A Solution for Street Lighting in Smart Cities

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Abstract— **Smart Cities is a domain of great interest in the modern society. The aim of a smart urban environment is to increase citizens' comfort and quality of life with minimum resources and power consumption and without affecting the natural environment. Street lighting is one of the main interests in such a smart environment. This thesis focuses on implementing a lighting control system that makes street lighting to be an autonomous and efficient part of the urban environment. The performance of the proposed system is analyzed using an OMNET++ network simulation. The results lead to the conclusion that the smart control system improves some drawbacks of a classic street lighting system.**

I. INTRODUCTION

The term "smart city" is a complex concept leading to multiple definitions, not always consistent. According to [1], a smart city has six characteristics: smart economy, smart mobility, smart environment, smart people, smart living and smart governance**.** This paper will use the term smart city with refer to smart environment.

Ubiquitous computing or pervasive computing paradigm is used to describe smart environments. This implies that robust, small and low-cost devices can be used to monitor and control various natural and infrastructure systems that affect the urban environment. These smart objects, mounted on buildings, streetlights, and cars, gather data autonomously transmitted to data centers for further analysis to efficiently manage the city such as street light management, water/gas leak detection, or traffic management.

The energy distribution system is very huge and expensive. Public lighting owns 10% from the electrical energy consumer categories, [2]. A lot of research is made to make the street lighting less power consuming and more suitable to citizens needs. There are several ways to achieve this by both hardware and software solutions.

The rest of the paper is organized as follows. The next section presents basics about street lighting, the third section describes related work, the fourth section presents the authors' approach, the fifth section discusses simulation results and the last section outlines conclusions.

II. STREET LIGHTING BASICS

A. Street lighting control systems

Street lighting control systems can be centralized or distributed. For the first category there is a single control unit that sends commands to all terminals, in the second category all terminals act as individual control units.

A centralized control system is presented in [3]. It is composed of three parts: control center, remote concentrator and street lighting control terminals.

The centralized control system is usually located into a government office. At the centralized control center, human operators monitor and control street lights by using operator's terminal. From the control center the command is sent to remote concentrator which operates every light terminal and gathers status information.

A remote concentrator manages a number of 16 to 20 terminals. The operations made by remote concentrator can be executed individually for every street light or group based. In both cases the control system and interface systems have some costs.

The street lighting control terminals are needed to control each light individually. They are installed to every light pole to control lights and to detect light status. The terminals communicate with remote concentrator to exchange status information and commands.

In case of distributed lighting control system every light pole has attached a control unit. This control unit commands the light equipment and can send or receive status information from the neighboring terminals.

B. Lamp nodes topology

In order to enable information exchange between lamp nodes, wireless sensor networks (WSN) can be a feasible solution. The network topology has a great influence in the WSN.

A linear topology with high depth is recommended in [4] for streets where lamp nodes are deployed along the road side. In this case a node must connect with few other nodes.

Different network topologies are used for lamp nodes deployed in parking lots, parks and gas stations. For these situations a node should be able to connect to a number of other nodes. The routing algorithm is responsible to deliver messages to target nodes. Due to limited resources of radio transceivers the routing mechanisms must be efficient and adaptive to changes of propagation conditions and deployment of nodes.

C. Lamp types

A lamp is a device that transforms electrical energy or gas into light. The amount of light produced by a lamp depends of the device's efficacy. Visible light output is usually measured in lumens.

In [5] the main lamp types identified are: incandescent lamps, tungsten halogen lamps, fluorescent lamps, compact fluorescent lamps (CFL), high intensity discharge lamps (High Pressure), mercury lamps, metal halide lamps, high pressure sodium lamps, electrode less lamps, induction lamp. A different category is solid-state lighting represented by light-emitting diodes (LED), organic light-emitting diodes (OLED) and light-emitting polymers (LEP).

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III. Related Work

As stated before there are several ways to implement a street lighting system based on WSN. There are multiple choices depending on the technology used, protocols, type of control and others factor that can influence the lighting systems.

Due to the rapid growth of industry and cities, the industry of street lighting systems has a fast development and is becoming complex. The paper [3] presents the drawbacks of most developed systems for street lighting. A new light control system is proposed which can overcome old systems drawbacks. The common drawbacks of most light control systems are uneasiness of handling and difficulty of maintenance. To reduce these weak points in operating light control system, the authors designed a street light control system by using Zigbee communication devices.

The proposed system is a centralized light control system. Remote concentrator and remote street light control terminal are H/W based system. Centralized control system was developed for windows 2000 based server system and most of developing works was SW oriented. Zigbee communication protocol is used to transfer data between concentrator and remote street light control terminal which transfers control and status information. The communication protocol chosen for data transfers between control center and concentrator is CDMA.

Jean-Philippe Vasseur, in the book "*Interconnecting Smart Objects with IP: The Next Internet*", [6], explains why the Internet Protocol, IP, is the protocol of choice for smart object networks including intelligent lighting systems. First part of the book demonstrates why the IP architecture is well suited to smart object networks by contrast with non-IP based sensor network or other proprietary systems interconnect to IP networks. Part II includes a detailed analysis of IP technologies. The final section of the book describes the use of smart object networks. This part discusses in details seven major applications: smart grid, industrial automation, smart cities and urban networks, home automation, building automation, structural health monitoring, and container tracking.

Maciej Mendalka et. al, [4], present an intelligent street lighting system based on WSN. As a result they obtained a system designed to increase functionality of light installations. The proposed system is made of WSN nodes integrated with light sources based on high power LED diodes. Their platform enable new services such as telemetry, monitoring of noise, humidity, temperature, as well as services associated with the road information systems, intelligent transportation systems and intelligent roads.

The paper [7], presents a street lighting implementation based on photovoltaic panels. The system uses solar energy as primary source and batteries as secondary source. Lighting emitting diodes (LEDs) are employed as lighting source. This system is being presented as an alternative for remote localities, like roads and crossroads.

Wu Yue proposes in [8] a street light control system able to detect environmental changes due to integrated sensors. The system has 2 function modes: the automatic timing control and a dynamic mode. Automatic timing is used to switch light on at a pre-determined time and keep them active a programmed time period. In dynamic mode the lights are activated when motion is detected. Simultaneously the system may act according to the actual determination of the sunlight degree of illumination and the degree of illumination control criterion.

Solid-state lighting technology has the qualities of cost-competitive, energy-efficient comparative to conventional electrical lighting, [9]. The authors present the history of lighting, discuss the benefits and challenges of the solid-state lighting technologies, and compare two approaches for generating white light from solid-state sources. The first is based on phosphor LEDs (which could be considered as solid-state replacement of fluorescent tubes) and the other the multichip LED lamps, which offer many advantages, such as chromaticity control, better light quality, and higher efficiency.

The power consumption problem is approached by R. Caponetto et. al in [10]. They present control equipment for monitoring and managing a street lighting system. The system consists of a local control and a remote control. The local control is realized by master boards located inside electrical panels and slave boards mounted on each lamp post. The remote control is realized by a central unit for the remote communication with the local control system. In case of master and slave boards communication power line modems are used, while the remote control central unit is connected to master boards via a GPRS-GSM communication. The user can select through master boards the electrical phase for the power line communication and send the control commands to the slave boards on each lamppost. Slave boards allow turning on/off the lamp post, to reduce power consumption using a device developed by ALBATROS Italia S.R.L., and to detect the lamp status, checking the current flow on the lamp itself. The solution presented in this paper allows reducing lamp power consumption of 28 - 32% with just a 3 - 5% lightness reduction.

The aspect of secure street lighting system is discussed in [11]. Street lighting systems are characterized by low-voltage loads, distributed in a large area and collectively protected by the same protective device. In fault conditions, hazardous potentials may appear on the metal parts of such equipment, and expose persons to shock hazards. To reduce such risk, different solutions for the grounding are available.

The Standard IEC 60364 recommends the use of Class II components, that is, equipment with double or reinforced insulation, for all the elements of the street light system. The authors analyze the possible technical alternatives in light of IEC standards. They also propose a solution to increase the safety of Class II metal poles by adopting a circuitry within lighting systems panel boards to monitor their double insulation-to-ground.

Chunguo Jing et. al. propose in [12] a routing protocol for monitoring and control of street lights. They described a geographical routing strategy based on the network features. The proposed solution groups lighting nodes into many clusters. One cluster comprises beside of the nodes, a power substation. The nodes from a cluster are disposed in either star or triangle topology. One node forwards the packet to the power substation where the remote terminal unit (RTU) is installed. The RTU uses cluster serial number to avoid the packet dissemination to neighbor cluster. The GSM network was used for transmitting and receiving data between the control center application and the remote RTUs. As a result, their approach is a connectivity solution based on Internet protocols and available with almost every GSM network.

Designing high efficient, low-cost and secure street lighting systems is a complex activity. Several aspects must be taken into account regarding the system architecture and the communication protocols. Wireless sensor networks are a popular solution when it comes to controlling and monitoring street lighting systems.

The need to better control the streetlight networks is caused by: the environmental and energy situation of the planet, the rapidly increasing price of electricity, the need for more security and safety, the need to efficiently manage budgets. These are the reasons why monitored streetlight systems are the future when it comes to outdoor lighting market.

IV. The Proposed Solution

This paper proposes an autonomous street lighting system based on a distributed command WSN network. The aim is to reduce power consumption using low-cost devices and reducing the active time of lighting devices as much as possible. The system was designed considering the deployment area as in Figure 1.

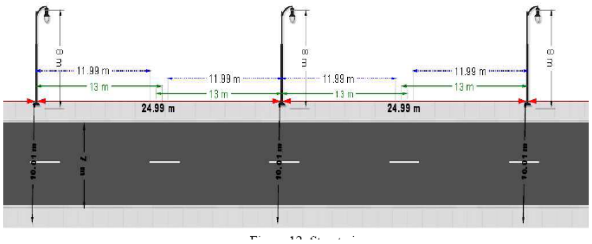

Figure 1. Street view

It is a residential street with two lanes and sidewalks on both driving directions. The road width is 7 m (3.5 m for each lane) and the sidewalk width is 1.5 m. The street has a total width of 10 m and it extends over a length of 2 km. lamp posts are positioned on one side of the road with a spacing of 25 m. The mounting heath of light sources is 8m. Figure 1 also shows that the maximum beam pattern's length is 13 m, in both directions, and the width is 10 m. The dotted line marks the maximum distance for pedestrian movement detection is 12 m. The light source is a LED luminary chosen in accordance with the distance parameters. Attached to each light source there is a node.

Every node represents a smart light control device and it enables pedestrian detection and natural light measurement. The control device will command the light element according to the level of environmental light measured. The light can be turned off or on with 3 levels of intensity (low, medium, intense). With an incorporated WiFi transceiver the control device can send wake-up commands to neighbor nodes. The block diagram of the proposed module is illustrated in Figure 2.

The ISL7668 block, [13], represents a light-to-digital device with 16 bit resolution. The module can be programmed via I2C interface to four sensitivity ranges depending on the lighting conditions. The power consumption is less than 300μA in normal operation mode.

DP-001A, [14], is a digital motion detector module. It can detect infrared radiation emitted by moving human body or animals. The detection range and activation time are programmable. Because the detection angle is 100 degrees the control device needs to incorporate two motion modules located on the left and right sides.

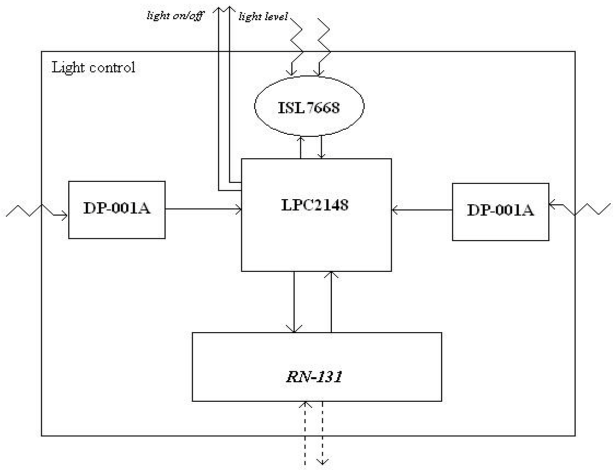

Figure 2. Smart light control device

RN-131, [15], is an embedded wireless 802.11b/g networking module. The module has an intelligent, built-in power management with programmable wakeup. It can host data rate up to 1 Mbps for the UART interface and a transmission rate of maximum 54 Mbps over the air.

The core of the smart light control device is the LPC2148 microcontroller, [16]. The tiny size and low power consumption make this microcontroller feasible for applications were miniaturization is a prime requirement. The variety of serial interfaces (USB 2.0, UARTs, SPI, SSP, I2C-bus) and 40 kB of on-chip SRAM are an advantage when implementing communication gateways, protocols converters, voice recognition or other type of applications that require high processing power. The interfaces together with DACs, ADCs, PWM and GPIO lines make it easy to connect the microcontroller to a great range of other devices.

V. Experimental Results

To test the proposed functionalities a simulation network with OMNeT++ (Objective Modular Network Testbed in C++), [17], was created..

OMNet++ is a free simulation library and framework based on C++ language that enables modeling a large number of networks such as wired and wireless communication networks, on-chip networks, queuing networks and so on. For wireless sensor network support OMNeT++ provides INET Framework which contains models for several wired and wireless protocols including 802.11, TCP, IP, UDP.

OMNeT++ is a modular discreet event simulation framework. The base element is a simple module. More complex devices can be represented as modules. A module is compound of simple modules. In OMNeT++ modules exchange data trough messages. The simulation time advances when a message is received by a module. In case of a module with no extern incoming messages, the simulation time can be advanced with the help of self messages.

The simulation is based on the main characteristics presented in section IV. The simulation was created for a network of 10 smart nodes with linear topology and a module representing a human moving along the street as depicted in Figure 3.

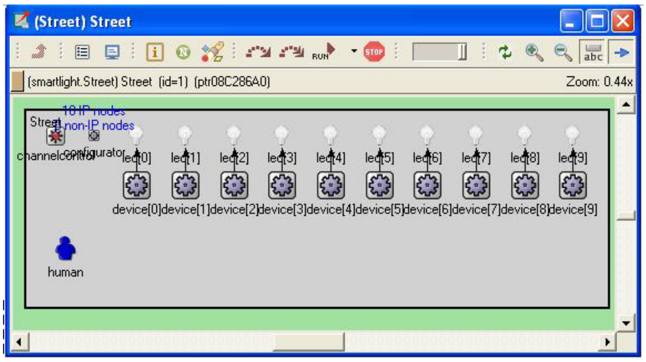

Figure 3. Smart street lighting simulation

The *human* model will update its position every 14 seconds to simulate a walking speed of 1m/s. Integration time for light sensor measurements is 100 ms.

The *human* is a simple module sending a message every time it moves. At initialization it sends a self-message to start "moving". This implies sending an "Approaching" message to one device at a time, every propDelay period. The propDelay period is configurable depending on the *human* walking speed.

The compound modules *device[i]* represent the smart light control devices. They are attached to LED luminaries implemented as simple modules *led[i]*. The light control components can be visualized in Figure 4.

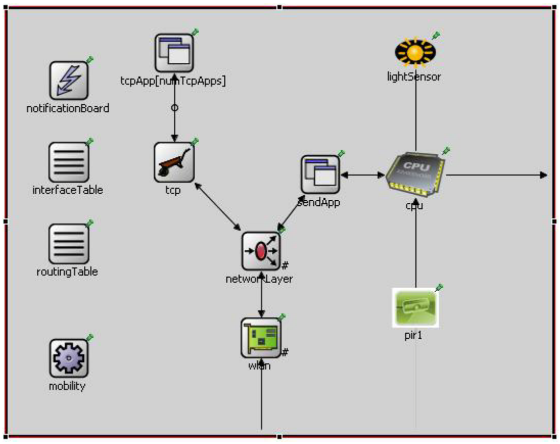

Figure 4. Smart light control device

CPU module represents the microcontroller. It receives inputs from the sensors or from the WiFi transceiver. The *CPU* processes the input information and according to it sends on/off commands to LED device and to left and right neighboring nodes. The movement of *human* is detected with a PIR sensor. For simulation purpose only one PIR sensor was used.

If *pir1* detects a movement it notifies the CPU. The sensor stays active for a programmable period of time. The sensor is working in a re-trigger mode. When the active period expires and no movement is detected, the sensor goes idle and notifies also the CPU.

After a movement has been reported, CPU launches a start conversion command to *lightSensor*. The sensor begins light measurement. After a stopSync period of time the CPU sends a stop conversion command. The measured data value is saved by light sensor and a new conversion begins. When a read message is received from the CPU, the sensor retrieves the latest saved light value. From the data supplied by the light sensor the CPU computes the actual illuminance, it compares it to predefined levels and it lights the LED according to the result. After this the control unit also sends a light on command to right and left neighbors trough the WiFi module. When no movement is detected, the lights on commands are revoked.

RN-131 networking module is represented in the simulation by multiple simple modules according to its capabilities: radio transceiver, TCP/IP support, routing table. The module implementation uses INET framework. In case of commands received trough WiFi module, they are executed but not send to the neighbors.

To have some comparison values, first simulations without movement detection were performed. Two cases were considered: 1 lux natural light environment (high luminary intensity lighting is needed) and 500 lux natural light environment (medium luminary intensity lighting is needed). The energy consumption was computed for a simulation time of 2 hours while lighting sources were on. The results are presented in Figure 5 and Figure 6.

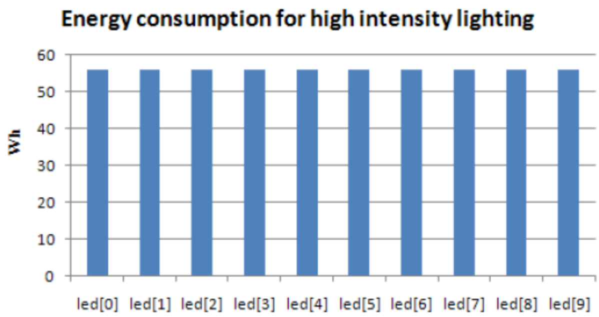

Figure 5. Energy consumption for 1 lux lighting

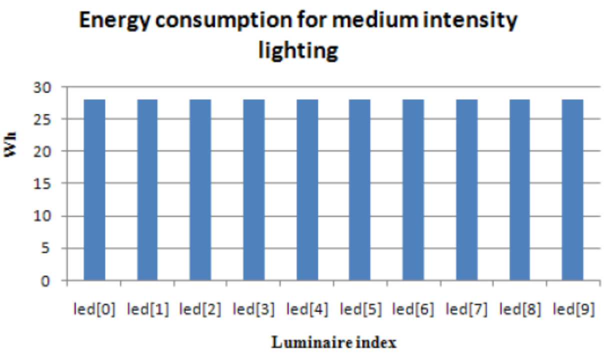

Figure 6. Energy consumption for 500 lux lighting

It can be observed that the energy consumption was 56 Wh in the first case and 28 Wh in the second one for each lighting source.

In the following simulations some assumptions will be done: the simulation time is 2 hours, the period between pedestrian passing along the street is variable and is generated with a uniform distribution between 60 s and 10 minutes and two cases are considered: 1 lux and 500 lux natural environment lighting conditions. In the first case, when pedestrian movement is detected the LED luminary is switched on at full capacity and in the second case at half capacity.

Scenario 1

The assumption is that only 1 pedestrian is moving along the street. The human model starts moving from the first led position until the last one. Figure 7 shows the minimum, average and maximum values for the total energy consumption registered for each LED luminary.

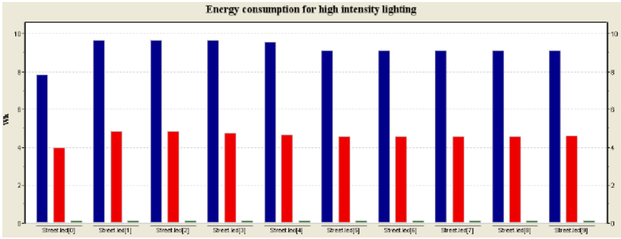

Figure 7. Energy consumption for 1 lux with movement detection

Conforming to the results, the minimum energy consumption is 0.107 Wh/LED luminary. The maximum energy consumption varies between 7.84 Wh and 9.66 Wh. Comparing the values with those from Figure 5, it results about 80% reduction of the energy consumption. A significant reduction is obtained even when the comparison is done with the values from Figure 6.

Figure 8 presents the results in the case of 500 lux natural environment lighting. The minimum values are the same for all luminaries, 0.053 Wh, the maximum values range between 3.92 Wh and 4.83 Wh meaning half of the energy consumption in case of 1 lux and 94 % decrease than the consumption in case of 500 lux lighting conditions without movement detection capabilities.

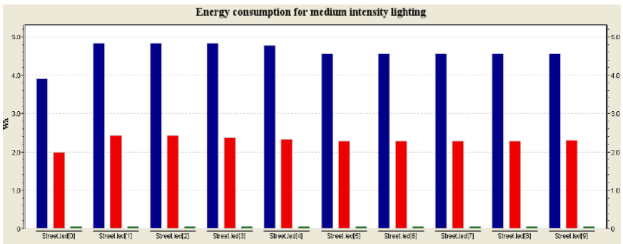

Figure 8. Energy consumption for 500 lux with movement detection

Scenario 2

The second set of simulations was based on the assumption that two pedestrians are moving along the street. One human model starts moving from the first led position until the last one. The second human model moves along the street in the same time but beginning at the fourth lamp post. Figure 9 shows the minimum, average and maximum values for the energy consumption in case of fully powered lamps (1 lux).

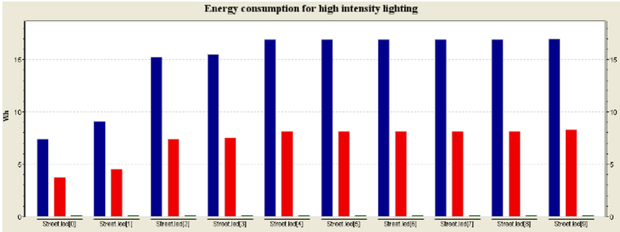

Figure 9. Energy consumption for 1 lux with movement detection, 2 humans

The minimum energy consumption slightly varies between 0.1069 Wh and 0.1086 Wh for the first half of the street and then becomes constant, 0.1069 Wh, for the second half of the street. The maximum energy consumption ranges between 7.38 Wh and 17 Wh. The results show a 69 % decrease of the energy consumption than the one from Figure 5 and a 48 % reduction if compared with the reference case of 500 lux natural environment lighting conditions.

Figure 10 presents the results in case of 500 lux. The minimum values are similar for all luminaries, 0.053 Wh, as in Scenario 1. The maximum values vary between 3.69 Wh and 8.5 Wh this being 50 % of the energy consumption in case of 1 lux and 72 % better than 500 lux lighting conditions without moving detection capabilities.

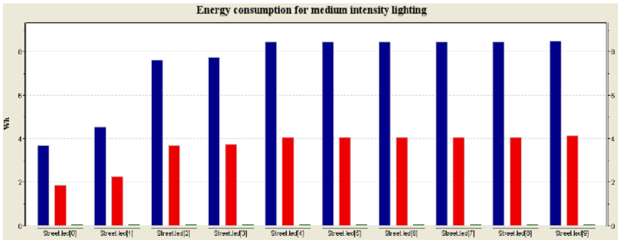

Figure 10. Energy consumption for 500 lux with movement detection, 2 humans

Scenario 2 represents an improvement compared with the conditions without moving detection possibilities but the energy consumption is increased with 40 % than that from Scenario 1.

Scenario 3

It is assumed that 8 pedestrians are moving along the street. The first pedestrian starts moving from the first led position until the last one. The following pedestrians move along the street in the same time but starting at consecutive positions.

Figure 11 illustrates the minimum, average and maximum values for the energy consumption at each LED luminary when high intensity artificial light conditions are required. The figure shows that the minimum values are reduced considerably ranging between 0.85 mWh and 107 mWh. The variation is constantly increasing from led 0 to led 9. The average minimum consumption is 80 % lower than Scenario 1 and 2. The maximum values have also an increasing variation with the average of 33.8 Wh this being with 40 % lower than the energy consumption in case of 1 lux with 2 hours of artificial constant lighting but 3.5 times greater than 1 lux case from Scenario 1 and 2.2 times greater than the same case from scenario 2.

Figure 12 provides the simulation results in case of 500 lux environmental lighting conditions.

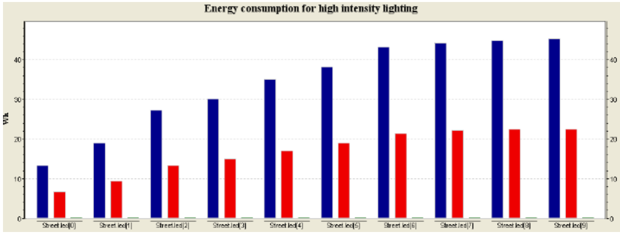

Figure 11. Energy consumption for 1 lux with movement detection, 8 humans

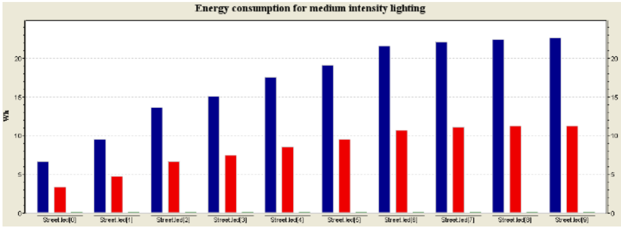

Figure 12. Energy consumption for 500 lux with movement detection, 8 humans

Compared with the previous case the minimum total energy consumption is reduced with 50 % taking values from 0.42 mWh to 53.4 mWh. The maximum values for the energy consumption ranges between 6.64 Wh and 22.6 Wh with an average of 17 Wh. This is 70 % more than 500 lux case from Scenario 1 and 50 % more than the same case from Scenario 2. Nevertheless these results are 40 % lower as compared to the case without movement detection possibilities.

For Scenario 3 the minimum values were much lower than the ones from the other scenarios but the total energy consumption was increased. This is caused by the greater number of pedestrians. This implies a considerable number of switching commands for the LED luminaries leading to short operational periods of time per luminary for starting points lamp post and prolonged periods for ending points.

VI. Conclusions

The paper has presented an efficient street lighting system with reduced power consumption in comparison to classical lighting systems. This is accomplished by using a WSN based street lighting system.

The power consumption is decreased using a smart light control device. The device uses low-power hardware with configurable functioning modes. Through this control device light will be active only when pedestrian movements are detected. Also the light intensity is adjusted in accordance to predefined levels of luminance. Using LED luminaries instead of other light sources will further decrease the power consumption with the advantage of increased light output efficiency, longer life and environmental friendly.

Using smart control devices increases the street lighting system's autonomy. Human operator intervention is necessary only for system deployment or in case of damaged devices.

The incorporated WiFi module enables easy collection of statistical information. The WiFi module also support remote configuration using Telnet.

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