2021 3rd East Indonesia Conference on Computer and Information Technology (EIConCIT)
April 09-11. 2021, ISTTS Surabaya, Indonesia

A Performance Evaluation of ZigBee Mesh Communication on the Internet of Things (IoT)

2021 3rd East Indonesia Conference on Computer and Information Technology (EIConCIT) | 978-1-6654-0514-0/20/$31.00 ©2021 IEEE | DOI: 10.1109/EIConCIT50028.2021.9431875

1st Puput Dani Prasetyo Adi
Department of Electrical Engineering
University of Merdeka Malang
Malang, Indonesia
puput.danny@unmer.ac.id

2nd Volvo Sihombing
Informatic Management and Computer Engineering Department
Labuhan Batu University
Labuhanbatu, Indonesia
volvolumbantoruan@gmail.com

3rd Victor Marudut Mulia Siregar
Computer Engineering Department
Politeknik Bisnis Indonesia
Pematang Siantar
victor.siregar2@gmail.com

4th Gomal Juni Yanris
Informatic Management and Computer Engineering Department
Labuhan Batu University
Labuhanbatu, Indonesia
gomaljuniyanris@gmail.com

5th Fricles Ariwisanto Sianturi
Computer Engineering Department
STMIK Pelita Nusantara
Medan, Indonesia
sianturifricles@gmail.com

6th Windania Purba
Computer Engineering Department
University of Prima Indonesia
Medan, Indonesia
winda.nia04@gmail.com

7th Saut Parsaoran Tamba
Computer Engineering Department
University of Prima Indonesia
Medan, Indonesia
sautparsaorantamba@unprimdn.ac.id

8th Julianto Simatupang
Computer Engineering Department,
AMIK Maha Putra
Riau, Indonesia
julianto.amp@gmail.com

9th Rahman Arifuddin
Department of Electrical Engineering
University of Merdeka Malang
Malang, Indonesia
rahman.arifuddin@unmer.ac.id

10th Subairi
Department of Electrical Engineering
University of Merdeka Malang
Malang, Indonesia
subairi@unmer.ac.id

11th Dwi Arman Prasetya
Department of Electrical Engineering
University of Merdeka Malang
Malang, Indonesia
arman.prasetya@unmer.ac.id

***Abstract*—This study examines the ability and Performance or Quality of Services of the IEEE 802.15.4 or ZigBee Radio Frequency module on the sensor node ZigBee based. Furthermore, ZigBee's communication capabilities, i.e., Tree, Star, and mesh networking, were developed on the internet or Internet of Thing using RaspBerryPi 4 as the Internet Gateway. The sensors used, e.g., Pulse sensor and temperature and Humidity Sensor. Moreover, the Spectrum Analyzer is used to measure the Radio Frequency Value (-dBm) per Channel (CH1 to CH12) on the Zigbee module (EDs and CN) communication at different distances, on the Mesh or Tree ZigBee Communication, ZR can be used, at Point-to-Point ZigBee, the role of ZR is neglected. Energy efficiency battery ZigBee sensor nodes need to be considered to obtain sensor nodes Long Life. Moreover, RSSI (-dBm) is the key to analyzing sensor node communication systems on different sensor node clustering, including Throughput, PacketLoss sensor data, and data analysis on Application Server.**

Keywords*—*ZigBee, RSSI, Throughput, Packet Loss, Application Server

I. Introduction

Recently, Wireless Sensor Network is a popular topic, for example is the development of wireless sensor applications into the application Server or the Internet of Things. The WSNs Communication techniques are implemented in the health monitoring. the health monitoring application e.g. Blood Pressure monitoring uses a Blood Pressure sensor, heart rate monitoring using a pulse sensor, and Oxygen Level or SPO_2. Moreover, the development of criteria WSNs seen in lightweight, prototype size and power consumption, energy Management for Wireless Sensor Network sensor node to achieve long life on WSNs. Furthermore, The Communication between Zigbee module Zigbee ED and Zigbee coordinator with e.g. topology. point-to-point, star, tree or mesh communication analysis can be done {Formatting Citation}.

Quality of Services from traffic communication e.g. Throughput, Packet Loss and delay [1]. moreover, ZD will be transmitting a sensor data to the Coordinator node (ZC) and the internet via the Internet Gateway e.g. Digi XBee Internet Gateway or Raspberry Pi 4, furthermore, Raspberry Pi 4 stores data in the MySQL database using the Python 3 programming language. The final step is displaying output on a Web-based Graphical User Interface using PHP [3], JASON, JavaScript and HTML programming languages and code scripts, this is done to obtain a real-time display of data in graphical form. It is also possible, displaying sensor data can be displayed on Smartphone devices. The development of the ZigBee or XBee communication system is an application to Artificial Intelligence (AI).

II. Theory

A. ZigBee End Node and Communication types

ZigBee is a Nircable telecommunication device, ZigBee focuses on the development of a Wireless Sensor Network (WSN), Xbee in Fig. 1 is used as an End Node which will later reside in objects and sensors as transmitting data. Fig. 1 provides an example of a Pulse sensor as a data sensor, namely

Pulse data [4]. or human heart rate (bpm). It should be understood that Xbee is an example of a WSN device that is only capable of short distances, i.e, 120 meters (S1 Xbee) and 1 km (Xbee Pro). Xbee or ZigBee (ZigZag Bee), this name comes from a communication system that is Mesh or Zig-Zag so that it is like the way a group of bees moves.

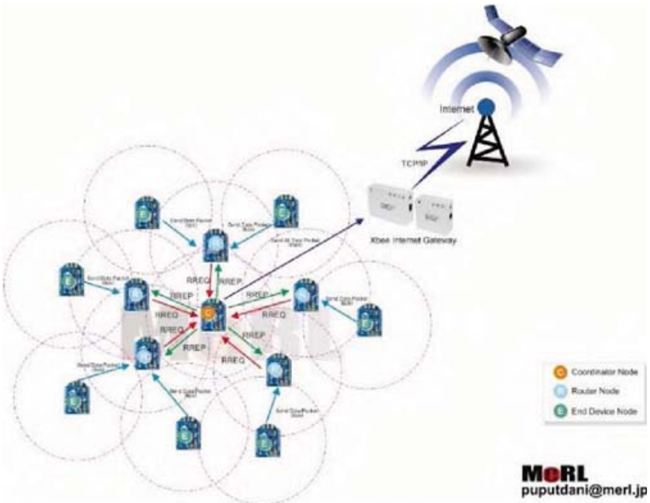

Fig. 1. ZigBee Communication IoT based

There are three types of ZigBee or Xbee communications that can be built use XBee X-CTU application, as in Fig. 1 & 3, and NS3 Simulation in Fig. 4 & 5. The ZigBee communication system is built through Point-to-Point, Star, and Mesh Communication, this communication uses End Node configurations, namely Coordinator Configuration, Router Configuration, and End Node Configuration. Moreover, Fig. 6 is communication with the ZigBee Internet Gateway (ZIG or XIG), then displays sensor data on the Internet Server or application Server [5].

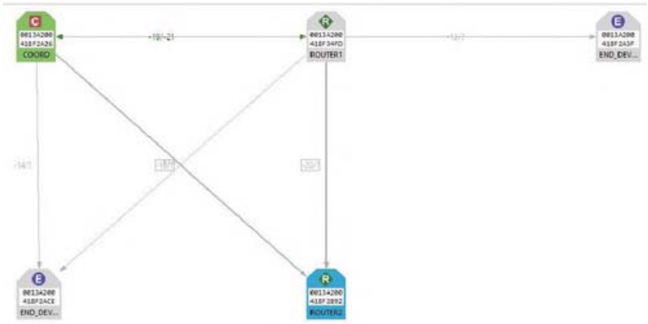

Fig. 2. ZigBee Communication example 1

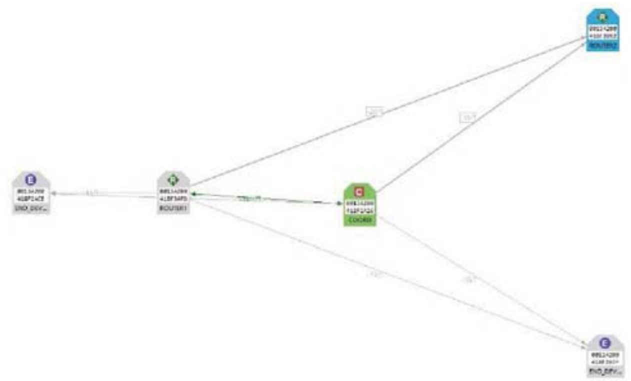

Fig. 3. ZigBee Communication example 2

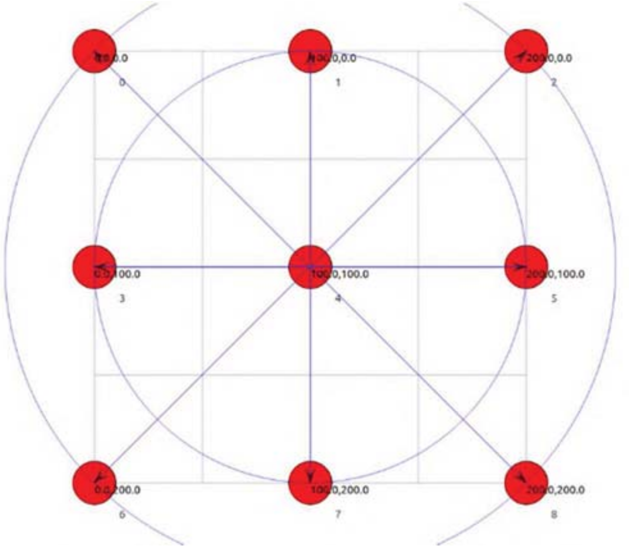

Fig. 4. ZigBee Communication use NS3 type 1

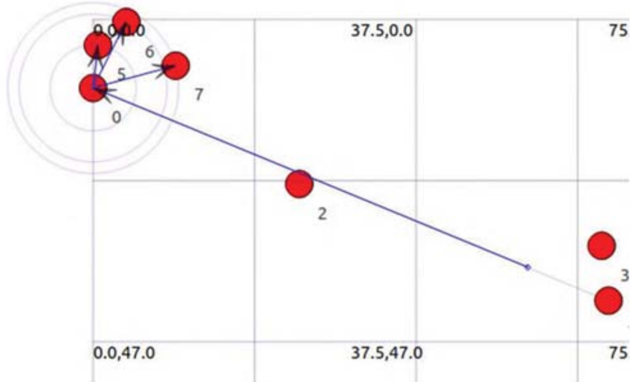

Fig. 5. ZigBee Communication use NS3 type 2

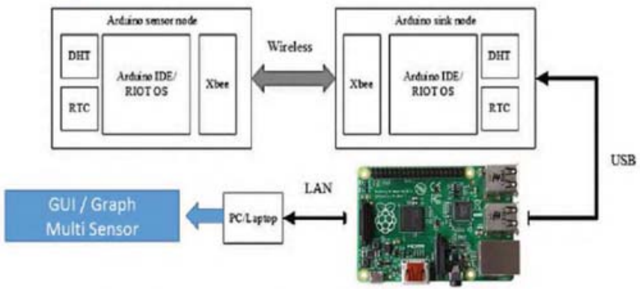

Fig. 6. ZigBee end node with RasBerry Pi 4

B. ZigBee Parameters and Equation

Signal strength is a factor in determining the parameters of the Received Signal Strength Indication (RSSI). Before measure the RSSI, recognize the parameters of the sending or transmit signal strength (P_{TX}) and signal strength of the P_{RX} receiver. This parameter has a watt unit. Moreover, on this research, ZigBee Pro s1 has Transmit Power (P_{TX}) = 63 mW (18 dBm) this data from ZigBee Datasheet. The theory of reception signal, the strength of signal reception can be represented as P_{RX} on the equation 1.

$$P_{rx} = P_{tx}.G_{tx}.G_{rx}.(\lambda/4\pi d)^2 \quad (1)$$

TABLE I. SIGNAL STRENGTH CLASSIFICATION

Signal Level Range (dBm)	Classification	Score
-120 to -95	Extremely Bad	1
-95 to -85	Bad	2
-85 to -75	Average	3
-75 to -65	Good	4
-65 to -55	Very Good	5
-30 to -55	excellent	6

RSSI is the strength of the signal received, therefore the signal strength is classified in a certain range that shows the Table I. Furthermore, Gain is a quantity produced by a comparison between the size of the output signal and the input signal in logarithmic number 10 with dB, where the exit signal is greater than the incoming signal. accordingly, Equation 2 is how to obtain the result G (dB) obtained from the results of the operation of a divide between Power Out (Watt) divided by the power input (Watt). e.g. The Pin is 100 mW, Pout is 20 mW, accordingly G = 10 log (pout/ pin) dBi, G =10 log (20/100), G=-6.9 dBi. dBi is an isotropic decibel, isotropic equal imaginary, this antenna calculation is done in theory and is used for measurement.

According to the digi.com data references, that XBee has a gain of less than 13.8 dBi, for distances of around 20 cm, it is not recommended to use ZigBee with an antenna gain of less than 13.8 dBi. accordingly, In the embedded system a signal strength of the Received Signal Strength Indicator (RSSI) is defined by Pref, Pref is 1 mW. e.g., the ZigBee Pro transmitter (P_{Tx}) signal strength will be calculated with the power of Transmit Power (P_{Tx}) = 63 mW (18 dB). Then the gain of 18 dB comes from combining equations 2 and 3. As follows: G (Tx) = 10.log PTx / Pref, then G(Tx) = 10.log (63/1)= 18 dB. Therefore, it can be concluded that ZigBee pro has a gain of 18 dB.

$$G(dB)=10.Log(P_{out}/P_{in}) \quad (2)$$

$$RSSI\ (-dBm)=10\log(P_{rx}/P_{ref}) \quad (3)$$

$$[Pr(d)]=[Pr(d_0)]\ dBm-10Log(d/d_0)+x\ dBm] \quad (4)$$

$$[Pr(d)]=[Pr(d_0)]\ dBm-10n\ Log(d/d_0) \quad (5)$$

$$[RSSI(dBm)]=[Pr(d)]dBm \quad (6)$$

$$[RSSI(dBm)]=A-10n.Log\ d \quad (7)$$

$$d=10\text{^}((A-RSSI)/10n) \quad (8)$$

Furthermore, The real distance and distance of the simulation can compare the percentage of the error rate (%). Therefore, the formula for finding the distance in a simulation can be seen in equation 8. Moreover, the Path Loss is the Power density reduction of a radio signal. and automatically can be known as the signal strength sent and received (dBm). [6] equation 10 is the Mathematical Formula for the Path Loss Model. And the situation is n = 2 (Free Space), in accordance with Table II [7].

Moreover, from the measurement, the specifications of the 3.7 Volt Battery node 1000 mAh, and load calculations e.g. XBee = 27 mA (TX Mode), LCD 8x2 = 2 mA, Arduino Pro mini 40 mA, FTDI232 is 50 mA and Pulse 5 mA, then total load is 124 mA. With a 5 Volt Voltage, then the Power is Voltage x Current = 5x0.124 is 0.62 Watt. Furthermore, I = 0.62 W / 3.7 Volt = 0.167 Ampere. Therefore, the power Consumption is 1000 mAH or 1AH / 0.167 A = 6 hours.

TABLE II. PATHLOSS EXPONENT VALUE

No	Environment	PathLoss Exponent, n
1	Free Space	2
2	Urban area cellular radio	2.75 to 3.5
3	Shadowed urban cellular radio	3 to 5
4	In Building line of Sight	1.6 to 1.8
5	Obstructed in building	4 to 6
6	Obstructed in factories	2 to 3

$$PL=P_{tx}-R_{rx}=-10n\log(d)+A\ (dBm) \quad (9)$$

Moreover, The difference of ZigBee Communication is on the JV Channel settings on the router, Coordinator, or end device of ZigBee, moreover, on the tree and mesh cluster of ZigBee, JV Channel Enable, vice versa, at the point to point and stare, JV Channel Disabled. In addition to the Zigbee communication system, the cluster method is known as the k-mean cluster method.

III. METHOD AND IOT HARDWARE CONNECTED

In this section, the WSN Sensor node or End Node connected to the RaspBerry Pi 4 with the Python programming language reviewed [8]–[11]. Fig. 6 shows the Connectivity of Arduino End Node and Server or RaspBerry Pi 4 with initialize from USB Port and Local Area Network (LAN) and Wi-Fi module [12], [13]. The research needs the strategy, management, design, and modelling [14], [15].

IV. RESULT AND DISCUSSION

ZigBee transmission data from <=100 meters, a software used is X-CTU type 6.4.2 and selecting the Radio range test section and obtain the RSSI data real-time on the Fig. 9. the average Local RSSI at a distance of <=100 meters is -68,8 dBm, the average remote RSSI at a distance of <=100 meters is -67,8 dBm and the average RSSI Local RSSI and Remote RSSI from a distance of <=100 meters is - 68,3 dBm in Fig. 7. Transfer ratio (kbps) or Throughput test within 10 seconds and the results can be seen in Fig. 7, transmission sensor data from ZED to ZC in Fig. 8 is <=100 meters distances.

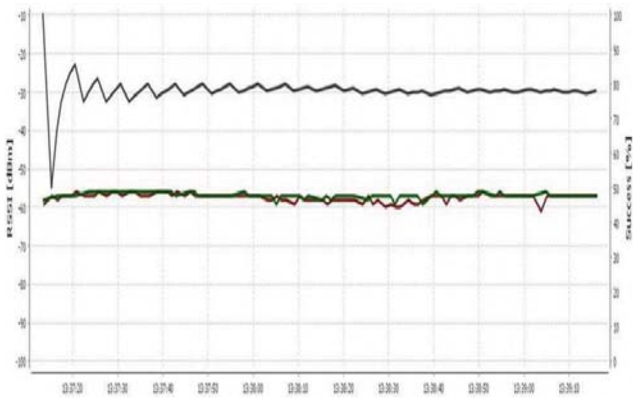

Fig. 7. RSSI data from ZED to ZC at <=100 meter distance

From the results of the RSSI signal strength comparison between local RSSI and Remote RSSI Fig. 9, the remote RSSI value is better than Local RSSI. the average Local RSSI at a distance of <=100 meters is -68,8 dBm, the average remote RSSI at a distance of <=100 meters is -67,8 dBm and the average RSSI Local RSSI and Remote RSSI from a distance of <=100 meters is - 68,3 dBm. In Fig. 10 shows the average of the transfer ratio (kbps) is the data throughput taken from the ZigBee network analyzer tool and then carried out the depiction of <=100 meters, in this measurement process data is obtained up and down in this data transfer process. But in broad outline shows that data throughput has decreased based on the distance between the TX node and RX node. In Fig. 10 the lowest throughput value is obtained at 100 meters, the throughput value obtained is only 3.4 kbps. The sampling is done for 10 seconds. So that the total data received is 3400 bits per second (bps) or the total data in 10 seconds is 34000 bits or 4,250 bytes. Furthermore, 12 Channels on ZigBee Radio Frequency system on the transmission DHT11 sensor data.

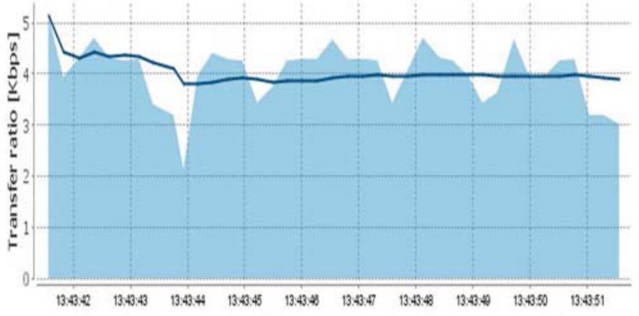

Fig. 8. Throughput (kbps) data from ZED to ZC at 10 second and <=100 meters distances

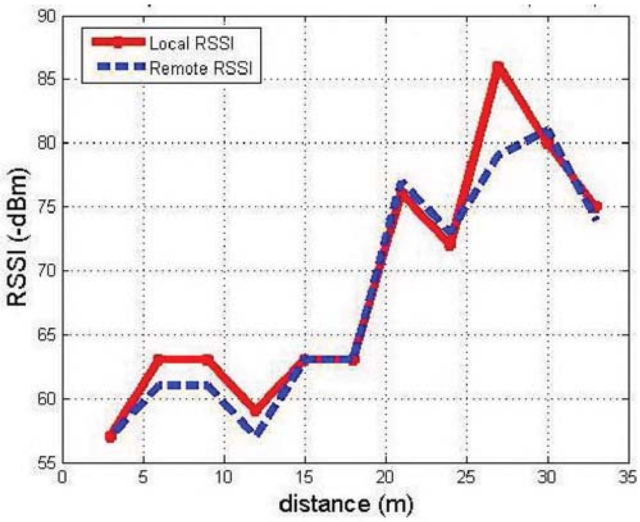

Fig. 9. Comparison Local and Remote RSSI (-dBm)

The software used is X-CTU Spectrum Analyzer, the feature that is used is to be able to know the most powerful ZigBee Spectrum on RF (dBm) and the weakest in each Channels. Taking these samples was taken at a distance of 12 meters, and will compare 12 ZigBee channels to this research, and concluded that the ZigBee Channel is the strongest and plays a major role in sending DHT11 sensor data, while the general configuration used is sampling interval 1000 ms and number sampling 100. more fully the data will be displayed in the form of a Table III.

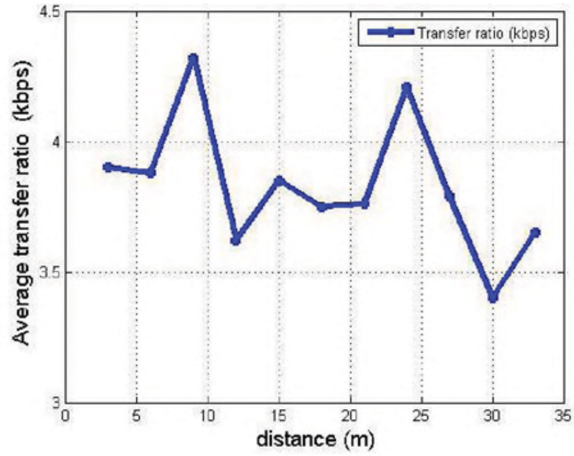

Fig. 10. Average Throughput (kbps) when sending the data from ZED to ZC with distance <=100 meter

TABLE III. NOISE LEVEL ALL CHANNEL ZIGBEE RADIO FREQUENCY

Channels	Maximum RF values (-dBm)	Minimum RF values (-dBm)	Average RF Value (-dBm)
CH1	47	91	83
CH2	47	93	84
CH3	78	93	87
CH4	45	93	85
CH5	69	93	80
CH6	34	90	76
CH7	47	90	78
CH8	50	92	79
CH9	48	95	88
CH10	47	91	79
CH11	61	88	80
CH12	35	89	77

Moreover, Fig. 11, a, b, and c is an experiment for sending data with RSSI (Receive Signal Strength Indicator) output using 3 ZigBee end nodes using different distance (m). Fig. 11 a and c are experiments at the same distance with different obstacle treatment. The distance in Fig. 11 a and c is <= 100 meters, while Fig. 11 b is the transmission of humidity sensor data at a distance of > 100 meters. The graphs in Fig. 11 a, b, and c are given by conditioning different positions at end nodes 1, 2, and 3 so that they get different obstacles.

Furthermore, Fig. 12 is Pathloss (-dB) on Free Space for ZigBee and Fig. 13 is Power Receiver (-dBm) on Free Space for ZigBee, in Fig. 14 is ZigBee's QoS test at 4 different conditions, broadly speaking PathLoss (-dB) experiencing attenuation based on the increase in distance (meters), the largest PathLoss (-dB) is -85 dB at a distance of 50 meters in Free Space conditions with the equation - (33 log d / 8 + 58.5). while Fig. 13 is a Power Receiver of Zigbee (-dBm) with 4 data used, namely Power Receiver with a large PTx 0 dBm and +20 dBm, the graph shows the highest power receiver is with Ptx 0 dBm of -50 dBm at a distance of 50 meters and the lowest is Ptx +20 dBm at -85 dBm at a distance of 50 meters. Fig. 14 is an output application server using Thingspeak Mathwork, the DHT11 sensor output is displayed in real time on a smartphone so it is more dynamic and easy.

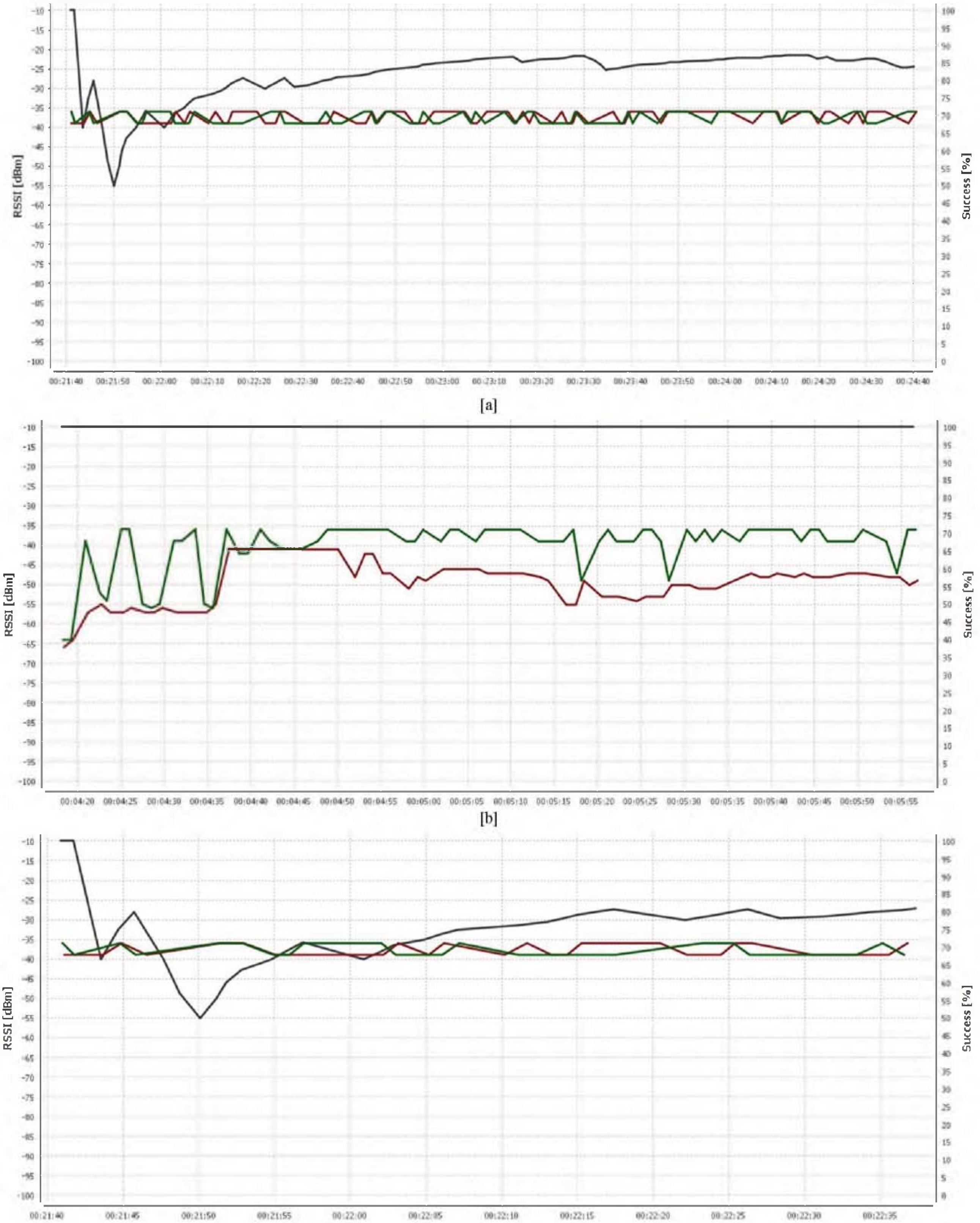

Fig. 11. Experiment for sending data with RSSI (Receive Signal Strength Indicator) output using 3 ZigBee end nodes using different distance (m)

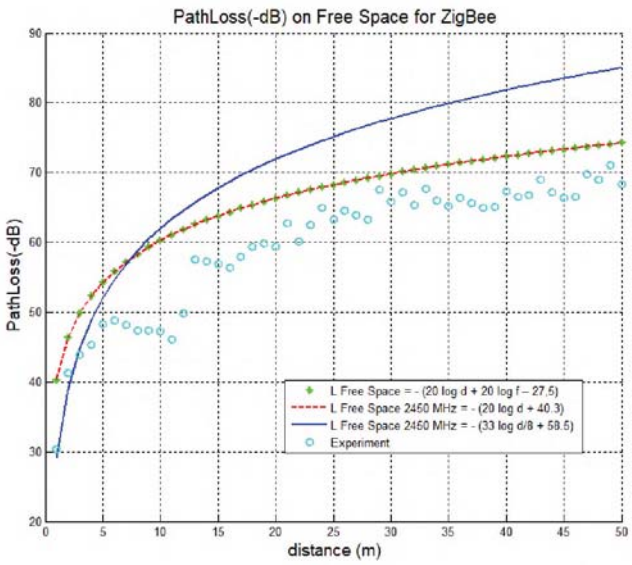

Fig. 12. Pathloss (-dB) on Free Space for ZigBee

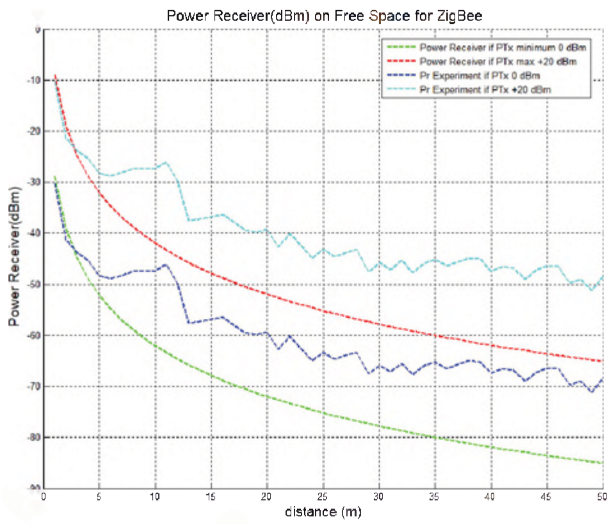

Fig. 13. Power Receiver (-dBm) on Free Space for ZigBee

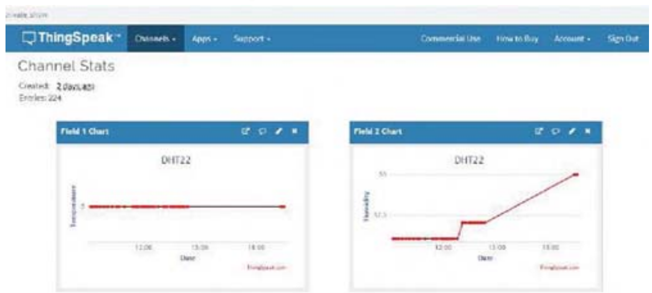

Fig. 14. Output Sensor on the Thingspeak Application Server

V. Conclusion and Future Research

At the Level Transmission sensor data use ZigBee on Line of Sight (LoS) and Free Space there are several Packet Loss due to errors in data transmission from Tx to Rx, not solely from distance, but from data processing.Transmission sensor data use ZigBee in free space from a sample distance of <=100 meters, it is found that RSSI has an average data transmission power of -67.8 dBm seen from the remote RSSI at ZED up to a distance of 100 meters, and this value is entered in the good category according to Table II with a score of 4. In Packet Loss, there is a decrease in the percentage of data reception due to the transmitter error (TX error), a decrease that occurs up to 64%.Tx error occurs at a distance of 27 meters, where the packet data loss due to transmitter errors and eliminating 13 data packets.The highest RF Channels noise at CH6 is -34 dBm and the average is -76 dBm, then CH7 with Maximum RF Value is -35 dBm and an average of -77 dBm.

The development of the ZigBee communication system continues to be improved in terms of regulating energy or power consumption sensor nodes. And the communication system with the C or Python programming language and communicated with a processor or CPU or mini CPU towards the server or application server, in this research, it was able to display DHT11 temperature data on the MySQL database owned by the server using RaspBerry Pi 4. Furthermore, it was developed with Graphical User Interface (GUI) so that the display of sensor data is more flexible.

A. Future Research

In developing research using the ZigBee Wireless Sensor Network (WSN), ZigBee carried out an analysis of the indoor and outdoor environments to obtain the Receive Signal Strength value, moreover built the ZigBee Mesh communication system on moving objects eg, cars, rockets, and developing communication systems at Internet level. of Things or Internet Server with a dynamic Graphical User Interface.

Acknowledgment

Thanks to Professor Akio Kitagawa and MeRL who have facilitated the author in terms of article and writing guidance, as well as on equipment needs such as XBee or ZigBee, XIG, analyzer and all other devices, and also thanks to all colleagues at UNMER Malang and all universities in Sumatra, Indonesia, which has contributed to the completion of this article.

References

[1] P. D. P. Adi and A. Kitagawa, "Quality of Service and power consumption optimization on the IEEE 802.15. 4 pulse sensor node based on Internet of Things," *Int. J. Adv. Comput. Sci. Appl.*, vol. 10, no. 5, pp. 144–154, 2019, doi: 10.14569/IJACSA.2019.0100518.

[2] P. D. P. Adi and A. Kitagawa, "ZigBee Radio Frequency (RF) performance on Raspberry Pi 3 for Internet of Things (IoT) based blood pressure sensors monitoring," *Int. J. Adv. Comput. Sci. Appl.*, vol. 10, no. 5, pp. 18–27, 2019, doi: 10.14569/IJACSA.2019.0100504.

[3] P. D. P. Adi and A. Kitagawa, "A Study of LoRa Performance in Monitoring of Patient's SPO2 and Heart Rate based IoT," *Int. J. Adv. Comput. Sci. Appl.*, vol. 11, no. 2, pp. 238–251, 2020, doi: 10.14569/-IJACSA.2020.0110232.

[4] M. Niswar *et al.*, "Performance Evaluation of Zigbee-Based Wireless Sensor Network for Monitoring Patients' Pulse Status," in *2013 international conference on information technology and electrical engineering (ICITEE)*, 2013, pp. 291–294, doi: 10.1109/ICITEED.-2013.6676255.

[5] S. Altaf, S. Ahmad, M. Zaindin, and M. W. Soomro, "Xbee-Based WSN Architecture for Monitoring of Banana Ripening Process Using Knowledge-Level Artificial Intelligent Technique," *Sensors*, vol. 20, no. 14, pp. 1–17, 2020, doi: 10.3390/s20144033.

[6] P. D. P. Adi and A. Kitagawa, "Performance Evaluation of LoRa ES920LR 920 MHz on the Development Board," *Int. J. Adv. Comput. Sci. Appl.*, vol. 11, no. 6, pp. 12–19, 2020, doi: 10.14569/IJACSA.-2020.0110602.

[7] P. D. P. Adi and A. Kitagawa, "A Performance of Radio Frequency and Signal Strength of Lora With BME280 Sensor," *Telkomnika*, vol. 18, no. 2, pp. 649–660, 2020.

[8] C. Bell, "XBee-Based Sensor Nodes," in *Beginning Sensor Networks with XBee, Raspberry Pi, and Arduino*, Springer, 2020, pp. 143–191.

[9] C. Bell, "Tiny Talking Modules: An Introduction to XBee Wireless Modules," in *Beginning Sensor Networks with XBee, Raspberry Pi, and Arduino*, Springer, 2020, pp. 35–101.

[10] V. M. M. Siregar and H. Sugara, "Implementation of Artificial Neural Network to Assessment the Lecturer's Performance," in *IOP Conference Series: Materials Science and Engineering*, 2018, vol. 420, no. 1, p. 12112, doi: 10.1088/1757- 899X/420/1/012112.

[11] S. P. Tamba, M. D. Batubara, W. Purba, M. Sihombing, V. M. M. Siregar, and J. Banjarnahor, "Book Data Grouping in Libraries Using The K-Means Clustering Method," in *Journal of Physics: Conference Series*, 2019, vol. 1230, no. 1, p. 12074, doi: 10.1088/1742-6596/12-30/1/012074.

[12] G. I. Hapsari, G. A. Mutiara, L. Rohendi, and A. Mulia, "Wireless Sensor Network for Monitoring Irrigation Using Xbee Pro S2C," *Bull. Electr. Eng. Informatics*, vol. 9, no. 4, pp. 1345–1356, 2020, doi: 10.-11591/eei.v9i4.1994.

[13] K. Rohman, D. Rahmawati, and L. Anifah, "Performance of 2.4 GHz Xbee for Digital Image Transmission with Yagi Antenna," in *Journal of Physics: Conference Series*, 2020, vol. 1569, no. 3, p. 32083, doi: 10.1088/1742-6596/1569/3/032083.

[14] D. A. Prasetya, A. Sanusi, G. Chandrarin, E. Roikhah, I. Mujahidin, and R. Arifuddin, "Waste Management to Produce Fuel Renewable Energy for Economic Support on The MSMEs and Public People," *Solid State Technol.*, vol. 63, no. 5, pp. 7311–7317, 2020.

[15] D. A. Prasetya, A. Sanusi, G. Chandrarin, E. Roikhah, I. Mujahidin, and R. Arifuddin, "Small and medium enterprises problem and potential solutions for waste management," *J. Southwest Jiaotong Univ.*, vol. 54, no. 6, pp. 1–9, 2019.