Power-managed smart lighting using a semantic interoperability architecture

Citation for published version (APA):
Bhardwaj, S., Syed, A., Ozcelebi, T., & Lukkien, J. J. (2011). Power-managed smart lighting using a semantic interoperability architecture. In 29th International Conference on Consumer Electronics (ICCE 2011, Las Vegas NV, USA, January 9-12, 2011) (pp. 759-760). Piscataway: Institute of Electrical and Electronics Engineers. DOI: 10.1109/ICCE.2011.5722848

DOI:
10.1109/ICCE.2011.5722848

Document status and date:
Published: 01/01/2011

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Power-Managed Smart Lighting Using a Semantic Interoperability Architecture

Sachin Bhardwaj[1], Aly A. Syed[2], Tanır Özçelebi[1], Johan Lukkien[1]
[1]Dept. of Mathematics and Computer Science, Eindhoven University of Technology, P.O. Box 513, 5600 MB, Eindhoven, The Netherlands
[2]Distributed System Architecture, NXP Semiconductors / Central R&D / Research, High Tech Campus 32, 5656 AE, Eindhoven, The Netherlands

***Abstract*—This paper presents a power-managed smart lighting system that allows collaboration of lighting consumer electronics (CE) devices and corresponding system architectures provided by different CE suppliers. In the example scenario, the rooms of a building are categorized as low and high priority, each category utilizing a different system architecture. The rooms collaborate through a semantic interoperability platform. The overall smart lighting system conforms to a power quota regime and maintains a target power consumption level by automatically adjusting lights in the building.**

I. INTRODUCTION

Electric power usage constitutes an important source of financial outflow for building spaces. Therefore, electricity providers offer various schemes for billing. One model is that a building gets a quota of electric power that it is allowed to use. This way, electricity providers can plan their power generation in a cost effective manner. If a building uses more power than its assigned quota, a significantly higher price for electricity is charged, which must be avoided in order to prevent excessive bills. However, the energy usage in a building may vary based on many factors, e.g. due to time of the day and special events such as gatherings. Thus, it is not a trivial task to keep power usage just tightly below a given quota. One approach to solve this problem is to buy more energy than the building would need on average, creating a power quota margin for times of excessive electricity usage, which is suboptimal. The alternative is to assign a power usage quota to the building [1] and use energy in a controlled way. In this approach, the rooms of the building can be divided into two categories: *i*) high priority rooms that are allowed to use power according to whatever demand there is at that time, and *ii*) low priority rooms that are obliged to use the power that is leftover from the quota after the consumption of high priority rooms. CE products from different smart lighting suppliers typically operate over different architectures due to lack of standardization. However, in practice, a smart lighting solution that is installed using CE devices of a given supplier should be easily extendable by products of another supplier. Hence, semantic interoperability between different architectures of different CE suppliers becomes a key challenge.

[1]This work is supported by Smart Objects For Intelligent Applications (SOFIA) project and funded through European JTI ARTEMIS under the subprogramme "Smart Environments and Scalable Digital Services".

II. SEMANTIC INTEROPERABILITY: SOFIA ARCHITECTURE

In the proposed smart lighting system scenario, high priority rooms (R_{high}) are deployed with power measuring lamps, light sensors and motion sensors. The light outputs of power measuring lamps are automatically adjusted as the user activity changes, consuming a certain amount of power for each activity. Smart lighting systems in the low priority rooms (R_{low}) are implemented using the OSAS (Open Service Architecture for Sensors) – an architecture for programming a network of sensors and actuators [2].

Semantic interoperability between these two different architectures is realized by using the Smart-M3 platform [3], [4]. Smart-M3 (multi-vendor, multi-device, multi-domain) is a solution for information interoperability, provided by the SOFIA[1] project. Elements called Knowledge Processors (KP) and Semantic Information Brokers (SIB) form a Smart-M3 network. A KP is an entity that produces or consumes information according to the ontology relevant to its defined functionality. A SIB is an entity, in which high level information for a smart space is stored and maintained. This information can be used and updated by a KP. For example, a producer-KP can collect raw data (e.g. sensory data) from the physical environment and provide semantically meaningful information to the SIB. Similarly, a consumer-KP can subscribe to information available at the SIB and make queries. The KPs and the SIB run the Smart Space Access Protocol (SSAP), which is a simple set of primitives to insert, remove and access data at the SIB, and can be used on top of transport technologies such as TCP/IP or Network on Terminal Architecture (NoTA). The KP can use SSAP for several transaction types such as *join, leave, insert, remove, update, query, subscribe,* and *unsubscribe*.

III. SYSTEM DESIGN

The system architecture of the proposed power-managed smart lighting system is shown in Fig.1.

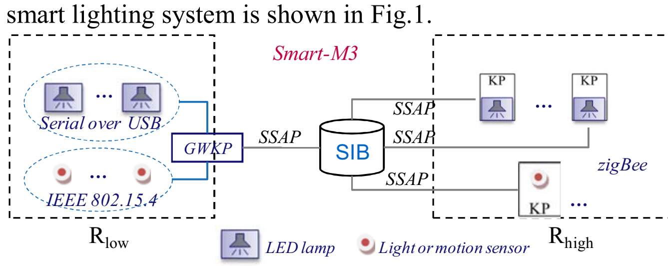

Fig. 1. System architecture of power managed smart lighting.

The lamps and sensors in R_{low} communicate to the SIB through a gateway-KP (GWKP), whereas the power measuring lamps and sensors in R_{high} themselves are individual KPs. Contextual data, e.g. light output and power consumption levels in each room, is stored at the SIB in the form of Resource Data Format (RDF) triplets. The KPs in R_{high} and the GWKP in R_{low} can read and update this data over SSAP as described in Section II. When the power quota is large enough to support all activities in R_{high} and R_{low}, the sensor readings in these rooms are used to set and maintain the illumination based on the user preferences and the activity performed in the room, e.g. reading, sleeping, watching TV [5]. If the illumination measured differs from the desired illumination, the light outputs of the lamps are automatically adjusted by the KPs in each room till the desired illumination is achieved.

R_{high}: All KPs in R_{high} individually and periodically update their power consumption values at the SIB. As these are high priority rooms, the lamps in R_{high} can utilize almost the entire power quota when necessary.

R_{low}: The GWKP translates contextual information between RDF triplet format and OSAS message format that is readable by OSAS sensors and actuators. When the power quota is not sufficient to support R_{low} and R_{high} simultaneously, the GWKP dims the illumination in R_{low} down to an acceptable level. Depending on the R_{high} power consumption information, retrieved via a subscription/query to the SIB, the GWKP brings the power consumption in R_{low} just below the remaining power budget for R_{low}, i.e. Q_l. Therefore, the system never exceeds the total power quota for the building, denoted by Q. Let the power usage (due to lighting) in R_{high} be P_h ($P_h \le Q$).

$$P_h = P_{h,1} + P_{h,2} + ... + P_{h,n} \quad (1)$$

$$Q_l = Q - P_h \quad (2)$$

where $P_{h,i}$ is the power usage by lamp i and n is the total number of lamps in R_{high}. The value of P_h is read periodically from the SIB by the GWKP of R_{low}. Let P_{lowReq} denote the power required for illumination of a certain user activity in R_{low}. The requested power can be provided to rooms in category R_{low} only if $Q_l \ge P_{lowReq}$. Otherwise, the smart lighting systems in these rooms must confine themselves to the leftover power quota (i.e. Q_l) only. The only constraint that the high priority room systems have is $P_h \le Q$.

IV. Experimental Setup

We consider two different system architectures for high and low priority rooms as discussed in Section III. To show interoperability clearly, different types of hardware and communication protocols are employed in the two system architectures. In R_{high}, the power measuring lamps and the sensor KPs communicate with the SIB over Ethernet and ZigBee, respectively, as shown in Fig. 2(a) and (b). On the other hand, in R_{low}, the lamps and the sensors are connected to the GWKP via serial over Universal Serial Bus (USB) and via IEEE 802.15.4, respectively. Furthermore, the GWKP is connected to the SIB by an IP connection, on which the SSAP protocol runs. The wireless light sensors[2] in R_{low} have been designed to measure the light intensity of human perceptible light level from *1 - 1000 lux* as shown in Fig. 2(c). Finally, the LED lamps in R_{low} are a combination of 36 regular LED lamps (6x6 square grid shaped) and attached to an LED actuator[3] as shown in Fig. 2(d) and (e).

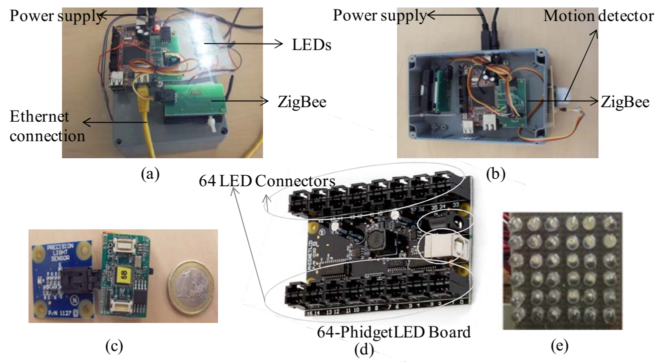

Fig. 2. Hardware for high priority room: (a) High brightness LED lamp, (b) Motion Sensor; and Low priority room hardwares: (c) light sensor (d) LED actuator and (e) LED lamp.

V. Results and Conclusions

The experiments carried out on the proposed system have shown that the semantic interoperability platform allows lighting products from different CE suppliers and the corresponding system architectures to work together. Power consumption management for smart lighting is accomplished without exceeding a given power quota. When the power quota for lighting is sufficient to support all rooms and all activities in a building, the desired illumination levels in both room types are set and maintained automatically based on the user activity. When the power quota is not able to support the low priority rooms, low priority room lamps are dimmed down to utilize the leftover power budget from the high priority rooms.

References

[1] Y. Ma , J. Yu , C. Yang , L. Wang, "Study on power energy consumption model for large-scale public building", 2nd International Workshop on ISA, Wuhan, China, 22-23 May 2010, pp.1-4.

[2] R.P. Bosman, J. J. Lukkien, R. Verhoeven; "An integral approach to programming sensor networks", IEEE CCNC, Las Vegas NV, USA, January 10-13, 2009, pp. 1-5.

[3] A. Toninelli, S. Pantsar-Syväniemi, P. Bellavista, E. Ovaska, "Supporting context awareness in smart environments: a scalable approach to information interoperability", International Workshop on M-MPAC, Nov 30, Urbana Champaign, Illinois, USA, 2009.

[4] S. Bhardwaj, T. Ozcelebi, J.J. Lukkien, R. Verhoeven, "Semantic interoperability in a heterogeneous smart lighting system," IEEE ISCC, International Workshop on SISS, Riccione, Italy, June 2010.

[5] S. Bhardwaj, T. Ozcelebi, J.J. Lukkien, "Smart lighting using LED luminaries", IEEE Percom, SmartE Workshop, Mannheim, Germany, pp. 654-659, March 2010.

[2] Wireless light sensors used in our testbed are a combination of BSN (http://ubimon.doc.ic.ac.uk/bsn/m621.html) nodes and the commercially available Phidgets precision light sensor.

[3] Phidget-64-LED board as an LED actuator (http://www.phidgets.com).