Design Bluetooth Low Energy for Battery and Photovoltaic Monitoring at Solar Powered Street Lamp System

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Abstract. In this paper, we designed an electrical power monitoring system for PV, batteries, and lamps at solar powered street lamps based on wireless sensor network (WSN) system using Bluetooth Low Energy. The power monitoring system is low-cost and open platform technology. The WSN used tree and linear topologies for data transmission and both in terms of the type of sensors and the number of sensor nodes. The distance between sensor nodes about 40 m as standard of street lamp. The network design used 2 chains in tree topology and each chain have 5 hop or nodes. The WSN at solar powered street lamps is well suited for a wide variety of applications related to environmental monitoring, because solar powered street lamps spread into remote areas and use solar energy as a main power source.

1. Introduction

Street lamps have an important role to determine the condition of the road environment so that drivers safely in driving. Several roads do not equipped with street lamps due to difficult access to the electricity. The best solution to light the road is to use solar panels as the main source of electricity. Solar powered street lamps have several devices which can produce electricity optimally. Those devices are solar panels, lamp emitting diode (LED) lamp, battery, and solar charge controller. From these devices batteries have very important role in solar powered street lamps. Incorrect operation can affect the battery capacity and the battery damaged short period \([1-2]\).

The position of the battery on a solar powered street lamp is usually placed on top of the lamp pole (Figure 1). This condition are difficult to monitor the condition of the battery and photovoltaic (PV) performance. Battery performance monitoring is useful for monitoring battery life predictions and to choose appropriate action when the battery has an operating error \([2-3]\). Some parameters to measure battery performance are battery voltage, battery temperature, and load current. In this paper, we proposed a design PV and battery monitoring based on wireless sensor network (WSN). Some researches use internet of things (IoT) concept to send data via internet gateway, but it takes use much power consumption and high cost if every lamp street uses IoT concept especially in a remote area \([4]\). But, WSN concept uses less power consumption and low cost for monitoring battery and PV condition \([5-9]\). The other advantage of this method is the operator does not need to climb to the top of the pole to retrieve data.
2. System Overview

2.1. Wireless Sensor Network (WSN)

Wireless Sensor Networks (WSN) is a collection of sensor nodes that make up a wireless network system to allow the physical condition of an environment using sensors in a real time and sending data collected at a centralized location wirelessly. Sensor nodes means from a small group of autonomous device with several the sensor inside. Basic functions of WSN generally depends on the application, but the important role is to get a parameter value in distributed location. A WSN can made with various types of network topologies such as Star, Tree, and Mesh (Figure 2). This type of topology for sensor node communicates to the other nodes [10]. WSN can be used in many fields such as healthcare monitoring [11-12], smart parking [13], agriculture [14], smart home [15], and environment monitoring [16].

A WSN system consists of sensor nodes, sink nodes, internet or information transport network and user computers [17]. Sensor nodes are using wireless mode to communicate with each other. However, the nodes have limited power to deliver meassages in large distance, therefore it forces to deliver massages from one node to another node using multi hop network [18]. One node belongs to one cluster, and every cluster has a sink node that acts as local controller or as a router. In star and cluster tree topology, the routing path is fixed.

2.2 Bluetooth Low Energy (BLE)

Bluetooth Low Energy (BLE) is a new technology devices which introduced in Bluetooth 4.0 and more economical version from classical Bluetooth technology [19-21]. Some new features of BLE such as support mesh network and extended sleep phase of the transceiver [22] and the power consumption is 2.5 times lower [18]. The characteristics of BLE is shown in Table 1.

BLE is a new promising technology in street lamp monitoring. It has low power consumption and support multi hop network, BLE also has high data rate around 1 Mbps in range 10 – 100 m [18,22,23]. The existing technology for street lamp monitoring such as Power Line Carrier (PLC). However, the PLC have some technical problems such as noise, carrier signal attenuation, and changing of lines input impedance [24].
### Table 1. BLE characteristics [18,22,23]

| Parameter         | Value          |
|-------------------|----------------|
| Frequency band    | 2.4 GHz        |
| Number of channels| 40             |
| Data rate         | 1 Mbps         |
| Range (distance)  | 10 - 100 m     |

### 3. Proposed System Architecture

In this paper, we proposed a WSN system architecture in street lamp using BLE technology. A WSN system consists of sensor nodes, sink nodes, internet or information transport network and user computers. A sensor node consisted of four main parts such as power supply module, sensor, microcontroller, and wireless transmitter/receiver (see Figure 3). The power supply is to provide electrical power to the system. The power supply from this design using PV system and lead acid battery with nominal voltage 12 V. But it need DC-DC Converter to reduce voltage from 12 V to 3.3 V as the nominal voltage to run the microcontroller and NRF52832 have a maximum voltage about 3.6 V [25]. The function of the sensor is to collect and change signals like temperature, voltage, and current into electrical signal. The sensor circuit uses PV power sensor, battery power sensor, DC load sensor to monitor PV and battery condition. The microcontroller is a hardware for data acquisition from sensor and communicating with transmitter/receiver module. The function of wireless transmitter / receiver module is to transfer data into other sensor nodes. The wireless transmitter/receiver module using NRF52832 module that uses a bluetooth signals for exchange data to another node.

The WSN system designed in this paper uses tree and linear topology. Tree topology is used on sensor nodes to deliver data measurement to sink node and continue to master node of each group. Based on literature review, BLE support 2 chain structure and each chain have 5 hop or nodes [18]. So the total node with one master node is 10 nodes. One pole is referred to as one node. The distance between sensor nodes referring lamp street standard is around 40 m [10]. Each node (eg. node 15) sends data to the next node (node 14), and the data is sent to the next node (node 13) and continue the data is sent to the master node (See Figure 4).
Street lamp in several places are located in remote area, so the master does have limited access to internet connection. Then, we introduced a concept that the operator uses electric vehicle act as an information transport network replace the internet gateway or LAN connection design [26-27]. The communication between master node and electric vehicle uses Bluetooth technology, then the operator does not need to climb the lamp pole. The operator can collect data from master node 1 into master node n (Figure 5.a). After the operator collecting data from several master nodes, the data transmit into user computers using serial communication (see Figure 5.b).

**Figure 4.** Proposed WSN topology for battery and PV monitoring

**Figure 5.** Electric vehicle act as an information transport network (a) collecting data from master node 1 into master node n (b) Data send to user computers after collecting data from several master nodes
4. Conclusion
In this paper, we proposed a design PV and battery monitoring at solar powered street lamp based on Bluetooth Low Energy (BLE) wireless sensor network (WSN). The battery and PV on a solar powered street lamp is usually placed on top of the lamp pole. This condition make difficult to monitor the condition of the battery and PV performance. Battery and PV performance monitoring is useful foresee life predictions and appropriate actions when the battery and PV has an operating error. Some parameters to measure battery and PV performance are battery and PV voltage, battery temperature, and load current. Street lamp in several places are located in remote area and does have limited access into internet connection. A WSN using 10 nodes with 2 chain structure and each chain have 5 nodes. A WSN device in this paper using NRF52832 using Bluetooth technology to transmit measurement data wirelessly into master node. The data from master node, is collected using electric vehicle operator using Bluetooth wave. After collecting data from several master node, the data is sent into user computers for to be analyzed. A WSN concept is suitable for monitor solar powered street lamp. For future work, we observe the power consumption and data availability from this design.

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References
[1] Andrew Swingler, and Jordan Torrealba, “Opportunity for Improving Lead-Acid Battery Management of Photovoltaic-Genset-Battery Hybrid Power Systems Based on Measured Field Data”, Energies, 2019.
[2] Tina G., Cosentino F., Ventura C. “Monitoring and Diagnostics of Photovoltaic Power Plants”. In: Sayigh A. (eds) Renewable Energy in the Service of Mankind Vol II. Springer, pp 505-516, December 2015.
[3] Hu T, Zheng M H, Tan J J, Zhu L and Miao W., “Intelligent photovoltaic monitoring based on solar irradiance big data and wireless sensor networks”, Ad Hoc Netw 35 127-36.
[4] N. Chowdhury, M.Hossai, S. Islam, “Detection of Keys, Controlling Machines and Wireless Sensing Via Mesh Networking Through Internet”. Global Journal of Researches in Engineering Electrical and Electronics Engineering, 2013, Vol. 13, No. 13, pp–.
[5] F. Jin, H.-A. Choi and S. Subramaniam. “Hardware-aware communication protocols in low energy wireless sensor networks”. In Proceeding of the IEEE Military Communications Conference, volume 22, no. 1. Boston, USA, pages 676-681, 2003.
[6] Wang H and Xu X L, “Wireless sensor network in the photovoltaic power generation monitoring system”, TELKOMNIKA, Vol. 11, No. 8, pp. 4774-4779, August 2013.
[7] N. Bindal, “Energy Efficiency in Wireless Sensor Network Contains Leach Protocol in Environmental Study,” Int. J. Explor. Emerg. Trends Eng., vol. 1, no. 2, pp. 31–37, 2014.
[8] Kaebbeh Yaeghoobi S.B., M.K. Soni, S.S. Tyagi, “Dynamic and Real-time Sleep Schedule Protocols for Energy Efficiency in WSNs”. International Journal of Computer Network and Information Security (IJCNIS), Vol.8, No.1, pp.9-17, 2016.
[9] Debadditya Choudhury, Debanjana Kar, Katha Roy Biswas, Himadri Nath Saha, “Energy efficient routing in mobile ad-hoc networks”, 6th International Conference and Workshop on Computing and Communication, 2015.
[10] Lin Jianyi, Jin Xiulong, Mao Qianjie, “Wireless Monitoring System of Street Lamps Based on Zigbee”, 5th International Conference on Wireless Communications, Networking and Mobile Computing, 2009.
[11] Alanazi S, Saleem K, Al-Muhtadi J, Derhab A. “Analysis of denial of service impact on data routing in mobile eHealth wireless mesh network”. Mobile Information Systems, 2016: 19.
[12] P. Christ, B. Neuwinger, F. Werner and U. Rückert, “Performance analysis of the nRF52832 ultra-low-power transceiver in a multi-transmitter and multi-receiver scenario,” Sensors, pp. 1205-1208, 2011.

[13] Urdiaín, Luis Ostiz, "Wireless sensor network protocol for smart parking application experimental study on the android platform." 2nd International Conference on Ambient Computing, Applications, Services and Technologies, 2012.

[14] S. Shiravale and S. M. Bhagat, “Wireless Sensor Networks in Agriculture Sector- Implementation and Security Measures,” Int. J. Comput. Appl., vol. 92, no. 13, pp. 975–8887, 2014.

[15] D. M. Han, J. H. Lim, “Smart Home Energy Management System using IEEE 802.15.4 and Zigbee”, IEEE Transaction on Consumer Electronics, 2010.

[16] A Rinaldi, A I Natalisanto, S Muliyono, S Said, “Implementation of Wireless Sensor Network (WSN) to calculate air pollution index of Samarinda City”, J. Phys.: Conf. Ser., 2019.

[17] Chunguo Jing, Dongmei Shu, Deying Gu, “Design of Streetlight Monitoring and Control System Based on Wireless Sensor Networks”, Second IEEE Conference on Industrial Electronics and Applications, 2007.

[18] Gaetano Patti, Luca Leonardi, Lucia Lo Bello, “A Bluetooth Low Energy real-time protocol for industrial wireless mesh networks”, 42nd Annual Conference of the IEEE Industrial Electronics Society, 2016.

[19] Bingqing Luo, Zhixin Sun, Yu Pang, Awais Ahmad, Jinzhao Lin, Jun Wu, Hui Zhang, “Neighbor Discovery for IPv6 over BLEMesh Networks”, Applied Science, 2020.

[20] Seyed Mahdi Darroudi, Raül Caldera-Sánchez and Carles Gomez, “Bluetooth Mesh Energy Consumption: A Model”, Sensors, 2019.

[21] Sefer Memi, Sandra H. Ibra, Alma Sečerbegovi, Asmir Gogi, “A Beacon-Based BLE Mesh Routing Algorithm for Smart Homes”, Elektrotehnički Vestnik, 2019.

[22] Philipp Zenker, Silvia Krug, Michael Binhack, Jochen Seitz, “Evaluation of BLE Mesh Capabilities: A Case Study Based on CSRMesh”, 8th International Conference on Ubiquitous and Future Networks, 2016.

[23] J. S. Lee, Y. W. Su, C. C. Shen, A Comparative Study of Wireless Protocols: Bluetooth, UWB, Zigbee, and Wi-Fi, The 33rd Annual Conference of the IEEE Industrial Electronics Society (IECON), 2007.

[24] Alexandru Lavrie, Valentin Popa, Ilie Finis, “The Design of a Street Lighting Monitoring and Control System”, International Conference and Exposition on Electrical and Power Engineering (EPE), 2012.

[25] Nordic Semiconductor, “nRF52832 Product Specification v1.4,” nRF52832 datasheet, 2017.

[26] Maciej Mendalka, Michal Gadaj, Lukasz Kulas, Krzysztof Nyka, “WSN for intelligent street lighting system”, Proceedings of the 2nd International Conference on Information Technology (ICIT), 2010.

[27] Chun-ling Fan, Yuan Guo, “The Application of a Zigbee Based Wireless Sensor Network in the LED Street Lamp Control System”, International Conference on Image Analysis and Signal Processing, 2011.