

System Architecture for a Smart University Building

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Abstract. This paper presents a system architecture that provides smart building monitoring and management. The proposed solution integrates heterogeneous geographically disparate sensor networks and devices, and enables optimal operations of the building while reducing its energy footprint. The platform is based on Semantic Web Services composition using AI Planning, that integrates and manages WiFi, RFID and ZigBee networks providing connectivity to the devices. The goal is to develop a model that follows the latest guidelines in the area of Information Communication Technologies (ICT) for sustainable growth, energy efficiency and better quality of life.

Keywords: Sensor Networks, Embedded Systems, Smart Building, Semantic Web Service Composition, Energy Efficiency.

1 Introduction

Information and Communication Technologies (ICT) enable the operation and integration of smart metering devices in complex environments in the form of sensor networks and embedded systems. Applications are met in various domains that target intelligent management, monitoring and improvement of QoL. Characteristic examples are environmental monitoring [1], smart building scenarios [2] and Telemedicine.

In this paper, an intelligent platform is proposed, that integrates sensors within a university building and campus based on Web Services middleware. The aim is to provide automation of common processes, reduce the energy footprint and provide control of devices in a remote manner. The proposed platform, named ‘Smart International Hellenic University’*, incorporates the ‘Intelligent Building’ concept [2] and the ‘Smart Building’ initiatives that target energy footprint minimization, following guidelines of various FP7 projects, such as Dehems [3] and Hydra [4]. Dehems presents a system architecture for energy efficiency monitoring in different households, mainly focusing on white appliances. Hydra proposes a middleware to expose various devices through Semantic Web Services. Our approach is also based on a Semantic Web Service middleware, which is further enriched with dynamic

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composition capabilities, proposes specific applications for a university building and facilitates educational processes.

The rest of the paper is organized as follows: In the first section of the paper the ‘Smart University’ concept is presented. This is followed by a review of the available sensor network technologies. Finally, the integration platform is presented with a brief explanation of the system’s components.

2 Smart Building Overview

The Smart Building concept enables remote monitoring and management of processes while providing energy efficiency. The objective of the proposed platform is to design, develop and evaluate a smart building in the International Hellenic University (IHU) and deliver the following services to the end users:

i) Power Consumption Monitoring

An essential step in reducing the energy consumption in a building is the implementation of a measuring and monitoring system. To support such functionality, we intend to monitor the individual electrical devices and appliances of the building, allowing the users to understand/determine further how the energy consumption is distributed among the various IHU facilities. In addition, the system will enable real time monitoring of the University’s data center and provide on line information concerning the Data Center infrastructure Efficiency index (DCiE) and the Data Center energy Productivity (DCeP), as defined by the green grid association and in [5]. Users will be able to convey their information in multiple useful formats, both in past time and in real time, and in different spatial granularity scales, ranging from department-wide, auditorium-wide to appliance-specific consumption characteristics.

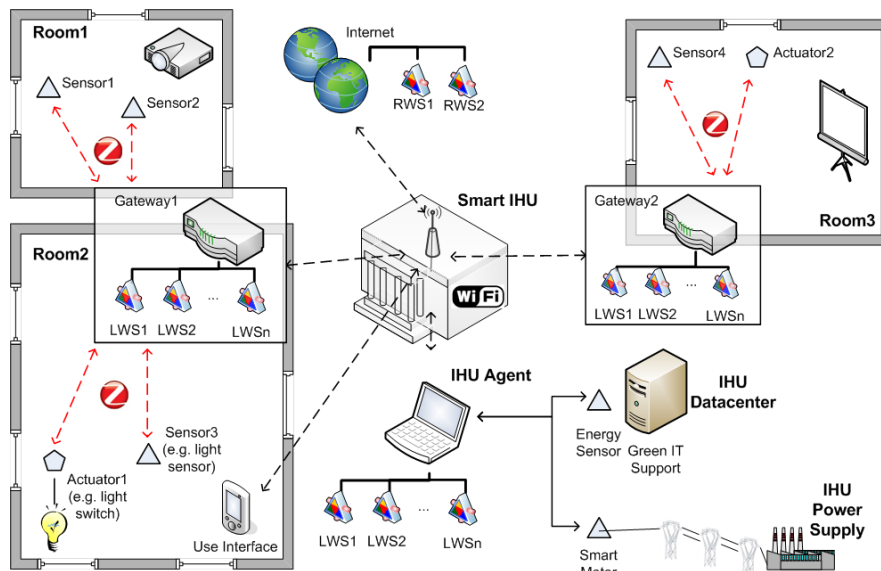


Figure 1. Architecture of the Smart University System

ii) Energy Efficiency savings

An interactive platform for controlling the energy consumption of nodes is also considered. Through consumption visualization, users are empowered to take energy saving actions based on i) the advanced statistics provided by the system's remote monitoring and optimization capabilities and ii) a simple look at the devices' status.

iii) Building Automation

In the smart building environment, whose architecture is presented in Figure 1, sensors and actuators are deployed spatially in those rooms of the building where monitoring and management is targeted. A number of WiFi/ZigBee gateways serve as both sensors sinks and interoperability agents for the various deployed sensor networks. All building-wide monitoring and controlling capabilities are published in the form of modular web services. The user can access content-based information of the building's parameters based on ZigBee, WiFi and RFID networks. Moreover, a smart metering device is utilized to monitor the building-wide energy consumption.

3 Home automation Network Technology

The system incorporates different types of sensors that are used to monitor standard environmental attributes, such as humidity, temperature and luminance. These are used to schedule the on/off switching of devices through actuators. Emergencies (e.g. fire, security breaches) are detected by smoke and motion sensors. The aforementioned devices serve as building blocks for the realization of all energy efficiency and automation scenarios.

It is known that the error rates of wireless communication systems can vary widely, depending on the positioning of the devices. Optimal positioning, will be resolved via simulations based on ray-tracing and coverage prediction techniques.

For the purpose of our investigation, the following communication technologies and corresponding protocols were reviewed for possible integration to the present project.

3.1 Power Line Communication Technologies

Power Line Communication (PLC) [6] technology uses the existing power line infrastructures to transmit data and control signals. There are several PLC protocols, aiming at home automation, home security, and lighting control.

X-10 is the oldest common automation protocol over power lines used in homes. It operates by sending 120 kHz signal bursts, each one millisecond, during zero crossings of AC voltage. X-10 is inexpensive and simple to use, however, it only supports a raw data rate of around 50bps and 100 bps in 60 Hz and 50 Hz respectively, while it is very prone to errors.

The Homeplug Alliance has released a series of standards with different Physical Layer modulation techniques. The first broadband power line communication specification HomePlug 1.0 [7] was introduced for home networking, with a rate of 14Mbps. Succeeding specifications are "HomePlug AV" which aim to provide sufficient bandwidth for multimedia applications in residences, "HomePlug BPL"

designed for high-speed Internet access inside residences and “HomePlug Command and Control” that provides a low-speed and low-cost solution for home automation.

The local operation networks (Lonworks) platform [8] was introduced to provide an open interoperability standard among vendors in the control network industry. The physical layer (PHY) signalling can be implemented over a range of communication media, including twisted pair, coaxial cable, fiber, Infrared/Radio Frequency (RF) and power line. The LonWorks PLC technology offers data transmission rate of either 5.4 or 3.6 kbps depending on the frequency.

3.2 Radio Systems

A variety of short-range wireless technologies have emerged, that provide flexible networking patterns suitable for residences. In terms of network control in a smart home, those wireless technologies yield speed, low power consumption, high cost-effectiveness, networking and deployment flexibility, as well as full house coverage.

The Z-Wave technology uses the proprietary 868.42 ISM MHz band in Europe (908MHz in U.S.A) and has a raw data rate of 40Kbps within 100 meters using Binary Frequency Shift Keying (BFSK). It is typically used for consumption monitoring of small houses.

Zigbee [9] is an IEEE 802.15.4-based bidirectional wireless technology for home and building automation domain aiming to reduce energy consumption and prolong wireless sensor battery life [10]. Based on this characteristic, Zigbee technology is preferred for home automation and sensor networking.

Insteon pioneers use both wireless and power line technologies simultaneously with a specially designed protocol. An insteon-based device works on a frequency of 131.65 KHz over the power line for a sustained bit rate of 2.88Kbps and also offers an instantaneous bit rate of 38.4Kbps over the Radio Frequency (RF) 904Mhz band.

Radio Frequency Identification (RFID) tags are used to provide environments that are safer, smarter, and more secure. This technology is the emerging way of controlling information and material flow, especially suitable for large production networks. It relies on the embedment of passive UHF tags in all monitored objects, which enables short distance tracking and low cost network deployments.

Known electrical interference issues of the power line technologies have led to the adoption of radio communication scheme among sensors in the IHU smart building. Furthermore, Zigbee was chosen as the most appropriate related protocol since it offers battery lifetime maximization for the sensors.

4 Information Integration

In the context of various devices, protocols and data formats, there is a need for a common framework that addresses interoperability issues. Most ambient intelligence approaches are based on the Service Oriented Architecture (SOA), where each module of the system is wrapped by a service defining the interface of the module in terms of protocols and functionality.

Nowadays, Web Services [12] are the preferred realization of the basic notion of SOA. As platform-independent APIs, they can be used to facilitate universal remote access to the heterogeneous sensor data as well as control of the system's actuators. Indeed, there are numerous ambient intelligence approaches implementing Web Services as a middleware that serves as a bridge between the various devices and a centralized computing module embodying the intelligence of the system [11, 13, 14].

Web Service descriptions can be vague or misleading, thwarting their efficient use by human users and especially by machines. Therefore, it is important to enhance the definitions of their functionality and interface with well formed metadata. The notion of Semantic Web Services [15] emerged through the evolution of the Semantic Web and Ontologies. Apart from the syntactic meaning of the exchanged messages, they also define the semantic meaning and exploit ontologies while their descriptions come in various languages, like OWL-S¹ and WSDL-S².

The proposed architecture, as presented in Figure 1, facilitates the integration of heterogeneous data by associating each sensor and actuator with Semantic Web Services, described in OWL-S and based on an ontology manager hosted in the IHU Agent. The smart IHU is based on five categories of services:

- a. Local information services (LIS) that connect to the sensors and provide their measurements.
- b. Local Action Services (LAS) that connect to the actuators and realize the requested adjustments (e.g. value on a thermostat)
- c. Local Computation Services (LCS) that perform complex computational tasks (e.g. face recognition on the data from a camera)
- d. Global Computation Services (GCS) that also perform computational tasks but are hosted outside the campus (e.g. public safety services)
- e. Global Providers Services (GPS) that are hosted by various providers (e.g. local gas station) and allow the automatic placement of orders.

LIS and LAS are initially placed in the corresponding gateways, since there is currently limited or no availability of sensors and actuators with computing and TCP/IP capabilities. LCS are hosted by the IHU Agent or other computers connected to the local TCP/IP network, and GCS and GPS are hosted in computers located outside the building.

The IHU Agent is responsible for carrying out complex tasks that facilitate everyday activities of the students and personnel of the IHU. In order to automate these tasks, the agent employs service composition techniques using AI Planning, which has proven to be a very promising approach [16, 17].

5 Conclusion

This paper presented a framework for developing a Smart University application, incorporating an energy-efficient, sensor and actuator network, and an appropriate Information Integration methodology, based on Semantic Web Service Composition.

¹ <http://www.w3.org/Submission/WSDL-S/>

² <http://www.w3.org/Submission/OWL-S/>

It enables real-time monitoring and control of devices towards energy-awareness and optimization. Future research essentially includes implementation of the proposed platform and evaluation of the equipment, network topology and ontology design, in order to exploit the system's Services, in the most efficient, dynamic and fault-tolerant way.

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