Realization of Zigbee Wireless Sensor Networks for Temperature and Humidity Monitoring

By Helmy Fitriawan

Proceeding of International Conference on Electrical Engineering, Computer Science and Informatics (EECSI 2015), Palembang, Indonesia, 19 -20 August 2015

Realization of Zigbee Wireless Sensor Networks for Temperature and Humidity Monitoring

Helmy Fitriawan, Danny Mausa, Ahmad Surya Arifin, Agus Trisanto
Dept. of Electrical Engineering
University of Lampung
Bandar Lampung, Indonesia
helmy.fitriawan@eng.unila.ac.id

***Abstract*— Many physical phenomena and processes in the environment must be monitored. This problem can be solved with an ad-hoc wireless sensor network (WSN), which consists of a number of small and self-power sensing devices (nodes) that are connected with each other using effective wireless networks. This paper reports development of an embedded wireless sensor network (WSN) prototype for environmental parameters monitoring. The network itself consists of a coordinator or data gateway which wirelessly collect temperature and humidity data over several sensor nodes. Each sensor node is developed from an arduino based microcontroller, Xbee wireless module based on Zigbee/IEEE 802.15.4 standards, and temperature and humidity sensor devices. In the prototype system, both temperature and humidity sensors are calibrated with accurate instruments to obtain precise measurements. Its communication functionality is also tested in various network topologies. The battery lifetime is calculated to predict the energy consumption. The testing results show that the system works well in terms of its functionality.**

Keywords*— *WSN; zigbee; arduino; temperature; humidity

I. Introduction

In our environment, there are many physical phenomena and processes that have to be monitored and controlled. In the same time humans challenge energy consumption and global warming. To achieve a reliable and robust system for environmental monitoring, there is an available technology that can be used to resolve this problem and moreover provide for better living. The recent advanced development of small and low power sensor and actuator, embedded microcontroller and wireless coomunication technologies is facilitating the development of wireless sensor networks (WSN) [1]. With the capabilites in sensing temperature, humidity, position, light, vibration, sound, gas concentrations, radiation, and pressure, WSN could be widely used in many applications such as habitat monitoring [2], environment observation and forecasting system [3], health and medical [4], precision agriculture [5], street lighting and transportation [6], and industry automations and instrumentations [7]. As shown in Fig. 1, WSN is an ad-hoc, multi-hop and self organizing network that consists of a large number of nodes deployed in a wide area. Those adjacent located nodes are allowed to transmit and receive data among them. Hence WSN enable environmental parameters sensing, data processing and wireless transmission all at once.

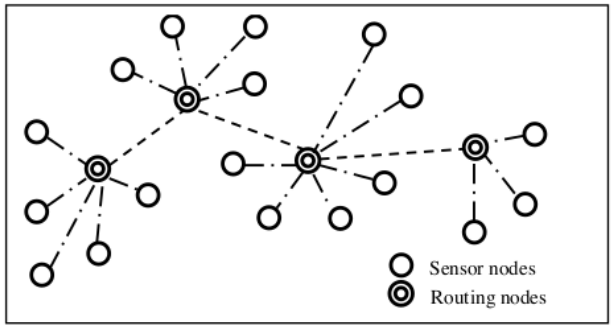

Fig. 1. Wireless Sensor Network

We have developed a protoype system of an embedded wireless sensor network for temperature and humidity monitoring. This network system is used for wirelessly temperature and humidity monitoring in our campus area. As the heart of its each node, the Arduino board with ATMega328 microcontroller is used in the protoype. Arduino is easy to be progammed and provide several analog and digital input/outputs. For the transmission task, we use Xbee module based on IEEE 802.15.4/Zigbee standard due to low power consumption, simple network deployment, low installation costs and reliable data transmission. Zigbee protocol is featured with multihop communication capability, therefore providing ideal and suitable requirement for WSN deployment in wide area coverage [8]. For the sensing capabilities, we use a low-cost analog sensor (for the temperature) and a low-cost digital sensor (for the humidity) to demontrate that the arduino works well with analog and digital inputs. The system is also featured with a graphical user interface (GUI) based application to display real time data monitoring which can be saved as a data logger.

The rest of the paper is organized as follows. The system architecture of WSN is described in Section II. Section III describes the methodoloy and implementation of WSN used in the project. Section IV presents the system testing and the research results. The paper is concluded in section V together with the possibility of future works of our project.

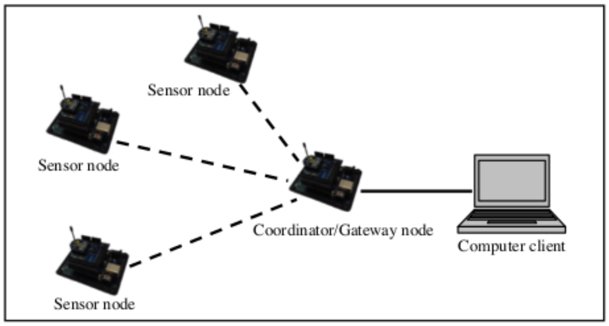

Fig. 2. Wireless Sensor Network

II. System Architecture

Generally, a wireless sensor network (WSN) consists of several sensor nodes, gateway/coordinator node and a computer client, as shown in Fig. 2 [9].

A. *Sensor Nodes*

Each sensor nodes plays as an end device which has temperature and humidity small and low-cost sensors, the microcontroller, and wireless communication module. The device sense the value of temperature and humidity of the environment and transmit the data readings to the coordinator. Therefore, the interfaces of the end devices has two parts: sensor interface and communication module interface parts. The sensor interfaces receive data from the temperature and humidity sensor. The communication interface connects the microcontroller with the communication module to transmit the data to the coordinator or adjacent nodes over wireless communication links. The microcontroller process the input data and also control when the sensor sensing and communication module transmitting data.

B. *Coordinator Node*

WSN always has a single coordinator node which is actually the center of the system. The coordinator node is responsible for managing end devices association. Data readings from all sensors are collected and gathered by the coordinator node which susequently send them to the computer client.

C. *Computer Client*

The computer client receives the measurements data from the coordinator node via wire link. Afterward, it presents the measurements data to the user through a GUI based application. The data monitoring also can be saved as a data logger.

III. Implementation

In the implementation phase, we proposed modular based design. Modularity design offers greater flexibility for the end product, since same nodes can be deployed for any specific applications with required sensor devices. The developed system has two types of nodes: the sensor node and the coordinator node. The sensor node is implemented using microcontroller arduino Uno, Xbee shield, Xbee S2, temperature and humidity sensors, as shown in Fig. 3. On the other hand, the coordinator node is realized using Xbee Adapter and Xbee S2, connected to the computer client, as shown in Fig. 4.

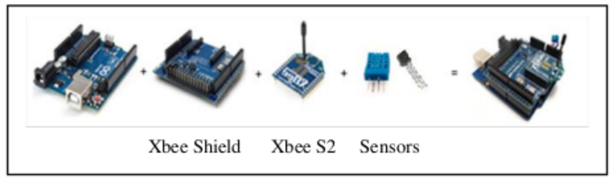

Fig. 3. Hardware platforms for sensor node

Fig. 4. Hardware platforms for coordinator node

A. *Hardware Spesification*

1) Arduino Uno: As the heart of the node, we use Arduino Uno R3 board which has microcontroller chip ATmega328. It is controlled by the computer using USB connection. It has 14 digital inputs/outputs (6 pins can be used as PWM outputs), 6 analog inputs. It has also 16 MHz ceramic resonator as a clock and a reset button. The Arduino Uno can be powered via the USB connection or with external power using AC-DC adapter or battery [10].

2) Xbee Shield: Xbee Shield is used to connect Xbee module to the Arduino board. It can directly plug in with Arduino/IFLAT-32 board, and use any pin of the basic board to connect with the Xbee module serail port. It has double shields interfaces in the top and bottom for cascading configuration with Arduino. It also has 3 LED indicators for Xbee (ON/SLEEP, RSSI and ASS) [11].

3) Xbee S2: As for communication task, Xbee S2 module is used in the system. It is designed to operate within Zigbee protocol and support the unique needs for low cost and low power of WSNs. The module operates within 2.4 GHz frequency band with 250 Kbps RF data rate. It is embedded with wire antenna and support for mesh network configuration. The distance between communicated adjacent devices in the line of sight outdoor use should not exceed 120 m. On the contrary, in the indoor use the distance is allowed no more than 40 m [12].

4) Sensors: For the environmental data monitoring, LM35DZ and DHT11 are used to read temperature and humidity, respectively. LM35DZ is an analog sensor device that displays the measurement in the voltage form with 10mV/^{0}C sensitivity [13]. Its accuracy is ±0.5^{0}C at 25^{0}C and operating temperature range from 0^{0}C to 100^{0}C. DHT11 is a digital sensor and has resolution on 16 bits [14]. This sensor has the capability of deriving the power (from 0.3V to 5.5V) via the data line, hence eliminating the need for an external power supply.

B. Network Specification

A group of nodes constructs a network. These nodes are able to transmit and receive messages in the network via wireless communication link. Zigbee protocol is a communciation standard which features of low rate, low power consumption, self-organizing, and self-recovery networks. Therefore, this technology is suitable for our WSNs prototype. Zigbee supports a variety of network topologies, such as peer-to-peer, star and mesh toplogy. This toplogy indicates how the transciever/receiver modules are logically connected to others.

1) Peer-to-peer connection: This connection is simply consisted of two nodes. The first one responsibles as a coordinator node that manages the network. The other is configured as an end device or sensor node.

2) Star topology: In this topology, all nodes are connected directly to the coordinator node. Messages transmiting from all end devices have to pass through this center node, which is responsible for decision making, routing and controlling the network. End device can not communicate with other end devices.

3) Mesh topology: In this topology, the network allows transmission between neighboring nodes. Mesh topology is a more robust system, therefore it is more realible for large scale sensor networks. In this topology, one node can have many nodes as neighbours where it can be routed to other paths whenever failure in one path.

C. Software Specification

The open source Arduino IDE (Integrated Development Environement) is used to program the Arduino board. Arduino IDE has capability as a program editor, code compiler and finally upload it to the microcontroller.

IV. Testing Results

A. Sensor Testing

1) Temperature Sensor: The accuracy of temperature sensor (LM35DZ) is calibrated by comparing its output to that of thermometer Testo 925 [15]. We put the sensor and the thermometer near the electric solder as the heat source. By changing the distance of the heat source to both instruments, the temperature is varied from nearly 28 ^{0}C to 41 ^{0}C. The comparison result is shown in Fig. 5. As seen from the figure, there is a linear correlation between the obtained sensor output (in Volt) and the reading value of the thermometer (in ^{0}C). Based on this calibration, we get the temperature value in degree Celcius using the following equation:

$$Temperature = Vout \times 10 \quad (1)$$

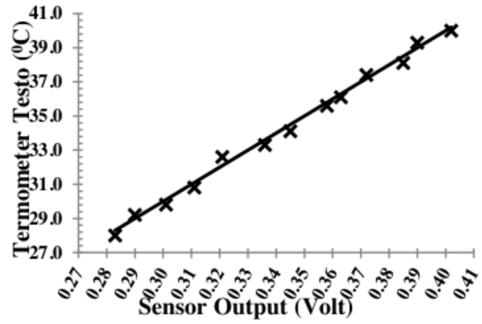

Fig. 5. Calibration curve of the temperature sensor, where its output compared to the thermometer Testo.

2) Humidity Sensor: In order to test the accuracy of humidity sensor (DHT11) in measuring environmental humidity, its output is compared to that of hygrometer of HTC-1 [16]. We put both instruments near to the water with heat source. When the temperature is increasing the water concentration on the air is increasing therefore the environmental humidity will be varied. Humidity value sensed by DHT11 is calibrated to that of HTC-1, as shown in Table. I.

TABLE XI. CALIBRATION OF DHT11 COMPARED TO HTC-1

No.	DHT11 (%RH)	HTC-1 (%RH)	Error (%RH)
1.	58	58	0
2.	58	59	1
3.	59	60	1
4.	60	61	1
5.	60	62	2
6.	61	63	2
7.	62	64	2
8.	63	65	2
9.	64	66	2
10.	65	67	2
Average Error			1.5

B. Communication Testing

Communication testing is carried out to see the performance of Xbee communication module in our WSN prototype system. In this testing, we consider three types of network toplogies, i.e. peer-to-peer, star and mesh toplogies. In each scenario, 100 data packets are sended from end sensor device to the coordinator device in various distances to see whether the system is working satisfactory in term of its communication functionality.

1) Peer-to-peer communication: In this configuration testing, the sensor device transmitted several data packets to the coordinator in various distances as seen in Fig. 6. From the testing results, as seen in Table II, we can see when the distance is 120m the data packets started to fail reach the coordinator.

This result is compliant with the spesification the Xbee module in our WSN prototype.

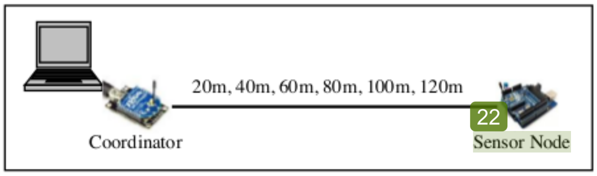

Fig. 6. Peer-to-peer communication testing in various distances.

TABLE XII. TESTING RESULTS OF PEER-TO-PEER TOPOLOGY

No	Distance (m)	Number of transmitted packets	Number of Received packets
1.	20	100	100
2.	40	100	100
3.	60	100	100
4.	80	100	100
5.	100	100	100
6.	120	100	98

2) Star topology: In this toplogy testing, three sensor nodes are located within range distances to the coordinator node as seen in Fig. 7. All three sensor nodes transmitted 100 data apckets to the coordinator. As seen in Table III, similar to the peer-to-peer testing result, when the distance is 120m, not all the transmitted data packets can reach the coordinator.

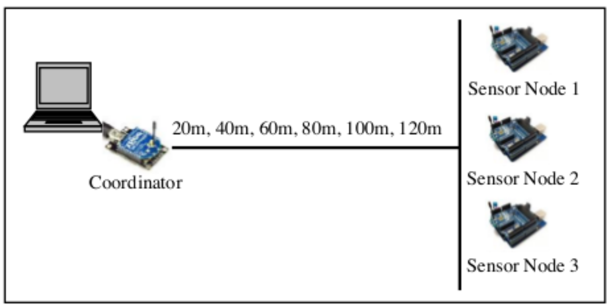

Fig. 7. Star topology communication testing in various distances.

TABLE XIII. TESTING RESULTS OF STAR TOPOLOGY

No	Distance (m)	Number of transmitted packets	Number of Received packets		
			From Node 1	From Node 2	From Node 3
1.	20	100	100	100	100
2.	40	100	100	100	100
3.	60	100	100	100	100
4.	80	100	100	100	100
5.	100	100	100	100	100
6.	120	100	98	97	98

3) Mesh topology: In this topology testing, the network has one router node to relay data packets from sensor node to the coordinator as illustrated in Fig. 8. The testing result as shown in Table IV, indicates that our sensor node is able to perform as a router to relay data packets from other nodes.

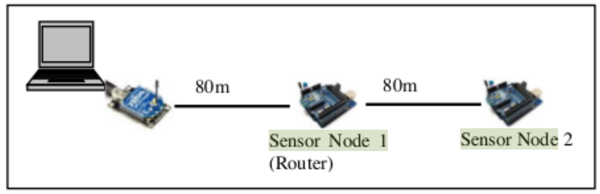

Fig. 8. Mesh topology communication testing.

TABLE XIV. TESTING RESULTS OF MESH TOPOLOGY

No	Distance (m)	Number of transmitted packets	Number of Received packets		
			From Node 1	From Node 2	From Node 3
1.	20	100	100	100	100
2.	40	100	100	100	100
3.	60	100	100	100	100
4.	80	100	100	100	100
5.	100	100	100	100	100
6.	120	100	98	97	98

C. *Energy Consumption Prediction*

For WSN deployed in the large or remote area, energy efficieny is the main concern. Due to the space limitation or dangerous environment, battery replacing is suggested not be carried out in all end devices of WSN. The power consumption measurement is only carried out for the end device, as the coordinator device located in the base station where there is no problem with the battery replacing.

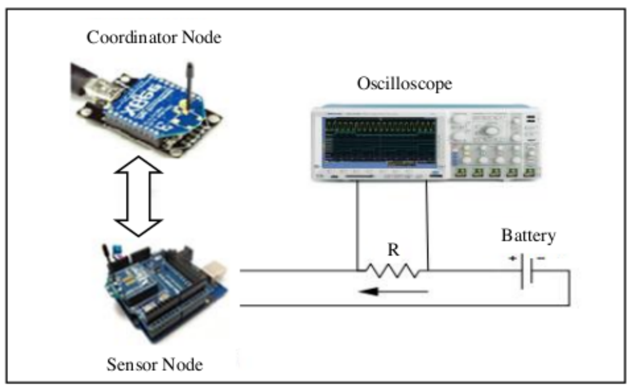

Fig. 9. Measurement setup of battery consumption by the sensor node.

In order to calculate the energy consumption, we monitor the current consumption and timing at each operating mode by the end device (sensor node). In this experiment, we put a 10 Ω resistor between battery supply and the power pins of the sensor node where it is located 1 meter from the coordinator node as shown in Fig. 9. The voltage and timing diagram of end device when transmitting data to the coordinator is illustrated in Fig.

10. The measured current and time intervals during data transmission and idle by the sensor node can bee seen in Table. V.

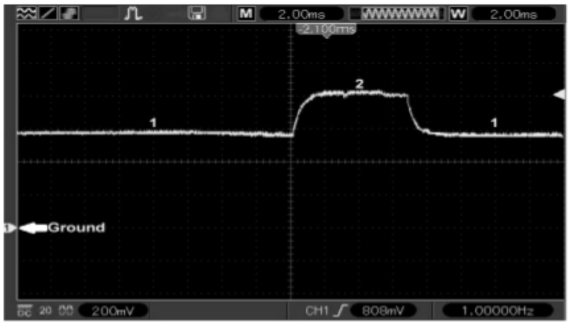

Fig. 10. Measured voltage during transmit the packet data (2) and idle (1) by the sensor node.

TABLE XV. CURRENT MEASUREMENT OF A SENSOR NODE

Parameters	Stages	Values
Idle current (i_{idle})	1	56mA
Transmit time (t_{tr})	2	6.8ms
Transmit current (i_{tr})		80mA
Battery capacity		10000mAh
Battery voltage		5V

Based on this experiment, we can calculate the current in each modes. The mean current consumed by the sensor node to transmit a data packet is expressed as in Eq. (2).

$$i(T) = \frac{t_{tr}}{T} i_{tr} + \left(1 - \frac{t_{tr}}{T}\right) i_{idle} \quad (2)$$

Where T is the time between two consecutive transmissions. The predicted life time of the end device can be approximated from the measured drain current as Eq. (3).

$$L(T) = \frac{C/i(T)}{30 \times 24} \quad (3)$$

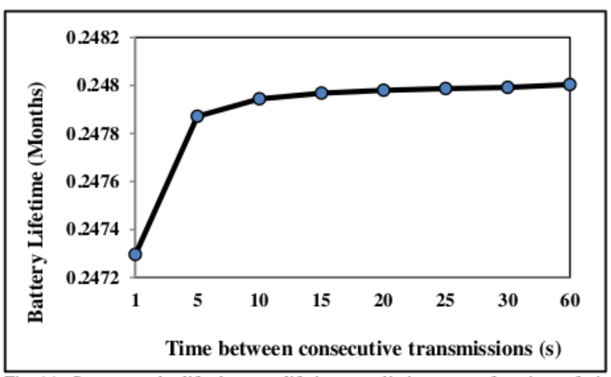

Fig. 11. Sensor node life battery lifetime prediction as a function of time between consecutuive transmission.

Based on the analysis above, Fig. 11 illustrates the estimation of battery lifetime in end device of WSN with variation of consecutive transmission time.

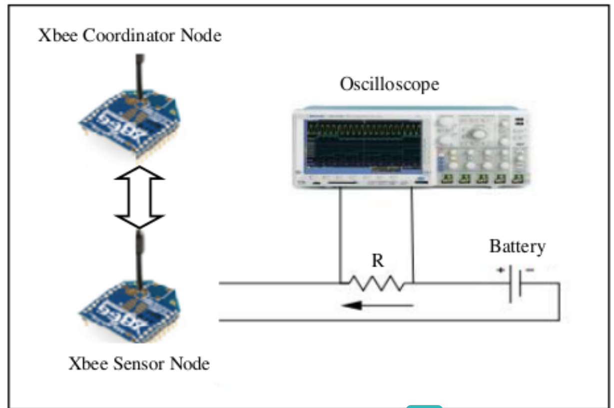

Fig. 12. Measurement setup of battery consumption by the Xbee sensor node.

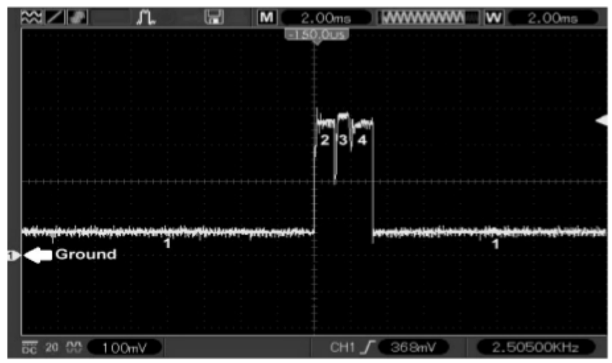

Fig. 13. Measured voltage during transmit the packet data by the Xbee sensor node.

From analysis above, we can see that the sensor node consumed still higher energy. Due to this result, we did energy consumption calculation for the Xbee module only without the arduino board, which needs more energy for its operation. Fig. 12 illustrates the experiment setup of energy consumption by the Xbee module in tranmission mode. Fig. 13 shows The voltage and timing diagram of the Xbee module when transmitting data to the coordinator node as captured by the oscilloscope.

The measured current and time intervals in each mode by the Xbee sensor node can be seen in Table. VI.

TABLE XVI. CURRENT MEASUREMENT OF A XBEE SENSOR NODE

Parameters	Stages	Values
Idle current (i_{idle})	1	6mA
Listen before Transmit time (t_{lbt})	2	1.2ms

Listen before Transmit current (i_{lbt})		37mA
Transmit time (t_{tr})	3	0.8ms
Transmit current (i_{tr})		39mA
Listen after Transmit time (t_{lat})	4	1.2ms
Listen after Transmit current (i_{lat})		37mA
Battery capacity		10000mAh
Battery voltage		5V

The calculation of current consumed by the Xbee sensor node is slightly different with that of the end sensor device. The mean current of Xbee sensor node during packet data transmission is expressed as:

$$i_{active} = \frac{(i_{lbt}t_{lbt}) + (i_{tr}t_{tr}) + (i_{lat}t_{lat})}{t_{active}} \quad (4)$$

where, t_{active} is the time for complete activity can be calculated from

$$t_{active} = t_{lbt} + t_{tr} + t_{lat} \quad (5)$$

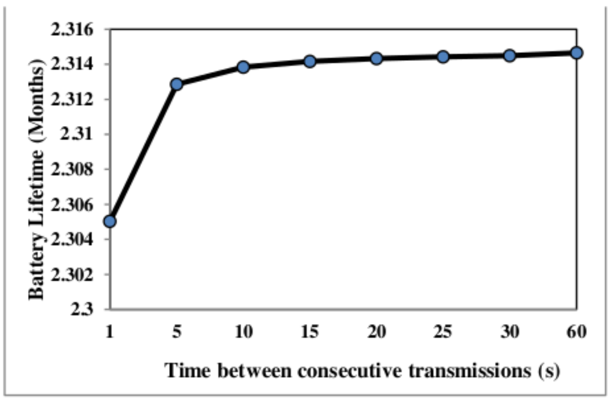

Fig. 14. Xbee sensor node life battery lifetime prediction as a function of time between consecutuive transmission.

Finally, the total current consumed by the Xbee sensor node and the predicted life time of battery can be computed as Equations of (4) and (5). Based on this analysis above, we can estimate the battery lifetime in Xbee sensor node of WSN with variation of consecutive transmission time as illustrated in Fig. 14.

From both calculations, it can be concluded that the arduino board in our prototype system consumes a large part of the power supply from the battery. The battery lifetime of the Xbee module is approximately only one nineth of that of sensor node. Since the XBee module has capability to work independently without a microcontroller, to reduce the energy consumption we can remove the arduino board for the sensor device development.

V. Conclussions and Future Works

The development of prototype of Zigbee based WSN to monitor temperature and humidity is reported. In order to have more accuracy measurement system, those sensors used in our developed system are calibrated to reliable instruments. In this works, we also considered several communication scenarios: peer-to-peer, star, and mesh topologies. In all scenarios, the system works well in terms of its functionality. Furthermore, the analysis of energy consumption shows that the end device can operate long enough without new battery replacing.

For the extention of future work, we will try to remove the arduino board which subsequently will increase the device lifetime and reduce the cost for each node. It is possible since the XBee module has capability to work independently without a microcontroller. XBee module can automatically sample sensor inputs and send them to the coordinator.

ACKNOWLEDGMENT

We would like to thank the Directorate General of Higher Education, Ministry of Education and Culture for financially support this research.

REFERENCES

[1] D. Estrin, L. Girod, G. Pottie, and M. Srivastava, “Instrumenting The World With Wireless Sensor Networks”, Proceedings of the International Conference on Acoustics, Speech and Signal Processing (ICASSP 2001), 2001.

[2] A. Mainwaring, J. Polastre, R. Szewcyk, D. Culler, and J. Anderson, “Wireless Sensor Networks for Habitat Monitoring”, Proceeding of Workshop on Wireless Sensor Networks and Applications, 2002.

[3] C. Hsieh, “Model Study for Temperature Microchange by WSN Technology”, International Journal of Electrical and Computer Engineering (IJECE), Vol. 2, No. 2, October 2012, pp. 632-638.

[4] N.M.Z. Hashim and M.S. Sizali, “Wireless Patient Monitoring System”, International Journal of Science and Research (IJSR), Vol. 2, No. 8, August 2013, pp. 250-255.

[5] A. Awasthi and S.R.N. Reddy, “Monitoring for Precision Agriculture using Wireless Sensor Network-A Review”, Global Journal of Computer Science and Technology Network, Web & Security, Vol. 13., No. 7, 2013.

[6] J. Zhu and C. Raison, “Cost Effective Automated Street Lighting Control”, International Journal of Electrical and Computer Engineering (IJECE), Vol. 4, No. 4, August 2014, pp. 637-642.

[7] V. Bhandari and P. Abrol, “Field Monitoring of Treated Industrial Waste Water”, International Journal of Electrical and Computer Engineering (IJECE), Vol. 4, No. 2, April 2014, pp. 237-242.

[8] ZigBee Alliance. “ZigBee and Wireless Radio Frequency Coexistence”. White paper, June 2007.

[9] H. Karl and A. Willig, Protocols and Architectures for Wireless Sensor Networks, John Wiley & Sons, 2005.

[10] M. Banzi and M. Shilloh, Make: Getting Started with Arduino, John Wiley & Sons, Maker media, Inc, 2014.

[11] Xbee Shield V1.1 Overview, http://www.iteadstudio.com, 2014.

[12] Digi International Inc. “XBee/XBee-Pro ZB RF Modules Product Manual”. http://www.digi.com, 2014

[13] LM35DZ Datasheet, http://www.itisravenna.gov.it/sheet/lm35dz.pdf, 2014.

[14] Aosong. “DHT Product Manual”, 2014.

[15] Testo 925 Datasheet, http://datasheet.octopart.com/925-Testo-datasheet-20683027.pdf, 2014.

[16] Thermo Hygrometer 103 – CTH Overview, http://www.htcinstrument.com, 2014.

Realization of Zigbee Wireless Sensor Networks for Temperature and Humidity Monitoring

ORIGINALITY REPORT

17%

SIMILARITY INDEX

PRIMARY SOURCES

1	www.researchgate.net Internet	62 words — 2%
2	knastik.ukdw.ac.id Internet	60 words — 2%
3	event.cs.usm.my Internet	54 words — 1%
4	scholar.google.co.uk Internet	32 words — 1%
5	hal.archives-ouvertes.fr Internet	28 words — 1%
6	citeseerx.ist.psu.edu Internet	27 words — 1%
7	www.communica.co.za Internet	27 words — 1%
8	www.ijecs.in Internet	26 words — 1%
9	docplayer.net Internet	23 words — 1%
10	iaescore.com Internet	23 words — 1%

mafiadoc.com

11	Internet	21 words — 1%
12	ethesis.nitrkl.ac.in Internet	20 words — 1%
13	Andreas Willig, Jan-Hinrich Hauer, Niels Karowski, Heribert Baldus, Axel Huebner. "The ANGEL WSN Architecture", 2007 14th IEEE International Conference on Electronics, Circuits and Systems, 2007 Crossref	19 words — < 1%
14	hiperrack.com Internet	18 words — < 1%
15	pdfs.semanticscholar.org Internet	18 words — < 1%
16	www.divilabs.com Internet	18 words — < 1%
17	hal.inria.fr Internet	17 words — < 1%
18	pt.scribd.com Internet	16 words — < 1%
19	"Communications, Signal Processing, and Systems", Springer Science and Business Media LLC, 2020 Crossref	15 words — < 1%
20	Martin Weibelzahl, Alexandra Märtz. "On the effects of storage facilities on optimal zonal pricing in electricity markets", Energy Policy, 2018 Crossref	14 words — < 1%
21	scholar.uwindsor.ca Internet	13 words — < 1%
22	Roshan Singh Sachan, Mohammad Wazid, D.P. Singh, Avita Katal, R.H. Goudar. "Misdirection	12 words — < 1%

attack in WSN: Topological analysis and an algorithm for delay and throughput prediction", 2013 7th International Conference on Intelligent Systems and Control (ISCO), 2013
Crossref

23 Peng, Xiaohong, and Guodong Liu. "Intelligent Water-Saving Irrigation System Based on Fuzzy Control and Wireless Sensor Network", 2012 Fourth International Conference on Digital Home, 2012.
Crossref
11 words — < 1%

24 hdl.handle.net
Internet
10 words — < 1%

25 Maheswaran Shanmugam, Asokan Ramasamy. "Sensor-Based Turmeric Finger Growth Characteristics Monitoring Using Embedded System under Soil", International Journal of Distributed Sensor Networks, 2014
Crossref
9 words — < 1%

26 epdf.tips
Internet
9 words — < 1%

27 Hakim, Lukmanul, Muhamad Wahidi, Trisno Handoko, Herri Gusmedi, Noer Soedjarwanto, and Federico Milano. "Development of a power flow software for distribution system analysis based on rectangular voltage using python software package", 2014 6th International Conference on Information Technology and Electrical Engineering (ICITEE), 2014.
Crossref
9 words — < 1%

28 Guangming Song, Yaoxin Zhou, Zhigang Wei, Aiguo Song. "A smart node architecture for adding mobility to wireless sensor networks", Sensors and Actuators A: Physical, 2008
Crossref
8 words — < 1%

29 globaljournals.org
Internet
8 words — < 1%

30 info.iet.unipi.it
Internet

8 words — < 1%

31 Yasmine Achour, Najib El Mernissi, Driss Zejli. "Design and Implementation of Greenhouse Remote Monitor System", 2018 IEEE 5th International Congress on Information Science and Technology (CiSt), 2018
Crossref
8 words — < 1%

32 Zixiang Wang, Meiqin Liu, Senlin Zhang, Meikang Qiu. "Sensor virtualization for underwater event detection", Journal of Systems Architecture, 2014
Crossref
8 words — < 1%

EXCLUDE QUOTES	OFF	EXCLUDE MATCHES	OFF
EXCLUDE BIBLIOGRAPHY	OFF		