

ZigBee Based Energy Efficient Outdoor Lighting Control System

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Abstract — This paper presents user-centric energy efficient lighting control architecture for street lamps. The system utilizes ZigBee technology to implement wireless mesh network of street lamps. The coordinator, serving as gateway between ZigBee nodes and internet, relays information of interests to remote user. The proposed system comprises of LED lamps, gateway node, and management software that offer remote monitoring and control of the lamps. Each LED lamp is integrated with ZigBee node, sensors and the Controller module along with ballast actuator. To realize effectiveness of proposed system, prototype has been installed inside University¹.

Keywords — Lighting Control, Energy Efficient, ZigBee, Smart lighting, internet.

I. INTRODUCTION

Conventional lighting systems work on bi-level approach, either on or off. When on, operates on rated power and there is no control to adjust power consumption by any means. Lighting control systems are introduced to reduce energy consumption inherent to conventional lighting systems. These control systems can be part of building automation system to cover indoor lighting or can be controlled through regional office of metropolitan area if needs to control outdoor lighting of large urban area, such as, street lights.

Street lights are controlled either individually or in group. In group based control, several lights are jointly connected to mains, decreasing wiring cost. Group based control system is simple in its functionality but disconnects all street lights within group due to maintenance and troubleshooting. However, in individual control, lamps are independently connected to mains at the expense of additional wiring and labour costs. Numerous lighting control systems have been proposed to reduce energy consumption [1], using occupancy sensing approach [2], and light level tuning [3].

Controlling of traditional lighting system mainly depends on effectiveness of adopted technology. Two major technologies, PLC and Wireless Sensor Network [4], have

gained much attention for lighting control applications. Despite reducing wiring structure in PLC based designs presented in [2], [5], [6], [7], occasional drops may occur in PLC networks operating on LV (Low Voltage) power lines [8]. These drops are caused by noise and attenuation, and can last from a few minutes to few tens of minutes. Due to carrier signal attenuation, there may be high latency or communication failure in PLC based design [4], [9]. On the contrary, deploying communication infrastructure based on WSN, such as ZigBee, eliminates wiring overheads.

A. Analysis of Existing Systems

For implementing wireless control of lights, several comparable architectures have been applied for indoor [10] [11], [12] and outdoor [9], [13], [4] lightings. [9] and [13] applies ZigBee standard, star topology and mesh topology respectively, with aim to reduce energy consumption. Exploring previous research in the area of lighting control reveals that more effort has been made in lighting control inside building by applying WSN technologies in contrast to outdoor lighting control. [4] demonstrated street lighting control using ZigBee for short distance communication similar to [13] and extends communication range by utilizing licensed band CDMA for sending information between remote concentrator and centralized control center. [4] and [13] both described preliminary result with common aim to save maintenance time, decrease costs and raise reliable level. Similarly, realizing the importance of WSN technology over PLC, [9] aims to reduce energy consumption by describing synchronized wireless mesh network model to connect luminaries while using licensed band GPRS for sending information to remote computer application.

Surprisingly, these papers demonstrated their work with specific goal of controlling energy consumption and do not address effects of reducing dimming level too much from user's perspective. Our energy efficient outdoor lighting control system aims to address both issues: reducing energy consumption while maintaining user satisfaction. The proposed system also allows remote operator to observe specific lamp parameters (power and temperature). Continuous monitoring of lamp parameters such as case temperature and power measurements help in locating faulty

¹ This work was supported by the GRRC Program of Gyeonggi Province.

lamp/node instantly. Control framework, shown in figure 1, capable of working with any outdoor lighting configuration to provide scheduled/demand based lighting for reducing energy consumption and at the same time maintaining user satisfaction.

Rest of the paper is organized as follows: section II describes system architecture along with ZigBee devices, sensors and actuators with monitoring and control software. Section III provides detail of the system implementation whereas conclusion and future work is discussed in section IV.

II. SYSTEM ARCHITECTURE

Wireless Mesh network (WMN) of ZigBee nodes combines advanced and traditional controlling features. Proposed system minimizes energy consumption for the benefit of user and environment concurrently.

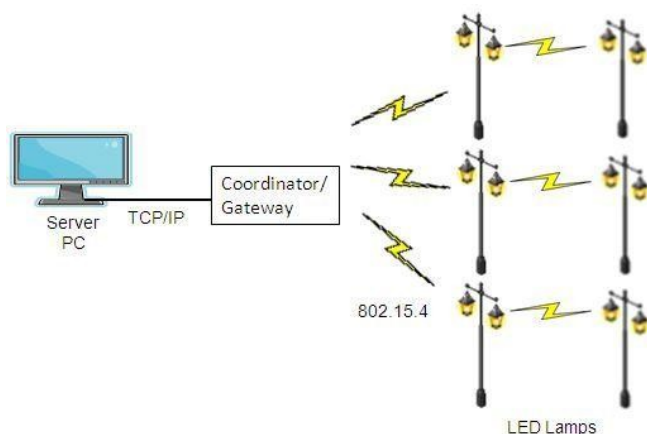


Figure 1. System Architecture

The system comprises of ZigBee based mesh networked streetlamps, gateway node, and management software that offers real time monitoring and control of lighting system. Each lamp is integrated with ZigBee node and the Controller module along with ballast actuator. The Controller interconnects light sensor, ballast actuator, and radio communication module (RCM). The system is remotely managed through developed software that allows operator to implement different strategies for saving as much energy as possible.

A. ZigBee Devices

Ember ZigBee stack is utilized for implementing energy efficient lighting control system for street lamps. Ember's EM250 is a single-chip solution that integrates a 2.4GHz, IEEE 802.15.4-compliant transceiver. It contains integrated Flash and RAM memory and peripherals of use to designers of ZigBee-based applications. The EM250 contains 17 GPIO pins shared with other peripheral (or alternate) functions. Flexible routing within the EM250 lets external devices utilize the alternate functions on a variety of different GPIOs. The integrated Serial Controller SC1 can be configured for SPI (master-only), I²C (master-only), or UART functionality, and

the Serial Controller SC2 can be configured for SPI (master or slave) or I²C (master-only) operation [14].

Self-route repairing ability of ZigBee enables packet to travel through different channel if current channel (path) fails to deliver packet. When a radio path fails to deliver packet to destination, routing table is updated to change route to destination. In a place of varying RF environment, deploying nodes forming mesh network increase communication route for reliable message delivery to ZigBee Coordinator (ZC) through different routes. In the system, every street light is equipped with ZigBee nodes that relay information and command signals between remote operator and Smart LED lamps.

1) Gateway Node

A gateway node serves as bridge between two heterogeneous networks of ZigBee and internet and performs protocol conversion. In proposed design, attributes of LED lamps are remotely observed and controlled through ZigBee gateway (GW). Designed ZigBee gateway, shown in figure 2, offers interoperability by providing message translation between WMN and TCP/IP network.



Figure 2. Gateway Nodes

B. Sensors and Actuators

Sensors are attached with ZigBee router (ZR) nodes to continuously monitor parameters of interests. Installed sensors observe following parameters:

- i. Lamp housing temperature,
- ii. Power consumption of luminaire and
- iii. Illuminance condition of the place.

1) Light Sensor

Illumination sensor is installed to aware the remote user about the brightness status of the place. By taking advantage of remotely controlling the network, operator can control brightness of the lamps in order to maintain user satisfaction. Light sensor, BH1710FVC, connected to the Controller through I2C interface and observes ambient light status.

2) Power Metering

Power status of lamp is measured to observe actual power consume by LED lamp. Metering IC, ADE7753 [15], connected to the Controller board via SPI.

3) Temperature Sensor

High-powered LEDs, besides providing high-intensity illumination, produce a significant amount of heat which would ultimately lead to device failure [16]. An increase in housing temperature due to heat dissipation of LED lamp is continuously monitored.

4) Ballast Actuator

[5] demonstrates four controlling levels, namely; OFF, MIN, MED and MAX. However, in our design, a ballast actuator can control up to six LED modules each of 35W rated power. LED modules are capable of multi-level dimming control (from 0 to 255) of lamps using monitoring and control software.

C. Controller

Controller, installed at each street lamp, is considered as main entity. Light and temperature sensors connected to the Controller; send information signals to microcontroller unit (MCU), ATmega128. ATmega128 manages information flow among sensors and ballast actuator and also responsible for generating pulse width modulation (PWM) signal for dimming control of LED lamps. Block diagram of the Controller is shown in figure 3.

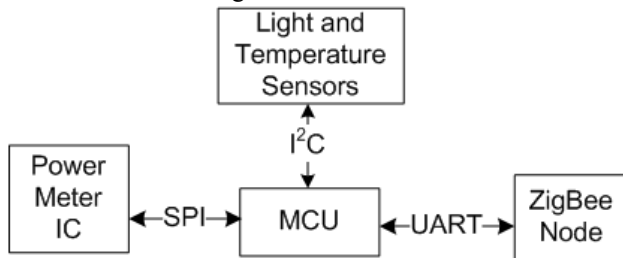


Figure 3. Block Diagram of the Controller

D. Monitoring and Control Software

For controlling street lamps, we adopt following software developing environment: client/server as structure, C++ as developing language and Microsoft Excel as database. The software offers operator to apply different strategies for controlling individual or customized groups of lamps. Each lamp is assigned long ID (EUI) and short ID (ShortID) for data logging. Acquired information is logged with time stamp and device ID of street lamps. For reference, captured status of nodes is shown in Figure 4. Power consumption of 70 W lamps having short ID 0xCF6C is 57.2W for corresponding PWM value of 206. Measured housing temperature remains approximately 15°C higher than outside.

III. SYSTEM IMPLEMENTATION

ZigBee based street light monitoring and control system aims to modernize infrastructure of traditional wired system, currently exercised for outdoor lighting systems.

Num	EUI	ShortID	D-Lev	Lux	Watt	Temp	Time
0	0x7F9F28	0xF9C7	255	0000	707	036	04:59:21
1	0x7F9F22	0xFB8D	255	0000	758	037	04:59:30
2	0x7F9F3B	0xA0D6	255	0000	756	037	04:59:28
3	0x7F9F1F	0x7574	255	0000	744	035	04:59:35
4	0x7F9F3E	0x5EED	255	0000	727	037	04:59:36
5	0x7F9F25	0x7691	255	0000	685	035	04:59:35
6	0x7F9C8C	0x7EBC	255	0000	749	036	04:59:34
7	0x7F9F24	0x08B6	255	0000	708	035	04:59:31
8	0x7F9F2D	0x1A6E	255	0000	738	036	04:59:18
9	0x7F9F3C	0xD90F	255	0000	709	033	04:59:35
10	0x7F9C97	0x2DC3	255	0000	713	035	04:54:59
11	0x7F9F39	0xC334	255	0000	772	037	04:54:59
12	0x7F9F23	0x69D4	255	0000	757	035	04:54:58
13	0x7F9F1E	0x1220	255	0000	710	035	04:54:43
14	0x7F9F1D	0xCF6C	206	0000	572	034	04:55:03

Figure 4. Status Display of Smart LED lamps in Software.

Controlling of building light to reduce energy consumption in office environment for user satisfaction has been presented in [17] that controls lighting fixture from a control PC. In proposed design for controlling outdoor lightings, ZC maintains mesh network of lamps and also serves as gateway. Figure 5 shows area inside university campus where traditional streetlamps have been replaced from smart LED lamps shown in figure 6.



Figure 5. Bird's view of Installed Area

A. Smart LED Lamp

Assembles Smart LED lamp, as shown in figure 6, consists of LED lighting fixtures. An LED module consists of 7x4 LED array with rated power of 35W. Each LED lamp is powered with ballast actuator that is controlled by the Controller as per operator's instruction.

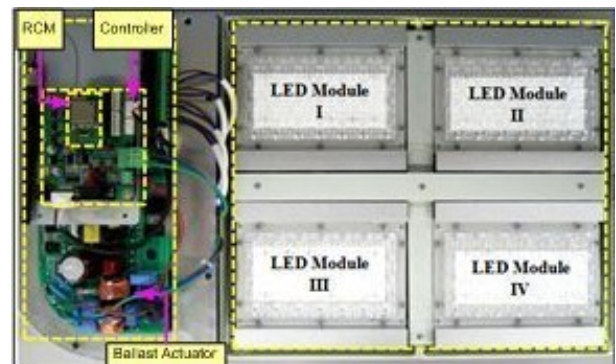


Figure 6. Smart LED lamp



Figure 7. Realization of Smart LED lighting system.

B. System Prototype

Prototype of the networked controlled Smart LED lamps has been installed inside the University campus. During deployment phase, 22 units of 150W and 16 units of 250W Metal Halide Lamps were replaced by 70W and 140W LED lamps respectively. Figure 7 depicts field view before and after installation of lamps.

IV. CONCLUSIONS AND FUTURE WORK

The proposed system is designed to reduce energy consumption of outdoor premises and demonstrated by developing prototype to control street lamps. The system minimizes energy consumption for the benefit of user and environment concurrently. Besides, the system may be integrated with [18] to assist in traffic management.

Based on preliminary results, partially installed user-centric lighting system can be expanded across the university campus due to reliability and robustness offered by proposed system. Besides, proposed design may also be optimized by providing sensor's feedback to the Controller.

ACKNOWLEDGMENT

Authors would like to thank Taemin Yoon and Byungoh Kim for providing LED lamps and installation of the system.

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