Streetlight Intelligent Remote Control System based on Wireless Communication

U. Hernandez-Jayo[1], I. Angulo[1], M.P. Elejoste[1], A. Perallos[1], A. Chertudi[1], A. Moreno[1]

[1] DeustoTech-Mobility, Deusto Institute of Technology, Bilbao, Spain

***Abstract*— This paper presents a streetlight remote management system, based on wireless communication technologies, which will provide tangible solutions to improve energy efficiency by adapting to the changes in the contextual needs. The proposed solution is said to be intelligent since light dimming is fixed based on the analysis of the data provided by the deployed sensors.**

***Index Terms*— street lighting, sensor networks, wireless technologies, intelligent systems, context-aware system, smart city.**

I. Introduction

Street lighting in Spain accounts for 10% of total energy consumption in lighting and stands at 116kWatt per year and inhabitant, facing with the 91kWatt or the 43kWatt in France and Germany, respectively. The latest available figures from the Ministry of Industry, Tourism and Trade, assume an electric power consumption of 3,630 GWh/year for the whole of Spain. Keep in mind that, in total, there were 4,800,000 points of light in 2010, and a third of street lighting is based on outdated and inefficient technologies. Besides, it is the cause of the greatest impact on energy consumption of a municipality (around 54% of total energy consumption of municipal facilities and 61% of electricity, according to some sector studies).

The Royal Decree 1890/2008 [1] and its corresponding Complementary Technical Instructions was approved on 14 November 2008 by the Ministry of Industry, Tour-ism and Trade. The main objectives of the Royal Decree are: (1) to improve energy saving and efficiency, and consequently, reduce greenhouse-effect gas emissions, (2) to limit glare and light pollution, because of too much light and/or the use of unsuitable luminaries, and (3) to reduce intrusive or annoying light. This Royal Decree is mandatory and it is part of the Spanish Government's 2008-2011 Energy Saving and Efficiency Plan, a strategy called E4 [2] which establishes a series of standard actions aimed at improving the energy system in Spain. The target set in this Plan was to achieve 75 kW per inhabitant per year, a major challenge considering that no Spanish province reached that objective today.

This paper presents a streetlight management intelligent system, based on wireless communication technologies, which will provide tangible solutions to improve energy efficiency. After a sort summary of related works, the desired capabilities of the systems are described (section 3) from a general point of view. Secondly, according to the analysis of the specific characteristics of the scenario (section 4) where the system is going to be deployed and considering the disadvantages of other similar existing solutions (also in section 4), the design of our system is detailed (section 5). Finally, conclusions and future work are presented (section 6).

II. Related work

There is a worldwide interest in control and give some communications skills to street-lights systems, in order to monitor their parameters every time to improve their efficiency. For example, this is the case of photovoltaic farms, where photovoltaic solar panels are physically distributed and they require technologically advanced solutions based on new technologies for positioning and communication. The recent evolution of these technologies helps to improve supervision systems, and there are new solutions arising with an acceptable success. These technologies are principally mesh sensor networks and ZigBee protocol for data capture and action signals distribution.

The ZigBee standard based upon the IEEE 802.15.4 specification has been specified by the ZigBee alliance with members of Freescale, Philips, Atmel, Siemens, Samsung, Analog Devices and Chipcon, and has the characteristics of large network capability (up to 65,000 nodes), long battery lifetime (up to a few years), short link establishment time (15-30 ms), but low data rate (up to 250 kbps) [3]. The 802.15.4 standard only specified physical and MAC layers, but for upper layers there are multiple different options to work with for improving features like battery life or fast network establishment. This is the case of the Beacon Networks [4]. ZigBee technology joined to mesh networking communications [5] is the last solution for monitoring the environment. The network is composed of nodes distributed around a wide area and a central base station that receives the information and controls the system. A simple medium access protocol and routing algorithm are proposed in [6] with the objective of reducing power consumption. The best solution is the one that achieves a good trade-off between power consumption and transmission delay improving communications algorithms and the architecture of the nodes.

III. Functional achievements

The main challenge to be achieved in our work is the development of a system capable of becoming a set of streetlights smart enough to work in an autonomous way, as well as to be able to be remotely managed (for diagnostic, action and other energy optimization services). These two capabilities can decisively contribute to improve the global efficiency of the lighting systems, both in an energy consumption point of view as in the cost required to their maintenance. To achieve these challenges some requirements have to be fulfilled, which are covered in this section.

TABLE I.
TECHNICAL SPEC. ALYA LED HE

IP/IK Ratio	**Class**	**System**	**Voltage**	**Watts**	**Freq.**
IP 66/IK 09	Class I/Class II	350/530 mA	230V CC	54	50/60 Hz
Leds nbr.	**C. Temp.**	**Flux**	**Efficiency**	**CRI**	**ULOR**
48 LEDS	5500K	4700lm	87,43lm/W	>75Ra	E1(<1%)

First, the autonomous performing of the streetlights requires that their behavior can be changed according to the environment conditions. Thus, they have to be able to perceive some relevant characteristics of the environment, such as ambient lighting, presence of vehicles or people, or their own performing (if they are working properly or not). Therefore, streetlights have to be equipped with some kind of sensors. Second, streetlights have to be able to act according to the knowledge obtained from the environment. In this case, actuation is translated into a lighting intensity regulation, being able to perform at lower level when it is not necessary.

Finally, the smart working of an individual streetlight also requires some knowledge about what is now happening in the nearest ones, as well as, what happened in the past and what the consequences of previous actions in similar conditions were. That is to say, a holistic knowledge which can be only supported by a remote control center to which streetlights report their local knowledge. Thus, streetlights not only need sensors and lighting regulators, but also need to communicate with an external management center. This last capability is also necessary to carry out the previously mentioned remotely management.

By the other hand, due to cost considerations to include a high number of sensors and a long range communication device (such as a GPRS modem) in each individual streetlight is not a feasible approach. Instead, using collaborative techniques could be an intelligent way of reducing the cost of the system. In that way, only the fewest number of streetlight would be equipped with sensors and long range communication devices (those which have the best location according to sensorial and communication requirements). The rest would only include a device needed to configure a mesh network between streetlights in the same geographical or electrical region. Their behavior would be coordinated by the smartest streetlights which would gather data from the environment and communicate with the control management on their behalf

IV. SCENARIO ANALYSIS

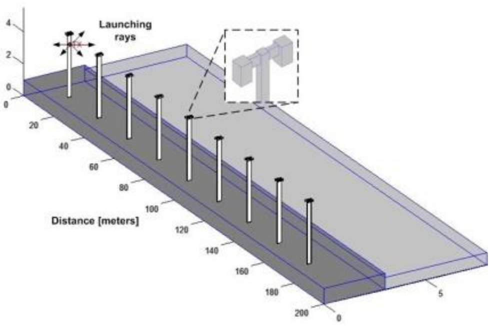
Although there are several projects to improve energy efficiency in street lighting, the introduction of these systems often requires the installation of new lights [7] hindering their deployment in functional facilities. The overcrowding of multiple sections of lights in the same electric cabinet, coupled with the significant loss of tension on power lines cause serious interference to Power Line Communications (PLC) based systems [8] [9] that sometimes prevent their proper functioning over poorly sized installations. Moreover, the evaluated systems [10] [11] [12] based on wireless communications, provide general solutions which do not take into account the particularities of the specific scenario where system must be deployed. The specific characteristics of electromagnetic propagation environment must be taken into account in the deployment of each section system in order to solve physical barriers and other issues affecting radio communication. Thus, in this paper we present not only an open architecture adaptable to different installations, but also indicate how it is adapted to a specific real scenario which is described in this section.

The selected street section has an estimated length of 1 km in Areta Street (Fig 1), a stretch of road connecting the city center of Llodio/Laudio with the district of Areta (in Spain). It is a recently renovated area with LED lighting that allows adjustment without changing the technology of existing facilities. In the electrical panel board, its power supply is separated from the rest, so accessibility and the management of this installation is easier than in shared facilities.

The roadway has two lanes for moving traffic and provides for two-way movement of traffic. At the beginning of the section there are a traffic light and a crosswalk. All along the road, the sidewalk is on only one side, where are located the streetlights which are going to be regulated. The facility has 9 points of light separated by 20 meters from one to the next (manufacturer SIMON Lighting, model ALYA LED, see technical specifications in Table 1), ideal for urban lighting applications

The distance to the electrical panel is about 300m from the nearest street-light, it is located at the rear of a residential area therefore entails adverse conditions for the establishment of communication link and its integrity preservation (private access points, distance, interference)

(a)



(b)

Figure. 1. Scenario under consideration: (a) real scenario and (b) schematic scenario

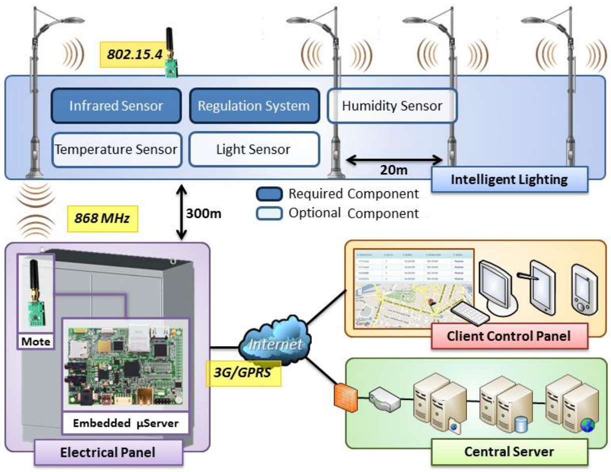


Figure. 2. General architecture of the system

V. INTELLIGENT SYSTEM DESIGN

The proposed intelligent streetlight system has been designed following a four-level hierarchical model. The lower level is composed by motes or end nodes. These devices are integrated on all the lamps in a section providing the computing power needed for its control and regulation [1]. These motes include 802.15.4 transceivers to communicate with the other lamps of the section creating Mesh type network between them. The second level of the hierarchy is made up of remote concentrators located in the electrical panels that power the light section. An embedded micro server (remote concentrator) is installed to control all the lamps integrated on the system powered by the panel. Long existent distances between electrical panels and sections of streetlights can sometimes overcome the physical limitations of 802.15.4 communication. The proposed system includes a third hierarchical level that allows some of the end nodes, equipped with a second transceiver, communicate directly with the cabinet via wireless communication at a frequency of 868MHz performing the task of bridge and increasing the coverage of the mesh network when needed. Each remote concentrator will connect with the top level of the system, the central server, though the Internet using a 3G/GPRS type communication. (Fig. 2 show the hierarchical model)

From the general architecture, there are some specific aspects totally dependents of the scenario where the system is going to be deployed. Main features according to the requirements presented in section 3 are now described.

A. *Sensor System Capacity*

To enable proper control of the illumination of the lamps it is necessary to provide sensing capability to end nodes in order to obtain environmental information to minimize energy consumption.

According to the specific scenario (section 4), and balancing between cost of end nodes and quality of environmental measurements, it has been decided to integrate a weather station in one of the intermediate nodes of the section (node 3) and install passive infrared (PIR) sensors in all of the streetlights of the section. The weather station will be capable of measuring key environmental factors as brightness, temperature, relative humidity or pollution level. Furthermore, PIR sensors will be responsible for detecting the presence of people inside or near the range of the line of lamps

B. *Light Regulation*

The key to energy savings result by the proposed system is to regulate the light intensity of each lamp inside a streetlight section depending on their specific needs. The multiple technologies used in the already deployed sections of streetlights prevents the use of a dimmer common, being necessary to custom design the regulation device to cover the needs of the lights installed.

In our scenario, consisting of LED lights that allow regulation to constant voltage, altering the maximum load supplied (Table 1), it is been integrated a regulator with a pulse-width modulation (PWM) input to set the percentage of light needed. The signal is provided by the MCU included on end nodes, which includes a PWM module.

C. *Autonomous Adaptive System*

One of the main contributions of presented work is to provide responsive sensors independently without requiring supervision of a higher order entity (autonomous response to changing environment and situations). Most of the time environmental information is inaccurate since the sunlight, the season, the UV index and some more may affect notably the measures, and indeed they do, and therefore the decisions. Therefore, it comes to getting the most complete and accurate information as possible and try to supplement that information with that obtained by other sensors so as to minimize possible noise and achieve adequate situational awareness. For such reason we propose a fuzzy system in charge of information fusion used for supporting decision making which cooperates with an ontology charged in the sensor.

With the aid of an adaptive neuro-fuzzy inference system we obtain a set of rules that can be easily integrated in the sensor node since the computational cost associated to its utilization is really low. The remote control and management center may deal with large data flows and may process complex rules involving large data sets, something that happens when using statistical information for planning new operating guidelines, but that it is impossible to carry out with the limited computing and storage capacities of a sensor. Although many other input parameters may be considered, our proposal considers five input parameters: twilight threshold, light intensity, pedestrian flow, daytime and weather conditions. The ANFIS is trained with a large set of measures and the neural network provides as output a set of fuzzy rules that can be embedded in the sensor. In this case, we obtain a set of rules related to the alerts that must be notified in case of dysfunction and a set of operation rules.

VI. CONCLUSIONS AND FUTURE WORK

The design of an intelligent system to improve the energy efficiency of the streetlight systems has been presented. The main challenge has been to design a smart enough system capable of working in an autonomous way, according to the environment conditions. The main innovation is that it has been designed to facilitate the deployment in existing facilities, minimizing the cost of investment. This has been achieved by using wireless technologies and through a depth analysis of the deployment scenario.

Besides, the open architecture which we have set out will create a robust, secure and flexible networking environment, in order to meet the world's digital demands. The combination of advanced wireless communications, sensing and metering capacities in a unique infrastructure will contribute to the deployment of the future smart cities. In that way, the long term future work could be focused on taking advantage of this infrastructure for the development of intelligent services

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