ORIGINAL ARTICLE

Smart Irrigation System Using Wireless Sensor Network with Cooja and Contiki

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Abstract: Automated irrigation systems are important for improving agricultural productivity, and such systems can be improved through the use of wireless sensor networks (WSN) for detecting and relaying critical information including location-specific temperature, humidity, light, etc. These measurements can then be used to produce more accurate data-driven decisions. This paper presents a smart irrigation system integrating wireless sensor network and using a low power and lossy network (RPL) protocol. Irrigation supply decisions are made in real time, based on data simulated using the Cooja simulator and Contiki operating system.

Keywords: Wireless sensor network; low power and loss network (RPL); Cooja; Contiki

Introduction

Effective agricultural irrigation relies on timely, accurate and location-specific information, including light intensity, humidity and temperature. This paper proposes using wireless sensor networks to collect such data, allowing for precise and timely real-time irrigation adjustments.

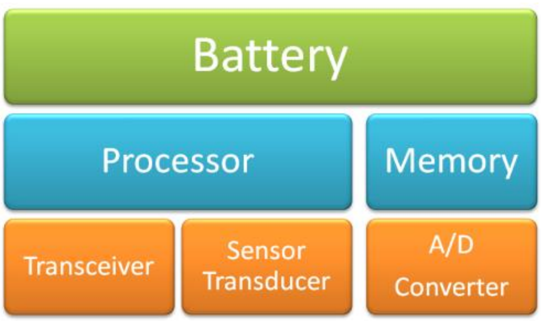


Figure 1. Modules of a sensor node.

Wireless sensor networks connect multiple sensor nodes to conduct environmental measurements remotely. These measurements can then be presented in easily comprehensible formats and transmitted to users at remote locations to make data-driven decisions. As shown in Fig. 1, sensor nodes generally consist of various modules such as transceiver, memory, processor, battery, sensor transducer, and analog to digital (A/D) converter. The transceiver receives the information from a source node and then relays it to other nodes. The memory module stores the sensed data for processing by the processor. The battery powers the sensor node. The sensor transducers sense particular qualities of the physical environment and convert the measured physical quantities into human-comprehensible numerical values. The analog to digital converter digitizes analog signals for processing.

In general, wireless sensor networks use two types of sensor nodes. A source node collects data from the environment, and a sink node collects the sensed data from the source node. Data transmission from one node to another node is also known as event. Routing protocols establish paths between nodes. Such networks employ two strategies, namely data dissemination and data collection. Data dissemination is a process by which data or queries are sent from one node to another or to a particular node or base station.

Data is collected from the source node and sent to the sink node or base station periodically or on-demand. Data dissemination consists of two steps, namely interest propagation and data propagation. In these cases, a node seeking specific data from other nodes can broadcast a request known as an interest propagation. Nodes containing the data of interest respond by sending the data to the base station. The efficiency of this process is determined by energy consumption and latency.

This paper presents a smart irrigation system using wireless sensor networks to control irrigation processes to improve agriculture productivity. The rest of the paper is organized as follows: Section II presents a literature review. Section III presents an overview of the smart irrigation system. Section IV presents the experimental results and discussion and Section V concludes the paper.

Literature Survey

Wireless sensor networks (WSN) have been used for monitoring applications in industrial, environmental, area, health care, and earth sensing contexts. WSNs also play a vital role in the Internet of Things (IoT) and big data analytics for collecting physical measurements.

Deploying WSNs for IoT applications entails considerable challenges in terms of data acquisition and transmission. Plageras reviewed various studies related to the use of WSNs, big data and internet of things (IoT) with the focus on big data delivery through IoT. This paper also explored challenges and issues related to big data transmission for IoT applications, and presented results for simulated WSN deployment using the Cooja simulator and the Contiki operating system (OS) [1]. The energy consumption of the WSN must be considered, since the energy efficiency of each node of the network determines the network lifetime, thus raising the importance of using an energy efficient routing algorithm.

Aymaz and Hacıoğlu presented schemes for measuring energy consumption of WSNs in indoor environments. The Low Energy Adaptive Clustering Hierarchy (LEACH) protocol is used for routing. Moreover, the nodes are deployed and simulated using the Contiki OS. The Ti CC2538 module is used for nodes. The sleep model was not restricted to taking additional readings over short time spans. Furthermore, the authors reported that the proposed measuring method produces better results, along with more realistic measurements given consideration of the packet delivery ratio on energy consumption [2].

Dave et al. presented an analysis on energy efficient protocols used for WSNs. They simulated an Internet of Everything (IoE) based home automation system using the IEEE 802.15.4 standard. This simulation was carried out using Cooja and the Contiki operating system. Moreover, this simulation inferred the factors that influence transferring the IPv6 in the WSN with IPv6 over Low-Power Wireless Personal Area Networks (6LoWPAN) and IEEE 802.15.4 [3]. Agustin et al. presented an implementation of IPV6 for routing over low power and lossy networks (RPL) using global repair. The performance of this implementation was compared with NS-3 and Cooja simulation environments [4].

Selection of an appropriate simulation tool is an important consideration. Of the many simulation tools currently available, most previous studies have used Cooja and the Contiki operating system to simulate WSN operations, such as Prist et al., who also developed a driver for the sensor node with advanced plug-ins [5]. Kim et al. proposed a data collection technique for greenhouse agricultural systems, used Low power and Lossy Networks (RPL) for data collection. The simulations were conducted using the Contiki operating system with the Cooja simulator. However, the performance of the original RPL and the proposed ETX-RPL was evaluated using metrics such as average power consumption, packet delivery ratio, and latency [6].

Farooq et al. analyzed the implementation of the carrier sense multiple access and collision avoidance (CSMA-CA) protocol with IEEE 802.15.4 on wireless channels using the Contiki OS. Results showed that wireless channels and sensor node transmission capacity can be used to design effective routing protocols, congestion avoidance and detection schemes, and mechanisms for admission control [7]. Sitanayah et al. evaluated coverage and lifetime of indoor WSNs. Moreover, they presented a Cooja-based tool WSN-Maintain for evaluating network lifetime and coverage requirements maintenance [8].

Some studies have used different approaches to address irrigation systems. Dursin et al. presented a model for a personal computer (PC)-based, solar powered, low-cost remote control drip irrigation system developed using Visual Studio.Net and C# programming language. This control system includes automatic and manual modes. The control circuitry works based on soil moisture sensors [9]. Nagarasu et al. proposed the use of automatic temperature detection in an irrigation system using Raspberry Pi and OpenCV. In this system, a web camera captures peanut leaf images, and visual determination of leaf dryness triggers additional irrigation. In addition, edge detection methods are applied to the leaves to identify worm infestations, thus allowing early intervention and increasing yields [10].

Kabilan developed an irrigation system using image processing and machine learning techniques. The training dataset was prepared using soil and leaf images. Fisher's linear discriminant analysis (LDA) and image segmentation techniques were used to extract leaf features and the transductive support vector machine (TSVM) is used to tigger adjustments to irrigation levels [11]. Gutiérrez et al. presented an automated irrigation system applying soil-moisture and temperature sensors to plant root areas. The gateway unit is used to transmit the sensed data over the Internet [12].

From these cited studies, existing systems are largely based on images which require special image processing algorithms which entail a high computational cost. The captured images must be normalized in terms of illumination, light intensity and various types of signal noise (e.g., Gaussian, white, fractal, impulse, periodic noise, etc), which limits detection accuracy.

To achieve energy efficient routing in WSNs, most previous efforts rely on the RPL routing protocol. For simulations, most authors rely on Cooja and the Contiki OS. Hence, this paper presents an RPL routing protocol for energy efficient data collection from the source node to sink node in wireless sensor networks for crop irrigation application, simulated using Cooja and Contiki OS.

Smart Irrigation System

The proposed smart irrigation system is illustrated in Fig. 2. The source sensor node is deployed in the field to sense temperature, humidity, and light intensity, and the sink node is used to collect the sensed data for transmission to the microcontroller and the computer system. The microcontroller receives the sensed data from the sink node and can send a control signal to the pump controller unit to adjust irrigation flow levels.

Simulation setup

The proposed system is simulated using the Cooja wireless sensor network simulator with the Contiki operating system. As shown in Fig. 3, a total of 10 sky motes (i.e. 2.2, 3.3, 4.4, 5.5, 6.6, 7.7, 8.8, 9.9, 10.10, and 11.11) are used as the source nodes, along with one sink node (1.1). Table 1 summarizes the simulation parameters.

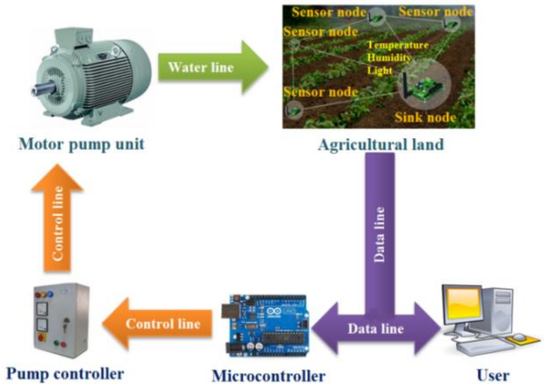


Figure 2. Smart irrigation system.

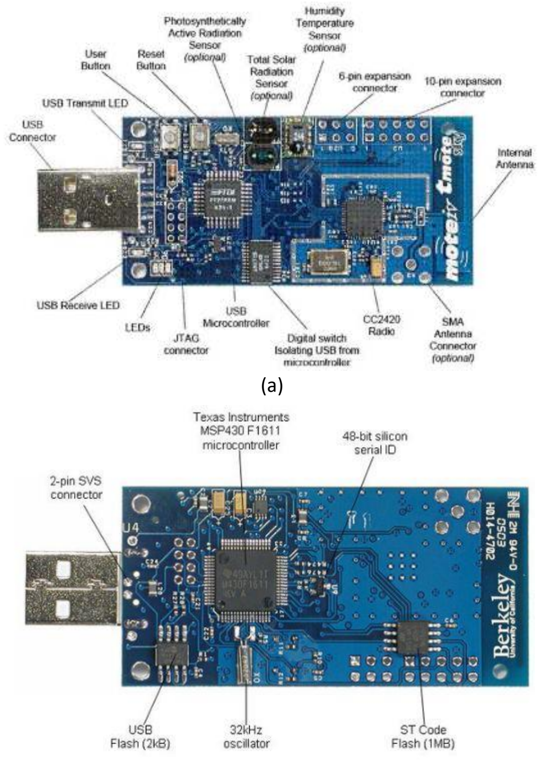


Figure 3. (a) Front (b) back of the Tmote Sky module.

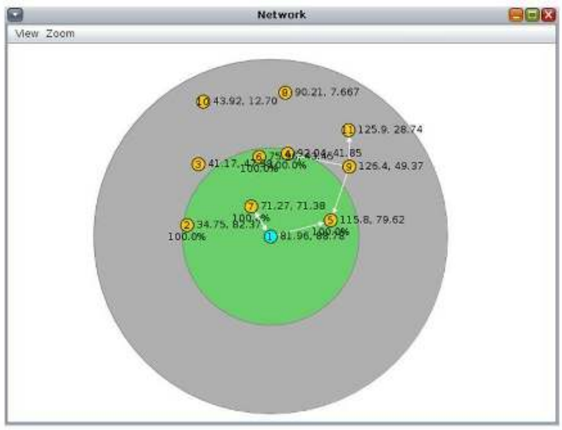


Figure 4. Deployment of sink and sender nodes.

Table 1. Simulation Parameters.

Parameter	***Value***
Objective function	Data collection
Positioning	Random position
No. of nodes	11
Simulation time	30min
Transport	UDP
Mote startup delay	1000
Radio medium	Unit Disk Graph Medium (UDGM): Distance Loss
Mote setup delay	1000
Random seed	123456
Description	Sky Mote Type #sky1
Contiki process/ Firmware	/home/user/contiki-2.7/ examples/ipv6/rpl-collect/udp-sink.c
Number of new motes	1
Positioning	Random positioning
Report interval	60 second
Report randomness	60 second
Hop-by-hop retransmissions	31 (retransmission 0-31)
Number of reports	0-reportr forever

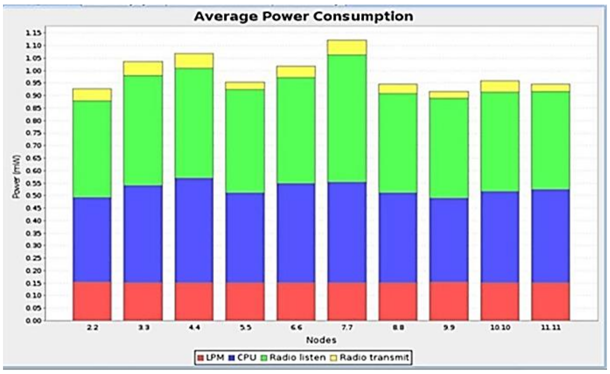
To deploy the sensor nodes in the Cooja network simulator with the Contiki operating system as shown in Fig. 4, the following steps are carried out.

Step 1: Start the Contiki OS using VMware Workstation using a default password of “user” for Cooja.
Step 2: To start the Cooja simulator, go to the terminal window and enter the following commands: (1) for change directory use the commend “cd /home/user/contiki-2.7/tools/cooja” and to run the Cooja use the command “ant run”.
Step 3: To start the simulation, select the option “start a new simulation” from the file menu and enter the name for the new simulation and “Create”.
Step 4: Select mote type from the “Motes” menu and the application that is written and complied in C programming language. Select the option “Create” to deploy the nodes.
Step 5: Select “Start simulation” from the “simulation” menu.
Step 6: Go to the tools menu and select the collect view option to obtain simulation results.

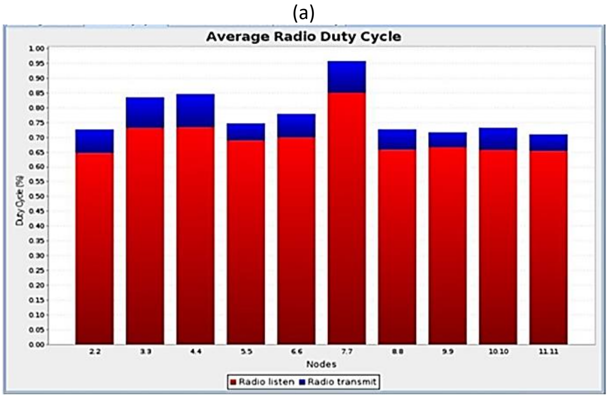
Results and discussion

This section presents the simulation results, such as sensor map, network graph, sensor information, network information, power information, and serial console. Figure 5 shows the (a) average power consumed (b) average radio duty cycle (c) instantaneous power consumption of all sender nodes and (d) power history of node 5.5.

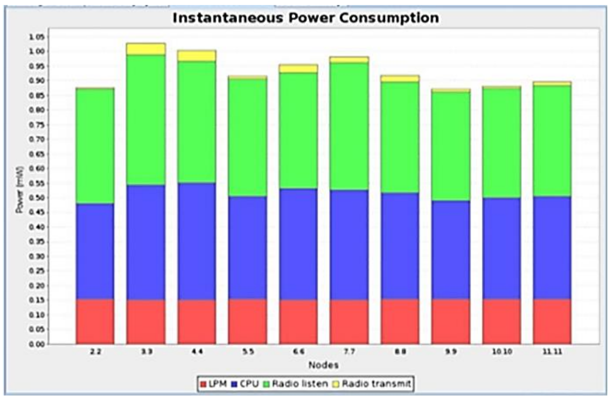
From Fig. 5 (a), it is evident that node 7.7 consumes more power for radio listening and radio transmission compared to other nodes, while node 4.4 consumes more power for CPU since it actively participates in routing, and all nodes from 2.2 to 11.11 consuming approximately the same amount of power for low-power mode (LPM). Figure 5 (b) shows that node 7.7 has more duty cycles and more radio cycles than the other nodes, with the exception of node 4.4. Figure 5 (d) shows that the power consumption of node 5.5 varies over time.



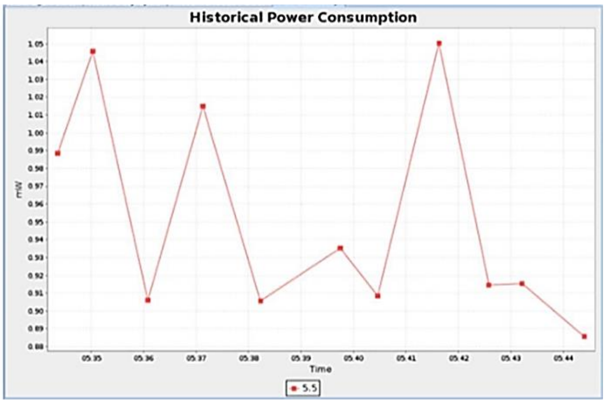
(a)



(b)



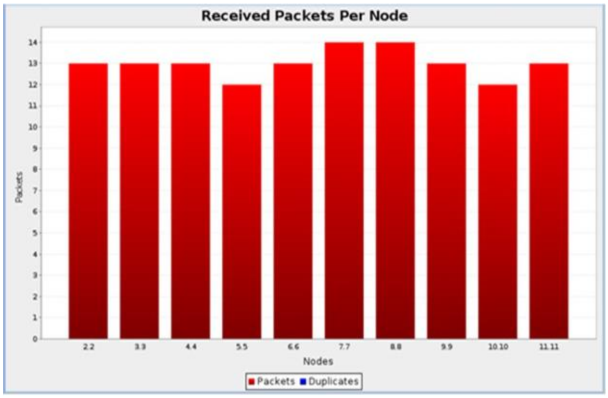
(c)



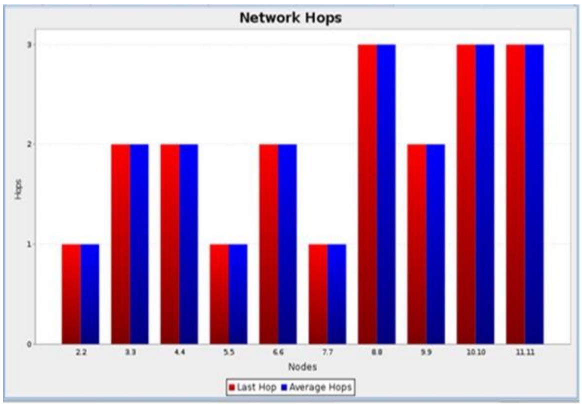
(d)

Figure 5 (a) Average power consumed (b) Average radio duty cycle (c) Instantaneous power consumption of all sender nodes and (d) Power history of node 5.5.

Figure 6 shows the (a) received packets per node (b) and network hops for the sender nodes. Figure 6 (a) shows that nodes 7.7 and 8.8 received more packets than the other nodes. Nodes 5.5 and 10.10 received less number of packets than other nodes.

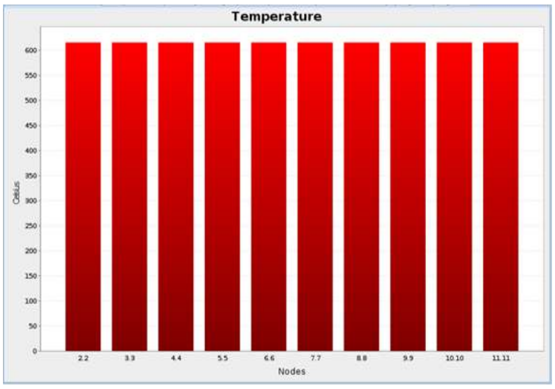


(a)

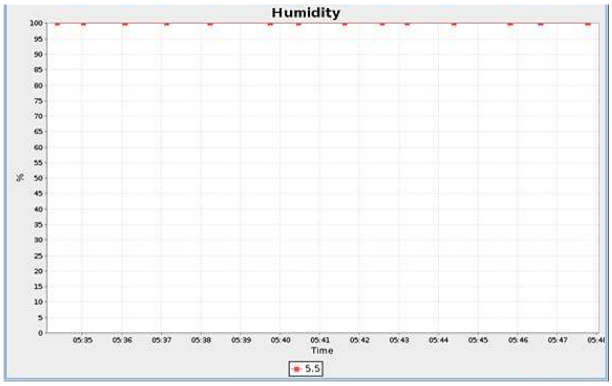


(b)

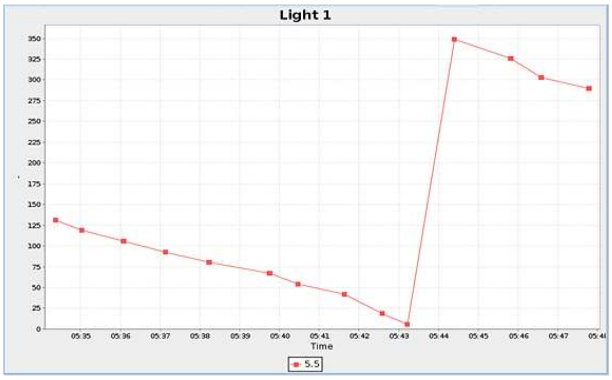
Figure 6. (a) Received packets per node (b) Network hops for the sender nodes.



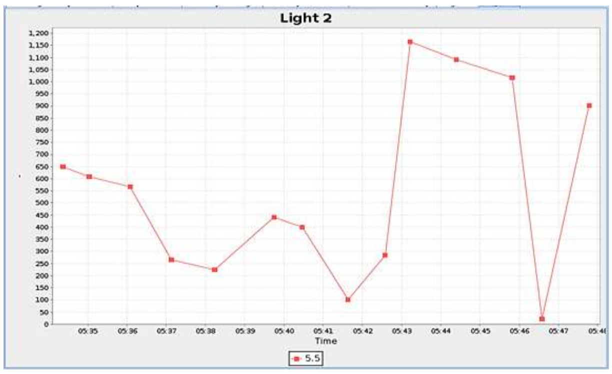
(a)



(b)



(c)



(d)

Figure 7. (a) Average temperature sensed by the sender nodes (b) Humidity sensed, (c) Light1, (d) Light2 sensed by node 5.5 over time.

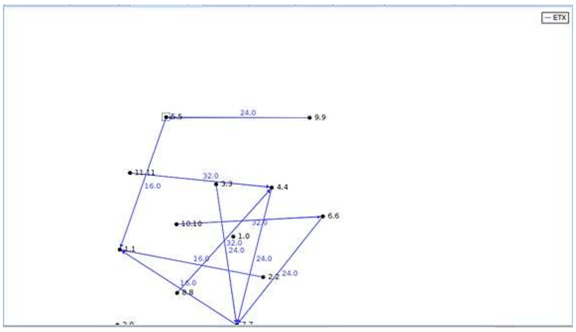


Figure 8. Network graph of the wireless sensor network.

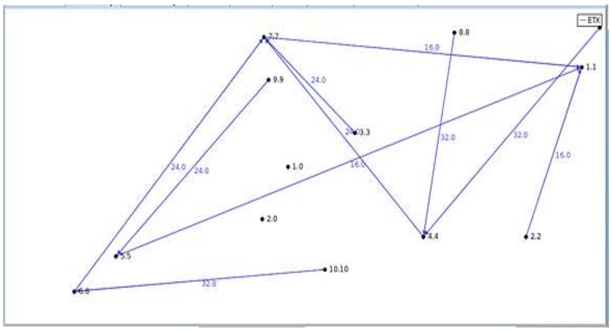


Figure 9. Sensor map.

Figure 6 (b) shows that nodes 8.8, 10.10 and 11.11 are 3 hops from the sink node while nodes 2.2, 5.5, and 7.7 are one hop from the sink node. Figure 7 shows the (a) average temperature sensed by the sender nodes (b) humidity sensed, (c) light1, (d) light2 sensed by node 5.5 over time. Figure 7 (a) shows that nodes 2.2 to 11.11 exhibit similar temperature levels. Figure 7 (b) shows that node 5.5 exhibited stable humidity levels over time. Figures 7 (c) and (d) show that light intensity varies over time. Figure 8 shows the network graph of the wireless sensor network, while Fig. 9 shows the sensor map.

Conclusion

This paper presents a smart irrigation system using wireless sensor networks, simulated using Cooja and Contiki with 10 source nodes and one sink node. The source nodes collected environmental data from agricultural fields, including humidity, temperature, and light intensity using the RPL data collection protocol. Network maps and graphs, network information, node power consumption, and sensed data by nodes are also analyzed. The pump control unit triggers adjustments to irrigation water flow, thus optimizing water use efficiency while maximizing crop yields using the sensed data.

References

[1] A.P. Plageras, and K.E. Psannis, "Algorithms for Big Data Delivery over the Internet of Things", in proceeding of *19th IEEE Conference on Business Informatics*, Greece, July 24-27, 2017, pp. 202-206. doi: 10.1109/cbi.2017.27

[2] Ş. Aymaz, and G. Hacıoğlu, "Measurement of Energy Consumption of WSN for Indoor Environment", *International Journal of Energy Applications and Technologies*, Vol. 4, 2017, pp. 87-93.

[3] G.P. Dave, and N. Jaisankar, "Analysis and design of energy efficient protocols for wireless sensor networks," in proceeding of *Innovations in Power and Advanced Computing Technologies (i-PACT)*, India, April 21-22, 2017, pp. 1-7. doi: 10.1109/ipact.2017.8244957

[4] J.P.C. Agustin, J.H. Jacinto, W.J.R. Limjoco, and J.R.I. Pedrasa, in proceeding of *TENCON 2017 - 2017 IEEE Region 10 Conference*, Malaysia, Nov. 5-8, 2017, pp. 3129-3134. doi: 10.1109/tencon.2017.8228399

[5] M. Prist, S. Longhi, A. Monteriù, F.Giuggioloni, and A. Freddi. "An integrated simulation environment for Wireless Sensor Networks." In proceeding of *IEEE 16th International Symposium on World of Wireless, Mobile and Multimedia Networks (WoWMoM)*, USA, June 14-17, 2017, pp. 1-3. doi: 10.1109/wowmom.2015.7158177

[6] Y. Kim, P. Bae, J. Han, and Y.B. Ko, "Data aggregation in precision agriculture for low-power and lossy networks," in proceeding of *Pacific Rim Conference on Communications, Computers and Signal Processing (PACRIM)*, Canada, Aug. 24-26, 2015, pp. 438-443. doi: 10.1109/pacrim.2015.7334877

[7] M. O. Farooq, and T. Kunz, "Contiki-based IEEE 802.15. 4 node's throughput and wireless channel utilization analysis," in proceeding of *IFIP Wireless Days*, Ireland, Nov. 21-23, 2012. doi: 10.1109/wd.2012.6402828

[8] L. Sitanayah, C. J. Sreenan, and S. Fedor, "A Cooja-Based Tool for Coverage and Lifetime Evaluation in an In-Building Sensor Network," *Journal of Sensor and Actuator Networks*, vol. 5, no. 1, p.4, 2016. doi: 10.3390/jsan5010004

[9] M. Dursun, and S. Ozden, "A prototype of PC based remote control of irrigation," in proceeding of *International Conference on Environmental Engineering and Applications (ICEEA)*, Singapore, Sept. 10-12, 2010, pp. 255-258. doi: 10.1109/iceea.2010.5596141

[10] B. Nagarasu, and M.Manimegalai, "Automatic irrigation and worm detection for peanut field using Raspberry pi with OpenCV." In proceeding of *Online International Conference on Green Engineering and*

Technologies (IC-GET), India, Nov. 19-19, 2016, pp. 1-5.
doi: 10.1109/get.2016.7916813

[11] N. Kabilan, and M.S. Selvi, "Surveillance and steering of irrigation system in cloud using Wireless Sensor Network and Wi-Fi module" in proceeding of *International Conference on Recent Trends in Information Technology (ICRTIT)*, India, April 8-9, 2016, pp. 1-5.
doi: 10.1109/icrtit.2016.7569526

[12] J. Gutiérrez, J. F. Villa-Medina, A. Nieto-Garibay, and M.Á. Porta-Gándara, "Automated irrigation system using a wireless sensor network and GPRS module," *IEEE transactions on instrumentation and measurement*, vol. 63, pp.166-176, 2014.
doi: 10.1109/tim.2013.2276487