TELKOMNIKA, Vol.16, No.6, December 2018, pp.2888~2895
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v16i6.11556

Sub-1 GHz Wireless Nodes Performance Evaluation for Intelligent Greenhouse System

I Nyoman Kusuma Wardana*[1], Ngakan Nyoman Kutha Krisnawijaya[2],
I Wayan Aditya Suranata[3]
[1]Department of Electrical Engineering, Politeknik Negeri Bali,
Raya Kampus St. Bukit Jimbaran, Badung, Bali, Indonesia
[2]Department of Electrical Engineering, Universitas Pendidikan Nasional,
Bedugul St. No 39, Sidakarya, Denpasar, Bali, Indonesia
[3]Department of Computer Science, Universitas Pendidikan Ganesha,
Udayana St. No 11, Singaraja, Bali, Indonesia
*Corresponding author, e-mail: kusumawardana@pnb.ac.id

Abstract

Greenhouses provide not only solution to problems faced by conventional farming systems but also play an important role to improve the energy efficiency and environmentally friendly awareness. To achieve benefits of greenhouse farming system in terms of energy efficiency, research related to this issue have been done by many researchers. However, resources that concern on how to practically implement the particular energy-saving technology for greenhouses need to be improved. In this research, field experiment results related to low-power communication between nodes have been reported by implementing universal prototype modules. The pros and cons of existing communication technology, the proposed architecture of network and module analysis, and the performance evaluation of the proposed module dedicated to intelligent greenhouse farming system were also discussed.

Keywords: *greenhouse, LPWAN, sub-1 GHz, wireless sensors*

Copyright © 2018 Universitas Ahmad Dahlan. All rights reserved.

1. Introduction

Climate change and global warming are serious issues faced by society. These challenges can directly affect many sectors, including agriculture [1-3]. A conventional-based agriculture in an open planting area is very susceptible with plant diseases and negative environmental impacts. An alternative solution to overcome this problem is by applying greenhouse farming systems [4]. At present, in a conventional method, most of regular activities related to agriculture such as irrigation process, regular fertilizing, temperature and humid control, etc. are based on personal experiences that may vary over time. This kind of variation may lead to lower production efficiency, ineffective human employment, or even environmental pollutions [5, 6]. These problems can be solved by applying methods that based on information technology. The diffusion of agriculture and information technology creates a possibility to widely implement smart greenhouse systems. Therefore, greenhouse provides more convenient environment for plants growth [7], and this concept is so called controlled environment agriculture (CEA) [8, 9].

Various works related to greenhouse development have been published. From these works, it is concluded that environmental data recording and control for electrical instruments are main activities in technology-based greenhouse [10]. Parameters such as temperature and humidity are often controlled to provide an appropriate planting environment [6]. Therefore, the development of recording and controlling modules for electrical instruments is a basic requirement to achieve intelligent greenhouse systems. Intelligent systems can be entirely based on how to collect environmental parameters (temperature, humidity, pressure, etc.) by the sensor nodes (nose), process these parameters by the central processor, and finally produce outputs to targeted instruments by the actuator nodes (noac) [11]. The sensors and actuators implemented in greenhouse can be managed as Wireless Sensor Networks (WSN) or Wireless Sensor and Actuator Networks (WSAN) [7, 12, 13]. If a large-scale multisensory data is needed, the concept of Big-data has been widely accepted [14].

Received June 4, 2018; Revised October 1, 2018; Accepted October 25, 2018

Connectivity is probably the most important issue of nodes development. The communication between nodes can be realized either by wired or wireless connections. However, over the last few years, wireless communication is preferable and one of the most studied fields [15]. Wireless communication offers advantages in terms of price, robustness, communication range, accuracy, flexibility, and installation. To improve flexibility in data collection and analysis, the data obtained from sensor nodes can be transferred through the Internet connection. If so, the paradigm so-called Internet of Things (IoT) can be implemented [6]. The users have options to select their own wireless technology, but the existing wireless technologies possess their pros and cons. At present, the main communication methods between nodes have been based on either long-range cellular technologies or short-range multi-hop mesh networks. However, these two methods unsuitable to support multisensory communication needed to realize IoT paradigm for greenhouse environment. Low data rate, low-power consumption, and long-range coverage area are more preferable characteristics for IoT [16]. A promising alternative solution which has characteristics between cellular-based technologies and multi-hop mesh networks is provided by the so-called Low-Power Wide Area Networks (LPWANs). This protocol works in the unlicensed ISM (Industrial, Scientific, and Medical) frequency bands [16].

This research is a further development of the previous study [17]. In this research, wireless node modules operating in sub-1 GHz were developed. Each module equipped with an 8-bit microcontroller acting as a main processor. A star topology was established so that there were two kind of developed nodes, namely central node (CN) and end node (EN). The developed modules then be analyzed to explore the transmission performances and life time of the devices.

2. Research Method

2.1. Connectivity Standard of WSAN

At present, a promising alternative solution that has the most ideal characteristics for wireless nodes communication is so-called Low-Power Wide Area Networks (LPWANs) operating in the unlicensed sub-1 GHz ISM frequency bands [16,17]. The LPWAN solutions are examples of short-range devices with cellular-like coverage ranges configured in star topology [13-14]. The LPWAN offers low-rate and long-range capabilities with higher penetration capabilities, better than 2.4 GHz or 5 GHz. The sub-1 GHz band is considered less interferences and support star configuration for wider communication area.

Based on the parameters comparison, sub-1 GHz connectivity has the most ideal characteristic to realize smart building applications [18]. In our case, intelligent greenhouse can be considered as smart buildings. In Table 1, basic parameters for existing wireless communication types are summarized. However, it is important to note that node physical design can strongly affect the final performances. For example, even the devices operate in the same protocol, if the antenna designs are different, the final coverage area will be also different. In Table 2, the effectiveness performance of each communication protocol for different kind of application areas are reported.

Table 1. The Comparison of Communication Characteristics for Different Protocols [18]

Wireless Standar	Range		Bit Rate (Mbps)	Throughput (Mbps)	Frequency (GHz)	Topology
	Indoor	Outdoor				
NFC	<0.2 m		0.424	0.22	0.014	p2p
Bluetooth	1-1000 m		1-3	1.4	2.4-2.5	Scatternet
BLE	~100 m		1	0.3	2.4-2.5	star, scatternet
BT v5	300 m		2	1.5	2.4	N/A
ZigBee	<20 m	<1500 m	0.25	0.15	2.4	star, tree, mesh
802.11 b/g/n	<70 m	<230 m	>1	2-50	2.4/5	Star
802.11ah HaLow	<700 m	<1000 m	0.15-40	>0.1	0.9	Star
LPWAN	<10 Km		<0,05	<0.5	sub-GHz	Star
3G	>5 Km		0.17	N/A	0.8-1.9	N/A
LTE	>5 Km		75-300	N/A	2.1	N/A

Table 2. The Effectiveness Performance of Each Communication Protocol for Different Kind of Applications [18]

Wireless Standard	Use Case Medical	Smart City	Smart Building	Otomotive	Industrial	Local Network (M2M)
NFC	medium	high	low	low	very low	medium
BLE	very high	low	low	low	very low	high
ZigBee, BT v5	medium	high	very high	very high	low	high
WiFi b/g/n	low	high	medium	medium	medium	high
HaLow	high	very high	high	high	high	very high
LPWAN	low	very high	high	high	high	high
Cellular Network (3G, LTE, dll)	low	high	high	high	high	very low

2.2. Network Architecture and Node Module Designs for Greenhouse System

A greenhouse needs node modules to sense and control the environmental parameters. These parameters can be soil humidity, air humidity, temperature, gasses, water level, water flow, etc. In this research, two kinds of modules were developed so-called central node and end node. The end nodes can act as a sensing node (nose), an actuating node (noac), or gateway. The noacs are generally implemented to control switches, solenoid valves, relays, etc., whereas noses are equipped with sensors to sense the environmental parameters. The IoT-based architecture for intelligent greenhouse is shown in Figure 1.

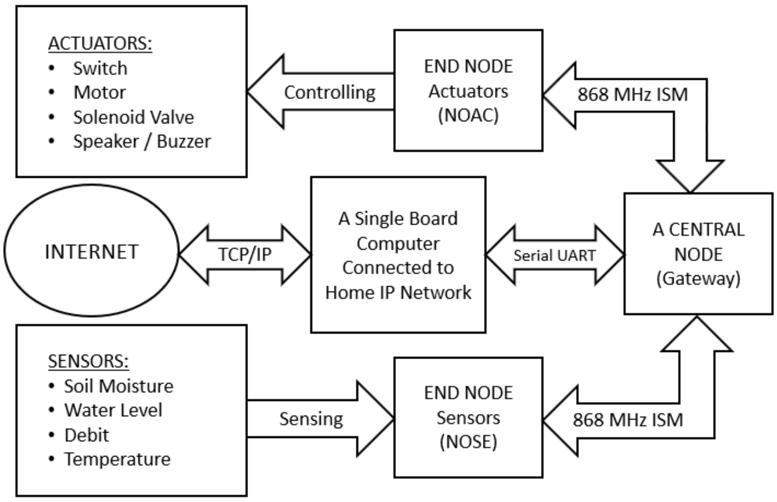


Figure 1. The IoT-based architecture for greenhouse system

A star-topology is implemented to realize the nodes communication. This topology offers robust network management, yet simple to be developed. The central node which acts as a main controller or gateway for sub-1 GHz protocol may consist of many end nodes. It is connected to TCP/IP or internet network through a small-sized single board computer (SBC). By using an SBC (Raspberry Pi), some services can be built, such as data logging, intelligent algorithm, user interface, etc. The implemented addressing format is similar to the IP address v4 for TCP/IP protocol. Each node has its unique device ID, network ID, and network key encrypted using an AES 128-bit.

All nodes operate wirelessly in 868 MHz frequency band. This frequency is selected as it offers clearer wave propagation compared to 2.4 GHz band which belongs to general commercial communications. This sub-1 GHz band can reach wider coverage area to support the IoT paradigm. In Figure 2, nodes installation for greenhouse is shown [17]. A node module is developed by using an 8-bit ATmega328-AU microcontroller. This microcontroller was selected as a main processor since it has all features required by both nose and noac, and it is the same chip used by Arduino UNO, one of the most popular open source platforms worldwide.

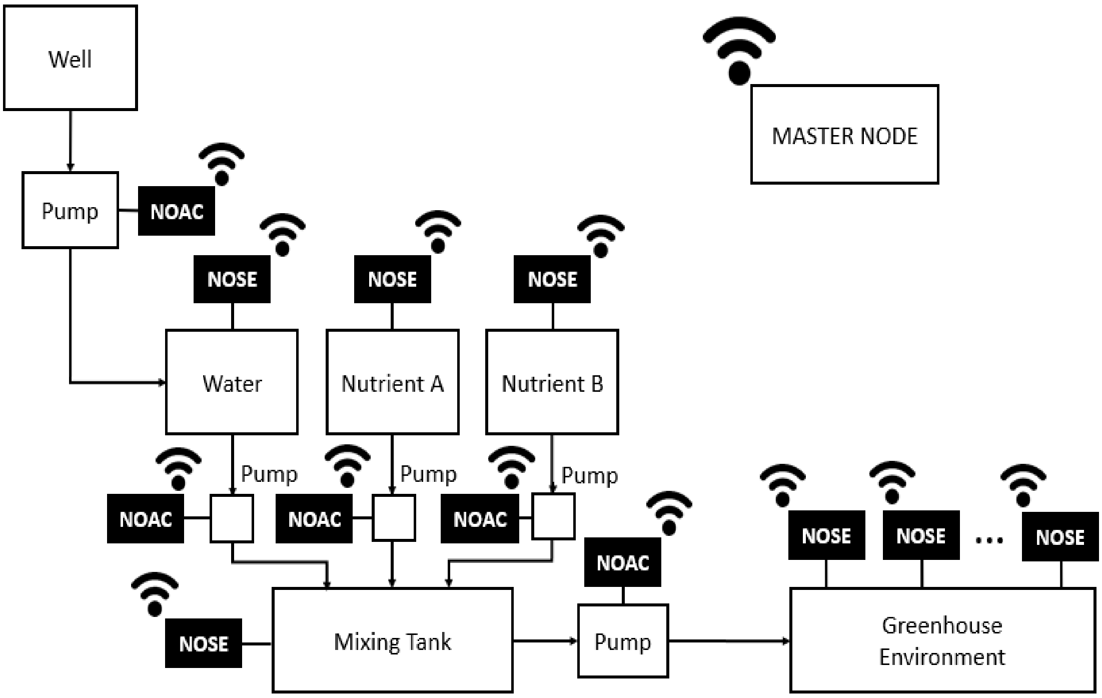


Figure 2. Devices and network installations for greenhouse system [17]

Therefore, all benefits possessed by the Arduino UNO such as programming software, libraries, community supports, etc. can also be used. The hardware blocks of each module are shown in Figure 3.

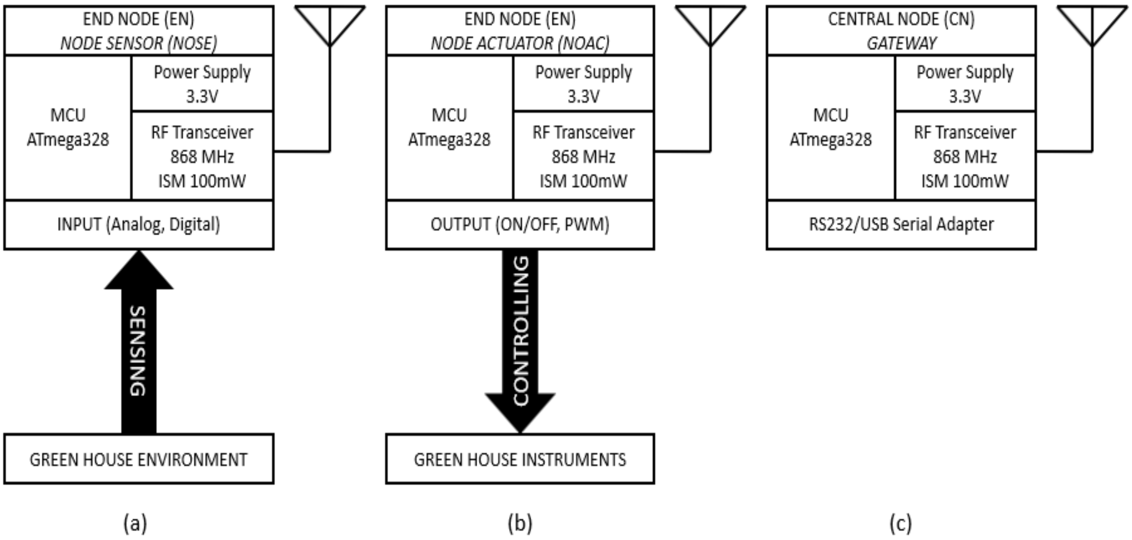


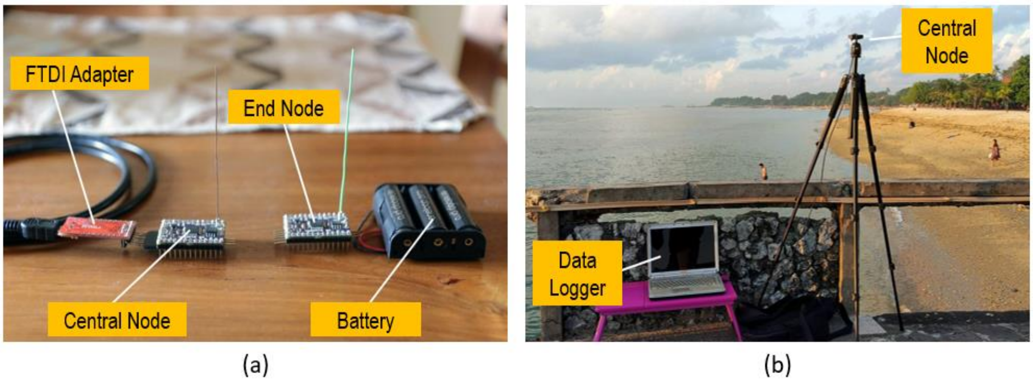
Figure 3. The hardware blocks: (a) nose, (b) noac, and (c) central node

All nodes are not necessarily to send or receive data overtime to reduce power consumptions. To achieve this purpose, a deep sleep function is needed. For the deep sleep activation, some microcontroller features are set to power down mode. Flash memory and transceiver can also be deactivated, and all microcontroller pins can be set to low states. The watch dog timer (WDT) acts to reactivate the microconcontroller from deep sleep state without additional circuits. Therefore, all modules can be reduced their power consumptions significantly.

3. Results and Analysis

To prove the concepts mentioned above, in this research, two prototype modules were developed to simulate both central and end nodes. Two evaluation steps were conducted. First, the transmission performance was conducted to explore the nodes characteristics. The transmission performance evaluation was conducted in two kinds of fields: at a wide seashore to find a line-of-sight (LoS) characteristics, and at a dense housing area to find non-line-of-sight (NLoS). Second, the power consumptions evaluation was conducted to find the node's life-time by employing low-powered batteries.

The transmission test was conducted by sending 50 data packets from the end node to the central node with every 300 ms interval. Powered by three NiMH AA batteries, the end node was moved every 25 meters from the central node. This process was conducted continuously until the data obtained by the central node was completely lost. By using this scenario, the maximum transmission distance can be recorded. The node module prototypes and transmission evaluation device installation are shown in Figure 4. As shown in Figure 4, the central node was connected by a USB cable to a laptop to run logger process.



(a) (b)

Figure 4. (a) Node module prototypes, (b) Device Installation for Transmission Test

The received data from the transmission test were processed by calculating the percentage of *packet loss* and *Rmean* of each test. The formula used in this test is $Ploss = \frac{(50-Prec)}{50}\ x\ 100$. Here, *Ploss* denotes the packet loss, and *Prec* is the number of data packet obtained during each test. After the percentage of packet loss was found, the average value of *received signal strength indication* (RSSI) can be obtained. The average RSSI value can be calculated by using formula $Rmean = \frac{\sum_{i=1}^{n} Ri}{Prec}$, where *Rmean* denotes average value of RSSI in dBm, and *Ri* means *i*-th row of RSSI data.

In Figure 5, the calculated *Rmean* versus transmission distance for LoS measurement is shown. According to the graph, there was a significant power decline over the first 300 meters of measurements. Then, there was a steady *Rmean* between -75 dBm and -85 dBm in the remaining distances and completely lost at over 90 dBm. Along middle-distance range (between 300 and 900 meters), the data packet will be potentially lost if obstacles present. The distance of 900 meters or over will hardly to achieve if the central and end node were not in a line-of-sight position. For NLoS measurement, the evaluation was conducted in a dense housing area. In order to receive more data, 50 data packets for every 15 meters range were sent from the end node to the central node, instead of 25 meters as conducted for LoS test.

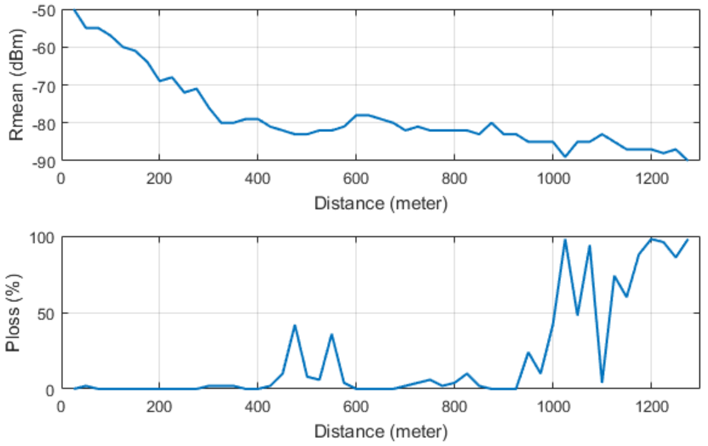


Figure 5. LoS measurement test

The received data in NLoS test is shown in Figure 6. According to the figure, a sharp decline of Rmean happened in the first 75 meters. Then, steady a Rmean between -91 dBm and -93 dBm was shown in the remaining distance and totally disappears at 135 meters. To conclude, the penetration range for NLoS is ideally up to 75 meters.

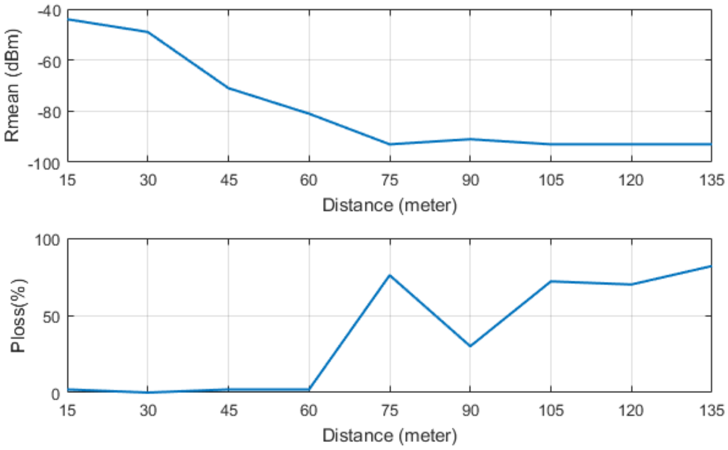


Figure 6. NLoS measurement test

As shown in Figure 6, in the worst case, where the communication blocked by many obstacles, the nodes connection can reach up to 135 meters. Assume that the greenhouse in the form of a circle area and the central node is placed in the center of the circle, in theory, the maximum greenhouse diameter will be 270 meters. If a better transmission performance is needed without considering the power consumption, a better transmission algorithm that make it possible to resend the missing packets is needed, like it does on TCP/IP protocol. Moreover, improvement in hardware parts, such as antenna design, may increase the performance.

For the life-time evaluation, the maximum and minimum electrical current consumptions (Imax and Imin) in milliamps during four processes were recorded, that are when analog-to-digital-converter (ADC) is running, when sending the data, when receiving the data, and when deep-sleep mode is activated. These four processes are considered as the main activities done by the nodes. There were 100 analog data read by ADC, and duration needed to complete the conversion was recorded. Based on return value of micros() function provided by the Arduino software, the value of ADC, transmit, and receive times of the nodes in microseconds can be recorded. Therefore, by calculating the durations of each process, the average current drains of the node (*Imean*) can be recorded. The life-time of the node can be obtained by using formula $T = \frac{BattCap}{Imean}$, where *T* denotes the possibility of node life-time in hours (h), BattCap denotes the battery capacity in milliAmps Hour (mAh), and Imean denotes the average current drawn in Amperes (A). based on the evaluation steps, the current drain of each process done by the node is reported in Table 3, and the current drawn is shown in Figure 7.

Table 3. Life-time Calculation of the Node

No.	Imax (mA)	Imin (mA)	Duration (mS)	Process
1	8.34	8.10	11.23	Read ADC (100x Samplings)
2	135.60	135.30	6.52	Transmit
3	23.12	21.72	0.72	Receive
4	0.0041	0.0041	8000	Deep Sleep
LIFE SPAN CALCULATION				
No.	Process	Loop Count (LC)	Duration x LC	*Imax x (Duration x LC)*
1	Read ADC (100x)	1	11.23	93.66
2	Transmit	1	6.52	884.11
3	Receive	1	0.72	16.65
4	Deep Sleep	1	8000.00	32.80
		Total	8018.47	1027.22
			Batt Caps. (mAh) NiMH	2550
			Imean (mA)	0.13
			Duty Cycle (%)	0.23
			Duration (Hours)	19905.34
			Duration (Days)	829.39

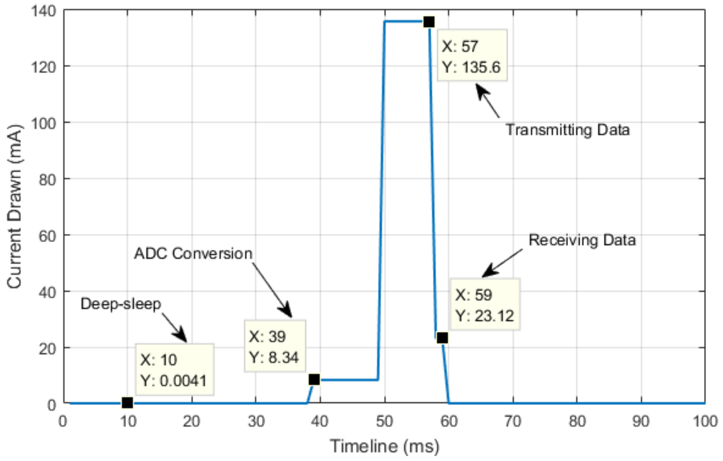


Figure 7. Current drawn of the node

As shown in Figure 7, the current drawn increased significantly from 50 ms to 60 ms. At this period, the node is transmitting the data. Based on Table 3, the transmitting process consumes 135.60 mA. The second highest current drwan is dedicated for receiving data that is 23.12 mA. The ADC and deep-sleep mode consume 8.34 mA and 0.0041 mA, respectively. After recording the current drawn, the Imean value was calculated. The obtained Imean value during was 0.13 mA. Finally, the battery capacity in mAh was divided by Imean to obtain the life-time of the node.

To find a general view of the node life-time, a 2550 mAh NiMH battery was used as a main power source, and calculation details are shown in Table 3. The node module can operate approximately up to 19,905 hours or 2 years and 3 months, provided that the used firmware has 0.23 duty cycle, consisting of 100 times ADC conversions, transmitting data, receiving data, and deep-sleep mode. All processes were counted only one loop (one time). The sensing node (nose) can ideally operate at 0.23 of duty cycle with only 8018 ms of full cycle time, considering that environmental parameters (temperature, humidity, light intensity, etc.) do not change immediately in 8 seconds.

4. Conclusion

In this research, wireless node modules operating in 868 frequency band have been developed for greenhouse system. The sub-1 GHz was selected since it offers a better wave penetration in housing area and less interferences compared to 2.4 GHz frequency band. The node architecture was developed by using an ATmega328 microcontroller, which is compatible with the Arduino open-source platform. Therefore, all benefits possessed by the Arduino such as programming software, libraries, community supports, etc. can also be used. In this research, two evaluation steps were conducted: the transmission performance test and the life-time test.

According to the evaluations, the maximum communication ranges for LoS and NLoS scenarios were 1,275 meters (Rmean -90 dBm, Ploss 98%) and 135 meters (Rmean -93 dBm, Ploss 82%), respectively. The node module can operate approximately up to 19,905 hours or 2 years and 3 months, provided that the used firmware has 0.23 duty cycle, consisting of one loop process (100 times ADC conversions, transmitting data, receiving data, and deep-sleep mode).

References

[1] Indonesian Agency for Agricultural Research and Development. Agricultural Sector Strategy Road Map Facing Climate Change (Revised) (in Indonesia Road Map Strategi Sektor Pertanian Menghadapi Perubahan Iklim (Revisi)). 2012. ISBN 978-602-9462-03-6.

[2] Himanshi J, Raksha J. *Big data in weather forecasting: Applications and challenges*. Int. Conf. on Big Data Analytics and Computational Intelligence. 2017.

[3] U Dorji, T Pobkrut, S Siyang. *Development of real time smart electronic nose system for monitoring organic abundance in soil*. International Conf. on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology. 2017.

[4] A Bseiso, B Abele, S Ferguson, P Lusch, K Mehta. *A decision support tool for greenhouse farmers in low-resource settings.* IEEE Global Humanitarian Technology Conference (GHTC). 2015: 292-297.

[5] K Rao, Srijana K, D Prasad. Ubiquitous Greenhouse Monitoring System. Conf. on Emerging Research in Electronics, Computer Science and Technology. 2015.

[6] Z Li, J Wang, R Higgs, L Zhou, W Yuan. *Design of an Intelligent Management System for Agricultural Greenhouses based on the Internet of Things*. International Conf. Computational Science and Engineering (CSE) and Embedded and Ubiquitous Computing (EUC). 2017.

[7] J Yuhan, J Yiqiong, L Ting, Z Man, S Sha, L Minzan. An improved method for prediction of tomato photosynthetic rate based on WSN in greenhouse. *International Journal of Agricultural and Biological Engineering*. 2016; 9(1):146

[8] RR Shamshiri, F Kalantari, KC Ting, KR Thorp, IA Hameed, C Weltzien, D Ahmad, ZM Shad. Advances in greenhouse automation and controlled environment agriculture: A transition to plant factories and urban agriculture. *International Journal of Agricultural and Biological Engineering*. 2018; 11(1): 1-22.

[9] M Suraj, EI Ekwue, RA Birchc. A Controlled Environment Agriculture Greenhouse for the Caribbean Region. *The West Indian Journal of Engineering*. 2018; 40(2): 10-16.

[10] Mohamed RMK, Ahmad NH. *Applications of WSN in agricultural environment monitoring systems*. Int. Conf. on Information and Communication Technology Convergence. 2016.

[11] X Bai, L Liu, M Cao, J Panneerselvam, Q Sun, H Wang. Collaborative Actuation of Wireless Sensor and Actuator Networks for the Agriculture Industry. *IEEE Access*. 2017; 5: 13286-13296.

[12] C Yang, S Yuling, W Zhongyi, H Lan. Connectivity of wireless sensor networks for plant growth in greenhouse. *International Journal of Agricultural and Biological Engineering*. 2016; 9(1): 89.

[13] Y Zhou, Y Xie, L Shao. Simulation of the Core Technology of a Greenhouse-Monitoring System Based on a Wireless Sensor Network. *International Journal of Online Engineering*. 2016; 12(5): 43.

[14] J Liu. Design and Implementation of an Intelligent Environmental-Control System: Perception, Network, and Application with Fused Data Collected from Multiple Sensors in a Greenhouse at Jiangsu, China. *International Journal of Distributed Sensor Networks*. 2016; 12(7): 1-10.

[15] P Rawat, Singh KD, Chaouchi H, JM Bonnin. Wireless sensor networks: a survey on recent developments and potential synergies. *J Supercomput*. 2014; 68: 1.

[16] M Centenaro, L Vangelista, Zanella A, M Zorzi. Long-Range Communications in Unlicensed Bands: The Rising Stars in the IoT and Smart City Scenarios. *IEEE Wireless Communications*. 2016; 23(5): 60-67.

[17] INK Wardana, PI Ciptayani, IWA Suranata. *Sub-1GHz wireless sensing and control instruments for green house farming system*. Journal of Physics: Conference Series (JPCS). 2018.

[18] F Samie, L Bauer, J Henkel. *IoT technologies for embedded computing: A survey*. Proceedings of the Eleventh IEEE/ACM/IFIP International Conference on Hardware/Software Codesign and System Synthesis. 2016.