# Remote-Control System of High Efficiency and Intelligent Street Lighting Using a ZigBee Network of Devices and Sensors

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Abstract—The proposed remote-control system can optimize management and efficiency of street lighting systems. It uses ZigBee-based wireless devices which enable more efficient street lamp-system management, thanks to an advanced interface and control architecture. It uses a sensor combination to control and guarantee the desired system parameters; the information is transferred point by point using ZigBee transmitters and receivers and is sent to a control terminal used to check the state of the street lamps and to take appropriate measures in case of failure.

Index Terms—Automation, control system, lighting system, sensors, wireless networks, ZigBee.

# I. INTRODUCTION

IGHTING systems, especially in the public sector, are still designed according to the old standards of reliability and they often do not take advantage of the latest technological developments. In many cases, this is related to the plant administrators who have not completed the return of the expenses derived from the construction of existing facilities yet. However, the recent increasing pressure related to the raw material costs and the greater social sensitivity to environmental issues are leading manufacturers to develop new techniques and technologies which allow significant cost savings and a greater respect for the environment. We can find three possible solutions to these problems in the literature.

The first one, and perhaps the most intuitive, is the use of new technologies for the sources of light. In this area, light-emitting diode (LED) technology is the best solution because it offers many benefits. Researchers [1]–[4] have already considered this possibility, designing an advanced street lighting system based on LEDs.

The second possible solution, and perhaps the most revolutionary, is the use of a remote-control system based on intelligent lamp posts that send information to a central control system, thus simplifying management and maintenance issues. Researchers [5]–[9] have developed a street lamp system using the general-packet radio service (GPRS), power-line carrier, or Global Systems for Mobile Communications (GSM) transmissions.

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Base Station

Fig. 1. Schematic image of the system.

Finally, the third possibility would be the use of renewable energy sources locally available, rather than conventional power sources, with a positive effect on the environment.

Solar energy is the most important resource in this field.

Our work aims at the unification of the three mentioned possibilities, creating an intelligent lamp post managed by a remote-controlled system which uses LED-based light sources and is powered by renewable energy (solar panel and battery).

The control is implemented through a network of sensors to collect the relevant information related to the management and maintenance of the system, transferring the information via wireless using the ZigBee protocol. The field of the ZigBee remote sensing and control system is widely present in the literature; we can also find ZigBee systems similar to (the) lighting systems in structure and management [10]–[18].

In this paper, we present our system, which is able to integrate the latest technologies, in order to describe an advanced and intelligent management and control system of the street lighting.

#### II. DEVICES AND METHODS

Fig. 1 shows the conceptual scheme of the proposed system. It consists of a group of observation stations on the street (one station for each lamp post) and a base station typically placed in a building located nearby. It is a modular system, easily extendable.

The measuring stations monitor the street conditions and the intensity of sunlight and, based on them, they decide to turn the lamps on or off. The conditions depend on the pattern of the street where the lights are located and on the solar irradiation at a given point of the street, with frequent changes, depending on weather conditions, season, geographical location, and many other factors.

For these reasons, we decided to make each lamp completely independent in the management of its own lighting. The on-street station also checks if the lamp is properly working

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Fig. 2. Schematic image of an on-street station.

and sends the information through the wireless network to the base station for processing data. If any malfunction is detected, the service engineer is informed through a graphical interface and can perform corrective actions.

#### A. Monitoring Stations

The monitoring station located in each lamp post consists of several modules: the presence sensor, the light sensor, the failure sensor, and an emergency switch. These devices work together and transfer all of the information to a microcontroller which processes the data and automatically sets the appropriate course of action. A priority in the transmission of information is assigned to each sensor, for example, the emergency switch takes precedence over any other device.

1) Presence Sensor: The task of the presence sensor is to identify the passage of a vehicle or pedestrian, giving an input to turn on a lamp or a group of lamps. This function depends on the pattern of the street; in case of a street without cross-roads, a single sensor is sufficient (or one at each end in case of a two-way street), while for a street requiring more precise control, a solution with multiple presence detectors is necessary.

This feature enables switching on the lamps only when necessary, avoiding a waste of energy. The main challenge with such a sensor is its correct placement. The sensor should be placed at an optimal height, not too low (i.e., to avoid any erroneous detection of small animals) nor too high (for example, to avoid failure to detect children). A study of the sensor placement enables deciding the optimal height according to the user needs and considering the specific environment in which the system will work. We discovered that in field tests, the SE-10 PIR motion sensor offers good performance and is quite affordable.

2) Light Sensor: A light sensor can measure the brightness of the sunlight and provides information. The purpose of this measurement is to ensure a minimum level of illumination of the street, as required by regulations (see CIE n°68 *et al.* [19]).

The sensor must have high sensitivity in the visible spectrum, providing a photocurrent high enough for low light luminance levels. For this reason, the phototransistor TEPT5700 (by Vishay Semiconductors) has been selected.

Based on the measured luminance, the microcontroller drives the lamp in order to maintain a constant level of illumination. This action is obviously not required during daylight time, but it is desirable in the early morning and at dusk, when it is not necessary to operate the lamp at full power but simply as a "support" to the sunlight. This mode enables saving electric power



Fig. 3. Control software flowchart.

supplied to the lamp because the lamp is regulated by the combined action of the sensor and the microcontroller to ensure the minimum illumination required.

3) Operating Control: This sensor is useful to improve fault management and system maintenance. Thanks to this sensor (in this case, a Hall sensor), it is possible to recognize when the lamp is switched on. The system is able to recognize false positives, because identified parameters are compared with the stored data (e.g., lamps are switched off during daylight and the sensor incorrectly detects a fault, but the microcontroller does not report the malfunction because of additional logic functions).

The information is reported through the ZigBee network to the station control unit, where the operator is informed about the location of the broken-down lamp and can send a technician to replace it. The system current is 1.5 A, so a sensor suited to detect this current is necessary. An appropriate threshold value to detect the operation of the lamp has been set between 1 and 1.5 A. The chosen sensor is the ACS756 [20] of the Allegro Microsystems, an economical and precise solution for ac or dc current sensing, particularly suitable for communication systems. Thanks to this sensor, it is possible to store in the microcontroller's memory the current value which flows in the LED lamp in normal operating conditions, enabling the online power consumption measurement.

4) *Emergency Device:* The system has an emergency button, which can be useful in case of an emergency. This device excludes the entire sensor system with the objective to immediately turn on the lamp. The light will remain on for a preset time. After that, the button must be pressed again. This prevents the system from being accidentally active even when the necessity ends. Obviously, this device does not work during the day, when there is no need for artificial light.

5) Control Unit: The sensors transfer the collected information to a controller which runs the software to analyze the system. Fig. 3 shows the control software flowchart. After the initial setting, the system is controlled by the light sensor which



Fig. 4. Lamp control system GUI and measurement of power consumption.

activates the microcontroller only if the sunlight illumination is lower than a fixed threshold. In this case, the system reads the state of the emergency button, and switches on the lamp if this is activated. The same happens in case of a vehicle or a pedestrian. Once the lamp has been switched on, the operating sensor starts the monitoring and, in case of a fault detection, an alarm is sent to the control center. If no fault is detected, the microcontroller measures the current flux by the Hall sensor memorizing the current values.

The entire operation is regulated by a timer which enables the system to work for the predetermined time. At the stop input, the lamp is turned off and the cycle restarted.

The algorithm has been written in Pic Basic and runs on the microcontroller.

## B. Base Control Station

The base control station is the hub of the system since it allows the visualization of the entire lighting system. The transmission system consists of a ZigBee device that receives information on the state of the lamps and sends it to a terminal.

The processing unit consists of a terminal with a serial Universal Asynchronous Receiver-Transmitter (UART) interface which receives information about the state of the lamps provided by a ZigBee device. The terminal is required for a graphical display of the results. Moreover, data on lamps' operation are associated with the lamp address; consequently, all faults are easily identified.

The graphical interface enables monitoring the state of the system (upper section of Fig. 4) with the state of the lights and the power consumption of each lamp (lower section of Fig. 4). The operator will have a graphical representation of the lamp location within the area where the system is installed.

Pressing the button "Power Consumption Data," a second window appears where power consumption and working time of any lamp are given. The program is also equipped with a management system that acts in case of no communication from the lamp posts well explained in Section III-E after the description of the entire system.

# C. ZigBee Network

ZigBee is a wireless communication technology based on the IEEE802.15.4 standard for communication among multiple devices in a wireless personal-area network (WPAN). ZigBee is designed to be more affordable than other WPANs (such as, for example, Bluetooth) in terms of costs and, above all, energy consumption. A ZigBee personal-area network (ZBPAN) consists of at least one coordinator, one (or more) end device(s) and, if required, one (or more) router(s). The network is created when a coordinator selects a channel and starts the communication, henceforth, a router or an end device can join the network. The typical distance of a ZigBee transmission range, depending on the environment conditions and the transmission power, shifts from tens to hundreds of meters, and the transmission power is deliberately kept as low as possible (in the order of a few milliwatts) to maintain the lowest energy consumption [21]-[26].

In the proposed system, the network is built to transfer information from the lamp posts to the base station control. Information is transferred point by point, from one lamppost to another where each lamp post has a unique address in the system. Each lamp post can only send the information to the nearest one, until the information reaches the base station. Thus, transmission power is limited to the required low value and the signals sent by the lampposts do not interfere with each other.

In case of failure of one lamp, the chosen transmission distance between the lampposts ensures that the signal can reach the next operational lamp post without breaking the chain. The ZigBee wireless communication network has been implemented with the use of Digi-MaxStream radio-frequency modules called XBee modules, which are available in Standard and Pro versions (pin-to-pin compatible) [20], [21]. The Standard Xbee modules have an operation range of tens of meters indoors and hundreds of meters outdoors, while the XBee Pro modules have a wider spread range in the order of hundreds of meters indoors and of about 1.5 km outdoors, because the Pro modules have higher transmission power, but imply higher consumption (about three times the consumption of the Standard version).

The receiver has very high sensitivity and a low probability of receiving corrupted packets (less than 1%). The modules should be supplied by 3 V from a dc source; the current consumption is in the order of 50 mA (for XBee) and 150–200 mA (for XBee PRO) in uplink and in the order of 50 mA in downlink (identical for both versions); moreover, they support a sleep mode where



Fig. 5. Printed-circuit board



Fig. 6. Prototypes.

consumption is less than 10  $\mu$ A. The XBee modules are distributed in three versions of antennas: with an on-chip antenna, a wire antenna, and with an integrated connector for an external antenna.

# D. Details and Buildup

In the proposed system the most important elements are:

- the voltage controllers which provide power to all other devices;
- the microcontroller (U2, Microchip PIC 16f688), which manages the system where the firmware is uploaded;
- the XBee module;
- connectors for programming the pic (ProgPort), for optional serial transistor transistor logic (TTL), for an external reference voltage, necessary for the correct activity of the PIC analog-to-digital converter (ADC), and for the input/output (I/O) ports.

Fig. 5 shows the printed-circuit board (PCB) of the monitoring station circuit. The circuit has been realized in surface-mount device (SMD) technology to reduce the overall dimensions.

Fig. 6 shows the realized prototype allocated in its box ready for tests. This is the prototype tested in real-life conditions.



Fig. 7. Test system.

Finally, Fig. 7 shows the operational test system working in real conditions. It is visible that the proposed systems can also be used for upgrading existing conventional lamp posts.

Power is supplied by a battery recharged by a solar panel during the daytime. The capacity of the battery depends on the specific needs of the final application.

The irradiation curves of the site have been studied during a project about making a photovoltaic system, in order to determine the right inclination and orientation of the solar panels to enable the best outcome of the operation. It is possible to refer to publications which provide precise data as a function of latitude (referring to UNI 10349 data obtained by PVGIS [27]). For the sizing of the panel, it is necessary to determine the annual energy required to power the lighting system under analysis. The project data here below are necessary to determine the energy produced annually by a photovoltaic panel:

- location of the installed panel;
- inclination of the absorbing surface;
- orientation of the absorbing surface;
- ground-level reflection;
- nominal power of the panel;
- losses of the solar panel;
- efficiency of the charger controller.

The charge controller manages the processes of the battery charge and power supply. Electric power generated by photovoltaic panels is handled by the controller to provide an output current for the battery charge. The charging process must be conducted according to the battery features (capacity, voltage, chemistry, etc.), providing current until the battery has been completely charged, and then switching to a standby current to compensate the battery self-discharge. The selected model (CMP12 JUTA of HARBIN Hopeful STAR [28]) provides voltage regulation of battery charging as a function of temperature and has built-in electronic protection to contrast overload, short circuit, and overvoltage.

## **III. TESTS AND RESULTS**

The prototype has been tested in variable real-life conditions to verify the overall functionality and seek better performance. The measurements collected during the test phase allow calculating energy savings so that it is possible to estimate cost savings also for larger systems using approximations.

#### A. Range Tests

The first tests on the Xbee modules performance were done at the Electric and Electronic Measurements Laboratory of Roma Tre University, to test the reliability of the communication between two or more ZigBee modules in the following environmental conditions:

- 1) open field in line of sight between modules;
- open field out of the line of sight where the obstacle is a big tree or a hill;
- 3) indoor test.

The tests were carried out using different types of Xbee modules, Standard and Pro, each one with three different types of antennas (patch, wire, external) provided by the manufacturer.

To check the reliability of the Zigbee transmission, we used the X-CTU software, provided by Digi-MaxStream.

Test cases were designed to check the network in various real-life operating conditions: clear weather, rain, and proximity of electrical or electronic devices possibly interfering with the transmission (such as a WiFi access points).

The indoors tests were done considering one or more walls between the transmitter and the receiver, while the outdoor ones were performed with one or more natural obstacles like trees or hills. Ten-thousand transmission tests were performed for each case, using an appropriate adapter to simulate the retransmission.

The X-CTU tool, using a terminal connected to an XBee module, sends a packet through the network and verifies that the data are correctly returned back from the XBee module which has received the packet. The obtained results, using the minimum transmission power available, are very satisfactory: all packets arrive to their destination and are correctly returned. Obtained average reliability was 99.99%.

The same tests were performed on the Xbee Pro and the percentage of reliability was 100% in each case.

Positioning the lamp post at about 25 m from each other, the proposed system can reliably operate using the Xbee Standard modules with patch antenna. These modules have a nominal range of about 100 m outdoors and are the cheapest ones.

Other functionality field tests were realized using the Xbee modules installed in the lamp posts (at the moment, they are four plus the remote central). A first test was to verify that the system is able to transfer information from any lamp post to the control center passing data through the other lamp posts. In these cases, we obtained a transmission rate between 99.99% and 100% depending on the location of the sending unit.

The second test verified the case of breakdown of an intermediate lamp post. At the moment, the system is not affected by this kind of problem, considering the transmission with the same positioning of the previously described case. The system equipped with Xbee modules with a patch antenna becomes nonoperating only when four consecutive lamp posts' transmission devices are nonoperational. This test was performed using two others Zigbee transmission stations. Placed 25 m from each other, the lampposts chain had upstream these two stations to

TABLE I Zigbee Reliability Tests

XBEE STANDARD - Patch Antenna - Outdoors						
Su	nny	Rainy				
50m	100m	50m	100m			
100%	99,99%	99,98%	99,97%			
99,97%	99,96%	99,98%	99,96%			
99,97%	99,95%	99,97%	99,94%			
	E STANDAR Su 50m 100% 99,97% 99,97%	STANDARD - Patch An           Sum           50m         100m           100%         99,99%           99,97%         99,95%	STANDARD - Patch Antenna - Outdoo           SUm         Ra           50m         100m         50m           100%         99,99%         99,98%           99,97%         99,96%         99,97%           99,97%         99,95%         99,97%			

XBEE STANDARD - Wire Antenna - Outdoors						
	Su	nny	Rainy			
	50m	100m	50m	100m		
No obstacles	100%	100%	100%	100%		
Tree	100%	99,99%	99,99%	99,98%		
Hill	100%	99,99%	99,98%	99,96%		

XBEE STANDARD - External Antenna - Outdoors						
	Su	nny	Rainy			
	50m	100m	50m	100m		
No obstacles	100%	100%	100%	100%		
Tree	100%	100%	100%	100%		
Hill	99,99%	99,99%	99,98%	99,97%		

XBEE STANDARD – Indoors – more than 10 m from WiFi AP						
	1 Wall	2 Walls	3 Walls			
Patch Antenna	100%	99,98%	99,96%			
Wire Antenna	100%	100%	99,98%			
External Antenna	100%	100%	100%			

XBEE STANDARD - Indoors – 5 m from WiFi AP						
1 Wall 2 Walls 3 Walls						
Patch Antenna	99,98%	99,88%	99,96%			
Wired Antenna	100%	99,95%	99,87%			
External Antenna	100%	100%	99,98%			

simulate the other lamps. A similar test was done with the Xbee Pro modules with an external antenna, in order not to leave anything out. It follows that the system is completely reliable also in the case of five consecutive lamp posts broken down (the worst case in our test system). No bypass line is necessary in this case.

#### B. Power Management

The system was designed to be stand alone, supplied by solar panel energy, with relevant advantages resulting from this kind of power supply. It is possible to avoid the tedious and expensive wiring of the supply power network, with considerable savings and ease of implementation. The control circuit is designed to consume the lowest possible power, minimizing the battery capacity and the energy supplied by the solar panel. These goals were achieved through the use of the XBee module for transmitting and receiving information, using LED lamps as a replacement for standard lamps and using special power-saving solutions for microcontrollers and radio modules. The program, which controls the system, is designed primarily to save energy. First, since the system only works at night, avoiding wasting energy during daylight hours occurs when the only active device is the solar panel recharging the battery. Second, various sensors allow the system to work only when necessary. Third, the system implies highly efficient LEDs to ensure proper illumination and ensure energy savings. For our work, a 84-lm/W

 TABLE II

 CURRENT CONSUMPTION AND OPERATING TIME OF LAMPPOSTS

Lamp ID	Ma	rch	April		
	Time (h)	I (A)	Time (h)	I (A)	
Lamp 1	108.14	1.47	87	1.44	
Lamp 2	108.33	1.51	87	1.50	
Lamp 3	108.14	1.48	86.64	1.47	
Lamp 4	108.14	1.53	87	1.44	

LED was used. Finally, when the system is disabled, all devices (XBee and microcontrollers) are in the sleep mode, which allows negligible power consumption. The wakeup is triggered by the change of conditions (emergency device, presence sensor, etc.). The management of the sleep mode is crucial, because we must ensure that the system quickly responds to interruptions. The choice of the battery depends on the conditions where the system is installed. For example, in case of a busy street at night, it is better to use a battery of higher capacity rather than the one in use for a street without traffic at night. We must also consider natural and weather conditions; in fact, we have to choose a larger battery which can compensate low sunlight for several days. In the worst case, the system needs a battery that is able to power the LEDs until 12 h (from 7:00 P.M. to 7:00 A.M.) at 1.5 A, with a total capacity of at least 18 Ah. A 5-Ah battery was chosen in the test case because the test street is not a busy one (the cost of a 5-Ah battery is almost 70%. lower than 18 Ah one). Finally, a solar panel capable of providing 1.5-A charging current at 12 V with 19-W maximum power was selected.

#### C. Measurements

The system provides an accurate reading of the switch-on times of the street lamps and of the absorbed currents. Both are stored in the memory of the microcontroller and are sent to the control center once a day. The transmission of a big frame of data could lead to the collision between data and to memorymanagement issues. This case occurs when two or more lamp posts send quite a large amount of information simultaneously. This matter can be solved using the transmission method that sends data from the farthest lamp post to another and, hence, down to the control center, storing all of the cumulated data in each lamp post. The high capacity memory needs would be incompatible with the components and devices chosen for the system, resulting in higher hardware costs and software complexity. To solve this issue, data were sent from a given lamppost only when asked by the control center.

A more accurate analysis of power consumption is shown in Table II, based on the data collected throughout the months of March and April 2011.

The average consumptions of current (I) are represented in Table III; switch-on time differences are due to the test of emergency conditions on the second lamp post in March, while in April, a failure was simulated to verify the third street light maintenance conditions. Given the time, the current, and the cost of a kWh of energy, different for each provider, it is possible to determine the real energy cost savings versus other systems.

For instance, lamp posts installed with a classical system are active for about 10 h/day during March and April, with a total of about 300 monthly working hours, versus the expected 108

TABLE III CURRENT CONSUMPTION AND OPERATING TIME OF LAMP POSTS

Lamp ID	M	ay	June		
	Time (h)	I (A)	Time (h)	I (A)	
Lamp 1	80.14	1.48	77.02	1.45	
Lamp 2	80.14	1.50	77.02	1.50	
Lamp 3	80.14	1.48	77.02	1.47	
Lamp 4	80.14	1.51	77.02	1.49	

h in March and 87 h in April for the proposed system, with a savings of about 66% of the time in the first month and 71% in the second.

Table III shows the new processed data for May and June 2011.

As we can see, the current consumption decreases in sunny months.

## D. Comparison With a Classic Lamp Post

To make a quantitative test of the advantages available by our system in comparison with a classical lamp post, three other lamp posts were added in parallel to the others. Their switching on is controlled only buy a crepuscular sensor which keeps the lamp posts on during dark hours. We made this test on July 2011, and the new lamp posts had these characteristics:

- 1) 18-W LED lamp with 1550 lumen (84 lm/W luminous flux), powered by a solar panel and a battery;
- 18-W LED lamp with 1550 lumen (84 lm/W luminous flux), supplied by mains through an ac/dc converter to have 12 V;
- 50-W mercury-vapor lamp by the OSRAM model HQL50 [29] with 1800 lm (36 lm/W luminous flux), supplied by mains through an HV starter and a reactor.

We have chosen this mercury-vapor lamp because its emissions are comparable to the LED one. A shunt resistor of 10  $\Omega$ was placed on the third lamp post for current measuring. The obtained results are in Table IV.

Thanks to a stand-alone supply based on photovoltaic panels, the first and second solutions have no power consumption (the value of kilowatt-hours (kWh) has been fixed by the Italian supplier ENEL at 0,2~euro; per kWh [30]). Considering cost differences of the different settings, the equation to find the break even is

$$PC_{Z} + \sum_{i=1}^{x} (\mathbf{k} \mathbf{W} h_{Zi} \cdot C_{\mathbf{k} \mathbf{W} h_{i}})$$
$$= PC_{Y} + \sum_{i=1}^{x} (\mathbf{k} \mathbf{W} h_{Yi} \cdot C_{\mathbf{k} \mathbf{W} h_{i}}) \quad (1)$$

also written as

$$PC_{Z} - PC_{Y} + \sum_{i=1}^{x} (kWh_{Zi} - kWh_{Yi}) \cdot C_{kWh_{i}} = 0 \quad (2)$$

where PC is a fix cost and represents the plant cost difference between different lamp posts, kWh are the number of kilowatts per hour used by the specific lamp post day by day,  $C_{kWhi}$  is the cost of kWh which can change during a long period, and x is unknown and represents the activity days necessary to reach the break even between two different choices of lamp posts.

	July				Plant Costs				
Lamp ID	Time (h)	I (A)	kWh	Cost h X kWh (0.200 €)	Battery type and cost	Solar Panel type and cost	Battery Recharger	Cost € (lamp)	Power supplier
New Lamp (L1)	75.12	1.48	1.334	0	5 A – 16 €	19 W – 50 €	10€	18	0
New Lamp without light sensor (L2)	263	1.49	4.702	0	20 A – 25 €	80 W – 220 €	10€	18	0
New Lamp without presence sensor and supplied by electrical net (L3)	263	0.09	5.260	0.9404	None	None	0	18	30
Mercury Vapor Technology without presence sensor and supplied by electrical net (L4)	263.1	0.22	13.155	2.631	None	None	0	15	40

TABLE IV CURRENT CONSUMPTION AND OPERATING TIME OF NEW AND OLD LAMP POSTS

 TABLE V

 Requested Time to Reach the Break-Even Point

 Between the Different Solutions

	L1	L2	L3	L4
L1		Always more	After 53	After 19
	-	convenient	months	months
L2	Never more		After 250	After 87
	convenient	-	months	months
L3	Before 53	Before 250		After 2
	months	months	-	months
L4	Before 19	Before 87	Before 2	
	months	months	months	-

It is possible to consider the price of kWh constant. Considering a particular month like July, when the amount of kWh is low and so the savings are even lower, Table V shows the break-even time between the different choices. It is possible to note as the solution L1 is obviously always more convenient than L2 and reaches the break even against the L4 with classical technology in only 19 months, it also becomes more convenient than the third solutions after 53 months.

Obviously, using a month more convenient for the calculus, the break-even can be quickly reached. That is, between the analyzed months, March is the most convenient. For it, L1 is always more convenient than L2, reaches the break-even against L4 in only 10 months and becomes more convenient than the third solutions after 29 months.

## E. Management of Lamp Post Fault

One of the purposes of our work was to make the system available to inform the remote central in case of a lamp post fault so that a restore operation would be quickly possible.

In case of the ZigBee communication fault, if the n-ism lamp post does not react to the inquiry of the central, the program sends a notification of a breakdown to the graphics interface.

In this case, the system goes on measuring and storing data into the EEPROM and random-access memory (RAM) (with a capacity of 512 B) of the microcontroller. So if we consider a sampling every 5 min and a lamp post switching on for 8 h/day (as a particularly demanding case), the system will store data for about three days consecutively. But if the system is not restored within three days and we want to know the consumption information, a PIC with higher storage capacity, or even an SIM card, is necessary. If the PIC is not powered by the battery of the system anymore, a 4.5-V backup battery is integrated in the box and provides the necessary energy. The next release of the system will be modified in the firmware, providing the reading of the voltage of the battery on the microcontroller pin, so if the voltage is zero, a battery fault signal will be sent to the remote central.

## IV. CONCLUSION

This paper describes a new intelligent street lighting system which integrates new technologies available on the market to offer higher efficiency and considerable savings. This can be achieved using the highly efficient LED technology supplied by renewable energy of solar panels, for which the cost of energy is independent from the power supplier prices, combined to an intelligent management of the lamp posts derived by a control system switching on the light only when necessary, increasing the lamps' lifetime.

Another advantage obtained by the control system is the intelligent management of the lamp posts by sending data to a central station by ZigBee wireless communication. The system maintenance can be easily and efficiently planned from the central station, allowing additional savings.

The proposed system is particularly suitable for street lighting in urban and rural areas where the traffic is low at a given range of time. The independent nature of the power-supply network enables implementing the system in remote areas where the classical installations are prohibitively expensive. The system is always flexible, extendable, and fully adaptable to user needs.

The simplicity of ZigBee, the reliability of electronic components, the feature of the sensor network, the processing speed, the reduced costs, and the ease of installation are the features that characterize the proposed system, which presents itself as an interesting engineering and commercial solution as the comparison with other technologies demonstrated.

The system can be adopted in the future for loads supplied by the power system, which enables the monitoring of energy consumption. This situation is particularly interesting in the case of economic incentives offered to clients that enable remote control of their loads [31] and can be useful, for example, to prevent the system blackout. Moreover, new perspectives arise in billing and in the intelligent management of remotely controlled loads and for smart grid and smart metering applications.

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