authors propose an approach which moves the application logic from the embedded devices to the cloud, enabling the reuse of deployed devices for different applications without changing the firmware.

In contrast to these works, which do not involve semantic technologies, in [4] the authors demonstrate how the smart self-annotation of devices with semantic information, combined with the use of state-of-the-art embedded web and Internet technologies like 6LoWPAN and CoAP, can enable basic plug-and-play configuration of devices. In addition, energy-saving policies can be set by means of semantic techniques. The demonstrator is based on the framework illustrated in [5], which enables devices to semantically describe themselves through Resource Description Framework (RDF) documents. In [6], another plug-and-play framework for sensor network based on Semantic Web technologies is introduced, where semantic annotation is executed at gateway level. However, the aforementioned approaches do not take into account network and device conditions as input for the device configuration process. Moreover, in SWEEB such process is executed dynamically since network status changes frequently in WSANs, and not only once, when a new device is plugged into the network.

3. APPROACH

This paper presents SWEEB, a semantic-based framework aiming to provide context information to the building environment, with the twofold objective of improving the energy efficiency of the building itself while optimizing the performance of the WSAN deployed within the building.

The framework leverages on Semantic Web technologies to combine data coming from heterogeneous sources like sensors, actuators, web services and open datasets. Such data can concern the following aspects.

- Building information such as room temperature, noise levels, lighting status, electrical power consumption and room occupancy.
- Application functionalities describing how sensors and actuators collaborate in order to perform energy saving tasks (e.g., light actuator *A* switches on a light section when sensor *S* measures a luminosity level lower than a certain threshold). Such patterns are either set by the user, i.e. the building manager, or inferred by the framework.
- Quality of Service (QoS) requirements of the application functionalities (e.g., lighting control applications have strict requirements in terms of delay and reliability, unlike noise monitoring applications). Again, these requirements can be either manually set or inferred.
- WSAN information like network topology, communication protocols implemented, routing policies, protocol parameters, and so on.
- WSAN performance, described by delay, jitter, throughput, packet loss, received signal strength, device battery level, measured by each WSAN node.

All this information, combined with building automation and WSAN knowledge represented through domain ontologies, forms a rich basis for the BMS application, based on a semantic reasoner, which is able to infer new information allowing for efficient queries, automatic or improved decision making, and anomaly/fault detection.

The decision making process mainly concerns the configuration of WSAN nodes by setting both protocol parameters (e.g., routing policies, reliability policies…) and application functionalities. The aim is to save energy and satisfy user comfort requirements, while optimizing the overall WSAN performance.

The architecture of the framework is represented in Figure 1 and described hereafter. The **WSAN** consists of a set of motes equipped with additional sensors or connected to relays. Each mote implements the protocol stack shown in Figure 2, and exposes both application functionalities and protocol configuration as resources through a RESTful API based on the CoAP protocol. WSAN available resources are available in the **Resource Directory**, which also exposes a RESTful API.

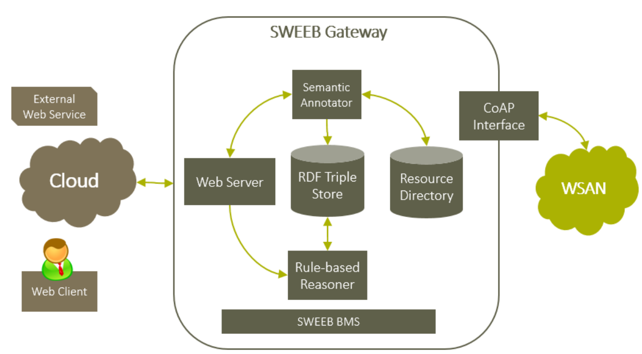

Figure 1. SWEEB Architecture

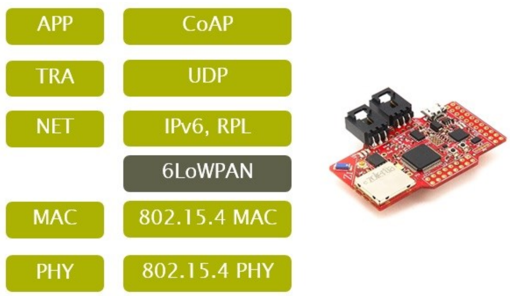

Figure 2. WSAN node: protocol stack

The **RDF Triple Store** contains all the information concerning the building and the WSAN. The core of this block is the SWEEB schema ontology, an OWL 2 ontology aligned with the Semantic Sensor Network (SSN) ontology. All the information is collected and semantically enriched by a **Semantic Annotator**, which is able to communicate with the WSAN through a **CoAP Interface** based on Californium[4], a CoAP implementation in Java.

The **Rule-based Reasoner** is based on the Pellet[5] reasoner, and operates according to rules expressed in Semantic Web Rule Language (SWRL). Based on this, the **SWEEB BMS** takes autonomous decisions on building management and WSAN management and send commands to the WSAN to execute the proper actions. The **Web Application** is the interface between the BMS and the user. It provides building management functionalities, and it also allows the user to configure the system (e.g., by specifying annotations for raw data or by setting rules for the reasoner).

4. CHALLENGES

Main challenges are due to the contrast between the complexity of Internet, Web and Semantic Web technologies, and the constraints that are intrinsic of the embedded devices that WSANs are composed of. Moreover, this work aims to investigate and analyze how WSANs must be configured in order to match the QoS requirements related to different application scenarios, so that rules for the reasoner can be automatically created. As an evidence, the characteristics of the low-power, lossy and unstable wireless channels makes dynamic network management a tricky task.

5. CONCLUSIONS AND FUTURE WORK

We have presented a framework based on state-of-the-art embedded Internet and Web standards, and Semantic Web technologies, which enables smart management of the building and of the WSAN deployed within it. This work is in progress. The existing preliminary ontology needs to be refined, and consistent implementation and testing work has to be done. A framework which enables the configuration CoAP reliability parameters at runtime has been developed, but such approach needs to be extended to the configuration of routing policies. Finally, the impact of this framework on WSAN performance must be analyzed.

6. ACKNOWLEDGMENTS

Part of the results described in this paper are obtained from the 6LowPan project. This project has been supported financially by the IWT - Flemish Agency for Innovation by Science and Technology under Tetra.

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8. BIOGRAPHY

Niccolò De Caro is a researcher at the ETRO department of the Vrije Universiteit Brussel (Belgium) since January 2012. He is now in the 2nd year of his PhD. He acquired his Master's degree in Telecommunications and Computer Engineering at the University of Perugia in 2011. His thesis focused on design and implementation of mechanisms based on IP and Web technologies for embedded devices, with the objective of achieving interoperability between sensor and actuator networks and the Web. He has worked on an EU-FP7-funded project “EDISON”, aiming to achieve energy efficiency in buildings through smart sensor-based control of a DC-based lighting infrastructure. Now he works on the Belgian-funded project “6LOWPAN”, where his research goal consists in optimizing the performance of plug-n-play sensor and actuator networks for home/building automation, leveraging on Internet, Web and Semantic Web technologies.

[4] https://github.com/mkovatsc/Californium

[5] http://clarkparsia.com/pellet/