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Smart Lighting solutions for Smart Cities

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Abstract*— Smart cities play an increasingly important role for the sustainable economic development of a determined area. Smart cities are considered a key element for generating wealth, knowledge and diversity, both economically and socially. A Smart City is the engine to reach the sustainability of its infrastructure and facilitate the sustainable development of its industry, buildings and citizens. The first goal to reach that sustainability is reduce the energy consumption and the levels of greenhouse gases (GHG). For that purpose, it is required scalability, extensibility and integration of new resources in order to reach a higher awareness about the energy consumption, distribution and generation, which allows a suitable modeling which can enable new countermeasure and action plans to mitigate the current excessive power consumption effects. Smart Cities should offer efficient support for global communications and access to the services and information. It is required to enable a homogenous and seamless machine to machine (M2M) communication in the different solutions and use cases. This work presents how to reach an interoperable Smart Lighting solution over the emerging M2M protocols such as CoAP built over REST architecture. This follows up the guidelines defined by the IP for Smart Objects Alliance (IPSO Alliance) in order to implement and interoperable semantic level for the street lighting, and describes the integration of the communications and logic over the existing street lighting infrastructure.

Keywords-Smart Lighting; Smart Cities; 6LoWPAN; CoAP; IPSO Alliance; Interoperability; Semantic.

I. INTRODUCTION

Smart Cities need to support a comprehensive proposal on the use of the wide set of technologies available, enabling it to maintain a thorough survey of all the processes that take place at a particular time, and that directly affect the scheme operation thereof, allowing therefore be aware of what's happening and adapt their behavior according to the events and situations that can be determined through an analysis of data collected or preset.

Additionally, due to the continued growth of the population at the same time of the development, at present, about half of the world population lives in cities, and this growth continues to escalate with forecasts that by 2050, this value will amount to around 70%. This undoubtedly poses new challenges in terms of city management, intelligent buildings and environments, especially in regard to efficient energy management.

The versatility in the application of the technologies used will result necessarily in services that can provide a more efficient model for energy management, environmental factors, or aspects related to the health and welfare of citizens, efficient management of public transport, or just to the monitoring of any variable of interest, system or service that can be potentially connected to an information network, with the ultimate goal of improving the experience and quality of life for the citizens, the efficient and rational use of the target resource, and at the ensuring a continued and sustainable economic growth.

From a technological point of view, the Smart City and the Internet of Things concepts are closely related because their *modus operandi* lies in the philosophy of M2M (Machine to Machine) communications and extend its capabilities within what it is defined as the Future Internet.

On this regard, the Future Internet, therefore is called to become a digital platform of global dimensions through which, in an ideal manner, will be connected any virtual or physical entity with the ability to send or receive information to or from a interconnection network. Undoubtedly, this new trend towards connectivity, will lead to new ways for becoming more efficient in the management whether they are applied to domestic appliances, infrastructures, companies or communities of users and systems, presenting even the ability to overcome national and supra-national management levels.

Within this context, the Smart Cities can be seen as a mechanism that will, ultimately, lead on a better exploitation of resources in a more efficient manner and result in a more responsible behavior of all actors involved in this new scenario at every level.

Concretely speaking about lighting, efficient illumination systems and energy consumption in homes, offices and streets of a city comprises a key component of a nowadays tenor. The trend to a massive and rapid escalation of new technologies with the aim of creating environments that enables efficient appliances will preserve our planet and our natural resources through the implementation of a sustainable and economic growth ensuring preservation and conscious consumption of energy assets.

On this way, lighting is responsible for 19% of global use of electrical energy, and accounts for about 6% of the total emissions of greenhouse gases [1]. As an example, getting a savings of approximately 40% of the energy we use for lighting would give a positive impact equivalent to removing half the emissions from the production of electricity and heat generation in the U.S. [2]. In definitive, it is required extension from the power consumption from the cites to also the street lighting, in order to reach the desirable reductions for Europe 2020 horizon about energy efficiency, and the low-carbon economy by 2050 [3].

This proposal is focused on promote the extension of the existing Street Lighting infrastructure with the integration of additional sensors, control and communication capabilities.

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This revolution is already underway within the lighting field. Momentum posed by technological advances in this area lead for, in addition to lowering the impact on the environment, the generation of economic value, and have the power to change our lives for the better.

Regarding to lighting technologies, LED (Light Emitting Diode) is an unprecedented revolution in the lighting field, excluding of course the days of Thomas Edison. Technological achievements as the generation of light based on LED semiconductor therefore represents a very sharp variation of technology as that which occurred with the appearance of incandescent lamps in the nineteenth century.

Regarding to cities, street lights are one of the most important assets to maintain and control, providing safe roads, inviting public areas, and enhancing security in homes, businesses, and city centers. However, this concrete asset is very costly to operate, with a share of about 40% of the total amount of electricity spent in a city. This factor, together with the continuous rising of electricity costs, is becoming more and more crucial day by day for the budget of a city.

Smart Lighting will become the domain of professional services organizations, by integration all options of natural light and digital enabled lighting into illumination solutions, which make better and more efficient use of the combined functionalities and interfaces.

It can be found in the emerging Internet of Thing and Smart Cities market some initial solutions such as the Connected Lighting solution from Greewave [4], which is offering IPv6 connectivity and the Philips Lighting Hub [5] which is offering a home gateway to link a local ZigBee network with the Internet.

These solutions are being powered with the embedded Internet Protocol connectivity [6], making thereby feasible an end-to-end connectivity between the smart phones and the lights. Thereby, the IP-based capabilities are opening a great number of opportunities for the integration with applications from external developers, and third party consumer devices.

One example of how these solutions enabled with IP are moving a step forward to the previous home automation solutions is the evolution of the user interface. This new generation of systems is relaying the user and management interface to existing platforms from the home such as the smart phone. Thereby, this is making them more usable for the users and cheaper.

But even when it is already being offered some solutions focused on enable IP connectivity to constrained devices through protocols such as 6LoWPAN [7] and GLoWBAL IPv6 [8]. This requires additional be enabled with embedded Web Services [9] through protocols such as the Constrained Application Protocol (CoAP) [10] built over the REST architecture. These embedded Web Services offer the mechanisms to interact with the resources offered by constrained devices [11] and discover new resources [12].

Finally, this also needs a common semantic description of the resources and services; it is a very important issue in order to provide a powerful interoperability. For this purpose are several the actions carried out in order EU projects such as SPITFIRE, from the European Commission with the support of events such as the Interoperability PlugFest in conjunction with Probe-IT project, and standardization groups such as IP-enabled Smart Objects (IPSO) Alliance [13, 14], ETSI and the recent released oneM2M and the Lightweight M2M (LWM2M) from the Open Mobile Alliance (OMA) [15].

Thee semantic layer defines as the resources and services are mapped to a common ontology and description based on existing ontologies and profiles. This work is focused on define the first instance of the IPSO Alliance Application Profile [16] for Smart Lighting. This describes the functionality defined.

Therefore, this paper describes the need for a smart lighting system in the Smart Cities in the Section II, the features required for the Smart Lighting in the Section III, and how this can be described and supported through the extension of the IPSO Application Profile in the Section IV. Finally, the Section V concludes this paper.

II. SMART LIGHTING SYSTEM

Smart Lighting comprises an heterogeneous and multi-disciplinary area within illumination management, with the possibility of integrating a wide set of sensor and control technologies, together with information and communication technologies, with the aim of achieving a higher efficiency and a lower negative impact derived from the use of energy for illumination, in combination with enhanced intelligent functionalities and interfaces of lighting in the ambient, commercial and public domain.

One of the principal Smart Lighting enabler has been the introduction and emergence of semiconductor based digital light sources such as LED (Light Emitting Diode) and next generation LED technologies such as Organic Light Emitting Diodes also known as OLEDs or Solid State Light (SLL) sources.

The lighting industry is facing the most notable transition since the introduction of electric light bulbs in the 19th century. Current business models are being scrutinized and future market potential is being assessed against those models. This is due to the rapid emergence of LED lighting that is transforming the technological and competitive landscape.

Related to that, the research focus for new applications on this area is mainly posed on digital enabled and controlled lighting interfaces and systems, allowing lighting functions to become more *dynamic*, *controllable* and *interactive*, and *adaptive* depending on external and internal variables, leading on more intelligent lighting solutions.

Smart Lighting comprises the integration of intelligent functionalities and interfaces at four complementary levels presented in the Figure 1.

- First Level or Embedded Level: The first integration level is in the lighting engine or light source itself.
- Second Level or System Level: The second level is in luminaries and lighting systems.

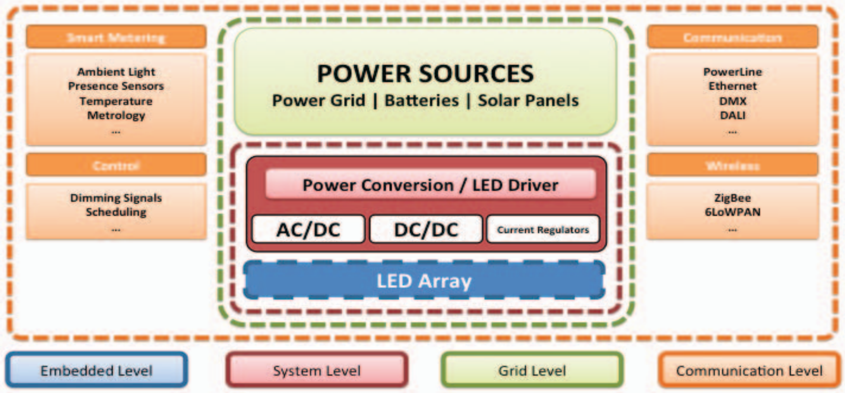

Figure 1. Smart Lighting Integration Levels.

- Third Level or Grid Level: The third level comprises management and monitoring of power sources, energy generation plants and distribution utilities and appliances.
- Fourth Level or Communication and Sensing Level: The fourth level is in complete lighting solutions with monitoring, control and management applications.

Smart Lighting has accelerated research regarding the impact of light and lighting on humans (in health as well as natural behavior), animals and vegetation [17]. It has already led to a better understanding of the importance of light for human and animal comfort and well being in homes, schools as well as for higher efficiencies in labor offices and commercial environments.

On this way, M2M Communications and Internet of Things Technologies provides capabilities for planning, increasingly precise regarding the installation and monitoring of lighting systems based on several parameters that can influence. All the retrieved measurements, stored, processed and properly analyzed can give answer to the question of what is the best area for the installation of a type of specific light, as well as what type of power generation equipment is more appropriate to install depending on the results, thereby achieving maximum efficiency within the alternatives.

It is clear that a managed streetlight network is necessary in combination with smart controls. This new vision of the cities together with data leads us to a new generation of applications within the concept of Smart Cities, where what happens in the physical world feeds our system, that makes a series of decisions as notifying an order to a particular service and adjust parameters, or even easing decision making processes based on previously retrieved data. This is a key factor in improving the aspects like efficiency and energy awareness, maximizing available resources and thus the responsible use of them.

III. INTEGRATING SMART LIGHTING SOLUTIONS

By way of argument, below are three of the key factors in determining the benefits of Smart Lighting Solutions based on LED technology versus traditional lighting systems:

- Efficiency. By utilizing Smart Lighting solutions it is possible to achieve energy savings of between 50% and 70% compared with conventional technologies. A similar reduction is obtained in terms of the rate of carbon.
- Improved Management. Through the incorporation of electronic and communication systems, it is possible to control the color of the light, the intensity and direction of the light beam, through new lighting system designs that can offer a wide range of beneficial factors. As an example, the use of LED technology for outdoor, to lampposts or other street lighting, provides better visibility for pedestrians and vehicles on a particular route, and the reduction of light pollution factor. With regard to indoors lighting, as has been demonstrated by implementing LED intelligent control systems is improved behavior in certain situations and helps improve the performance of the activity. Finally, by installing smart controls allows the LEDs to dynamically change the lighting levels in response to external conditions and may reach levels of energy savings by reference to the consumption of the overall system can be up to 80%.
- Durability. LED lighting systems have a well-designed life expectancy that in standard conditions may range between 50.000 and 100.000 hours. Besides this, the lifetime can be extended further by the use of intelligent control systems.

When comparing Smart Lighting systems with traditional lighting systems based on individual switching, its found a clear advantage based in the ability to control and manage any light, either by groups or in an isolated manner without caring about if they are in a building, or in an open environment, nearer or far a way from a single management interface. This basic feature opens a wide set of possible lighting configurations, also known as lighting scenes enabling the creation of different lighting environments depending on the concrete use we are doing of a determined place. On this way, the responsive design of different lighting scenes for the execution of concrete performances or activities allows to create the adequate atmosphere at the same time that fulfills the comfort level of the end-user.

The integration of smart control on a lighting management system contributes also for a sustainable architecture and lighting systems designs such as green energy environments where through intelligent control interfaces it is possible to remotely monitor and operate the whole system in order to achieve an efficient operating mode at the same time that preserving an appropriate behavior depending on the physical world interactions with the system. Between other benefits, it is clear the ability of the system for reducing energy consumption and reduce costs through a more efficient mode of operation conscious of what is happening in a concrete stage.

Between other important benefits, it is clear the ability of this kind of intelligent systems for reducing the energy consumption and equilibrating operating costs due to a more efficient usage depending on the strictly real necessities and the behavior of the actors involved in a concrete monitored scene.

Furthermore, thanks to the proliferation of wireless technologies, it is possible to obtain side benefits such as a reduced installation cost (both economic and regarding complexity), and a more flexible configuration by the utilization of wireless switches and sensors networks that can be controlled and monitored remotely without the need of direct human intervention.

Smart Lighting systems (both for control and management) can provide the capabilities to automatically operate a device or a set of them in a wide set of determined situations:

- Chronological and Astronomical scheduling: By chronological and astronomical scheduling it is possible to pre-set timers for managing lights and it behavior during a concrete period of time. It includes also the capability of modify the operation of the system depending on sunrise and sunset hours varying thorough the year.
- Environmental and human behavior: By the design and deployment of Smart Lighting systems in a concrete environment, it is possible to adapt the behavior of the system according to the behavior of the monitored entities and variables of interest for a concrete situation. For example, room or streetlights can be controlled based on data retrieved by the installation of motion or activity sensors.
- Concrete Events programming: It is possible to need special configurations for determined situations such as holidays, dark nights, or concrete dates where some kind of special illumination is necessary or appropriate depending on different requirements.
- Alarm conditions: Security could be also improved by the integration of this type of smart systems that can include operations such as doors opening and lighting by the detection of some possible alert situation.
- Complex Program Logic or Intelligent Inference: Event-based setups and pattern recognition could be implemented for a better performance of a system that needs to adapt its behavior in an automatic way depending on external or internal variables values based on if-then-else statements, logical operators and advanced pattern recognition algorithms.

Regarding to the Smart Grid is particularly relevant, specifically, when referring to the integration of energy networks together with ICT, giving them hitherto untapped capabilities in order to achieve unprecedented improvements in such vital areas as their performance and reliability.

Smart Grid is a key element for the integration of smart systems; it could be possible to design and manage in a more efficient manner, any kind of production and distribution system. Concretely speaking about lighting systems, this are one of the most important energy liabilities of cities and large buildings. Therefore, it is an element to be considered ahead of the regulation of consumption according to the state of the grid, environmental conditions, timetables and comfort standards.

To this end, terms such as climate change, the reduction of carbon footprint, global warming and renewable energies have been becoming more common in the everyday vocabulary. There is a global awareness that advocates a technological change towards the eco-efficiency, and one of the keys to achieving such change passes through the modernization of the increasingly obsolete electricity distribution networks. It is at this point where the application of technologies encompassed within the Internet of Things industry touches its peak, enabling the incorporation of these networks of autonomous elements able to communicate and interact with each other, improving team coordination in together, thus making them becoming more efficient.

IV. The IPSO Application Framework

The IPSO (Internet Protocol Smart Object) Alliance is an organization for promoting the use of the Internet Protocol (IP) for Smart Object communications. IPSO is a global non-profit organization founded in 2008 and has more than 60 members from leading technology, communications and energy companies.

Within the IPSO Alliance, there exists an Interoperability Committee, with the main goal of defining a framework where products and services using IP for Smart Objects are able to interoperate together in order to achieve the requirements and needs for industry standards in communication aspects.

One of the main contributions in this context, is described in [16], this defines a RESTful (Representational State Transfer fulfillment) design for use within IP networks with smart objects and systems. It defines and describes several sets of REST interfaces that may be used by a smart object to represent which services and resources makes available to the system and other objects in its context.

Regarding to the basis and motivation of the IPSO Application Framework, it makes use of the mentioned IETF standards, such as CoAP and 6LoWPAN, for remain it a simple and efficient RESTful design model for IP smart objects.

CoAP, REST, JSON (JavaScript Object Notation), and the key components of the reigning web technologies are especially important for the building of an Internet of Things application. Nevertheless, they are, by definition, overmuch flexible for choosing a particular way for data representation and operation.

Within the IPSO Application Framework context, it is proposed a particular way for using these mechanisms and technologies for representing concrete classes of typical Internet of Things applications as a guide for designers and developers but never for being considered a strict standard. It needs to be considered as a pattern on which to base future developments so they may make it easier to design and develop systems without the need of rethinking communications patterns and data formats every time. The next section presents how the IPSO Application Framework has been extended to support Smart Lighting.

V. IPSO Application Framework for Smart Lighting

Using the IPSO Application Framework as a basis for developing a framework for interoperating with a concrete object, in the following lines is described an specific profile implementation of the IPSO Application Framework for Smart Lighting, the defined as: *IPSO Profile for Advanced Lighting Control*.

The framework is organized into groups for every resource type called Function Sets, following the recommendation of the IPSO Alliance. A function set, normally has a recommended root path under which its sub-resources are described.

Every Function Set has a Resource Type parameter, therefore making it possible to be discovered. Each type should include the following parameters: a Human Readable Name, a Path Template, a Resource Type for discovery, the Interface Definition, and the Data Type with the corresponding allowed values.

- Path Template (PT): It includes an index parameter, and possible fixed path segments. The index allows for inquiring one concrete or multiple instances of the specify type of resource, and can be any string.
- Resource Type (RT): It defines the value that must be included in the RT field of the CoRE Link Format when dealing with a link to this concrete resource.
- Interface Definition (IF): It defines the REST interface for that type of resource making use of the CoRE resource types defined in [18].
- Data Type (DT): It describes the type and range of values that will be either returned or accepted as response in a GET or a PUT operation over the resource respectively.

An example of the usage of the described resources is presented in the Table 1, this assumes that the IPv6 address of the devices is the 2001:DB8::1, which is an address in the range of IPv6 reserved for documentation, and the port 5683, which is the default port in CoAP. This assumes that is the first instance of light (lt). Therefore, the URL for the resource is *coap://[2001::10]:5683/lt/1/*.

This presents how to GET the status from the functions described and presented in the Table 4, and how to set the status of the light through a PUT command.

Table 1. Example of usage.

Type	URL	Payload
GET	coap://[2001::10]:5683/dev/status	Empty
PUT	coap://[2001::10]:5683/lt/1/on	1 to turn on 0 to turn off

Regarding to the concrete implementation for the IPSO Profile for Advanced Lighting Control, in the following sub-sections are described the implementation of each one of the different Function Sets defined:

A. Light Control Function Set

The Table 2 presents the main function of the light, first the basic light description and after switching resource (on) and the dimmer (dim) regulation.

Table 2. Light Control Function Set.

Type	PT	RT	IF	DT
Light	/lt	ipso.lt	Sensor	-
On	/lt/on	ipso.lt.on	Actuator	Integer
Dim	/lt/dim	ipso.lt.dim	Actuator	Integer

B. General Purpose Input/Output Function Set

This defines the general purpose Input/Output (GPIO) interface for the zero crossing detector. This is commonly used to count the time that the light is switched on, when it has not access to a real time clock. It is mainly based that the electricity has a fix frequency of 50Hz in Europe or 60Hz in USA.

Table 3. GPIO Function Set.

Type	PT	RT	IF	DT
Status	/gpio/status	ipso.gpio.cross.status	Sensor	Binary
Frequency	/gpio/cross/fr	ipso.gpio.cross.fr	Sensor	Integer
UserCount	/gpio/cross/ct	ipso.gpio.cross.ct	Sensor	Integer
ResetCount	/gpio/cross/rst	ipso.gpio.cross.rst	Actuator	Binary

C. Messages Function Set

Table 4 presents the basic messages to get information about the devices and the manufacturer. For example, it is defined the serial number, the model, and also other relevant data as the status to collect all the details from the device at that moment, and the history of alarms.

Table 4. General messages about the device.

Type	PT	RT	IF	DT
Serial Number	/dev/ser	ipso.dev.ser	Sensor	String
Model	/dev/mdl	ipso.dev.mld	Sensor	String
Status	/dev/status	ipso.msg.status	Sensor	String
Alarms	/dev/alarms	ipso.msg.alarms	Sensor	String

D. Management Function Set

The Table 5 presents the management functions in terms of consult the total uptime, the keep-alive frequency to detect when the device fails, and other functions as reboot.

Table 5. Management Functions.

Type	PT	RT	IF	DT
Uptime	/dev/uptime	ipso.dev.uptime	Sensor	Integer
Keep-alive	/dev/keepalive	ipso.dev.keepalive	Sensor	Integer
Reboot	/dev/reboot	ipso.msg.reboot	Actuator	Binary

E. Config Network Function Set

The Table 6 and Table 7 define the required functions to bootstrap and reconfigure a street light controller.

Table 6. Configuration: Network Layer.

Type	PT	RT	IF	DT
IPv6 address	/cfg/stack/net/ip	ipso.cfg.stack.net.ip	Actuator	String
Listening Port	/cfg/stack/net/port	ipso.cfg.stack.net.port	Actuator	String
Autoconf	/cfg/stack/net/auto	ipso.cfg.stack.net.auto	Sensor	Binary

Table 7. Configuration: MAC Layer.

Type	PT	RT	IF	DT
MAC Address	/cfg/stack/mac/addr	ipso.cfg.stack.mac.addr	Sensor	String
PAN ID	/cfg/stack/mac/pan	ipso.cfg.stack.mac.pan	Sensor	String
Channel	/cfg/stack/mac/chan	ipso.cfg.stack.mac.chan	Actuator	Integer
Security Enabler	/cfg/stack/mac/sec	ipso.cfg.stack.mac.sec	Actuator	Binary
Security Key	/cfg/stack/mac/key	ipso.cfg.stack.mac.key	Actuator	String
Security IV	cfg/stack/mac/iv	ipso.cfg.stack.mac.iv	Actuator	String

F. Others Function Set

Finally, table 8 presents other functions such as geo-location, which can be used for other applications such as the discovery of resources presented in [12].

Table 8. Other optional resources.

Type	PT	RT	IF	DT
GPS location	/loc/gps	ipso.loc.gps	Sensor	String

VI. Conclusions

This paper has presented the relevance of the smart lighting control to reach the sustainability of the smart cities. This has described the impact in the total power consumption of the lighting and consequently the interest to offer a higher control and optimization of its usage. For this purpose, Smart Lightings requires a higher connectivity, context awareness, control level, and finally the definition of standard and interoperable semantic layers based on the existing profile from Alliances such as OMA and IPSO Alliance. Emerging solutions are enabling with IP connectivity to Smart Lighting solutions, but it has not been yet described an implementation of a semantic layer for smart lighting. For that reason, this work has presented the example of the description for the IPSO Profile for Advanced Lighting Control.

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