Analysis of Zigbee Data Transmission on Wireless Sensor Network Topology

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***Abstract*—The purpose of this study is to measure the distance in the line of sight environment and to see the data resulted from zigbee transmission by using star, mesh and tree topologies by using delay, throughput and packet loss parameters. The results showed that star topology had the average value which tended to be stable on the measurement of throughput and packet loss because there was no router nodes in star topology so that the accuracy of data delivery was better and it had the smallest delay value because the number of nodes was less than in mesh and tree topology, while the mesh and tree topologies had a poor average value on throughput and packet loss measurements, since the mesh and tree topologies had to go through many processes in which they had to pass through the router node to transmit the data to the coordinator node. However, the mesh and tree topologies had an advantage in which the data delivery could go through more distances than the star topology and they could add more nodes.**

***Keywords*—Zigbee; delay; throughput; packet loss; topology**

I. Introduction

Wireless sensor network (WSN) is a set of nodes arranged in a network of cooperation [1]. Each sensor node has the ability to collect data and can communicate with other sensor nodes. Using WSN, a system for measuring temperature, humidity, pressure, flow velocity, fluid levels and the others can be made. The measurement is done by the sensor, and then the sensor node sends the information to the base-station for reprocessing.

Zigbee is a protocol on Wireless Personal Area Network (WPAN) that can be used for Wireless Sensor Network (WSN). Zigbee is expected to transmit at a distance of 10-75 meters, depending on the RF environment and output power [2]. Despite its short communications distance, Zigbee has very easy operating advantages, its shape is small and requires very low power (low power consumption). Zigbee is also capable of supporting low-cost, stable networks and able to handle a set with a very large number of nodes [3].

The use of wireless sensor network is widely applied in many areas such as agriculture [4], environmental observations [5], building automation [6], health [7] and other fields. From the above applications, the analysis of Zigbee data transmission with the maximum distance that can be reached by xbee on star, mesh and tree topology with parameters throughput, delay and packet loss has not been discussed. This research measures the temperature in the line of sight environment to see the difference of zigbee data transmission results using star, mesh and tree topology so delay and packet loss is known and can be minimized to optimize network performance and throughput value can be increased.

The results of this research can be used to show how reliable the xbee 2 series device is with the zigbee protocol if applied in the line of sight environment so that it can consider the use of the right zigbee data transmission whether to use star, mesh or tree topology in order to know the shortest transmission time without missing data and information.

This paper is organized as follows. Section I about introduction contains the background of the zigbee protocol testing. Section II discusses related work of zigbee data transmission and wireless sensor network topology. Section III is about the system design methodology used in this test. Section IV is the result of this test and Section V contains the conclusions and suggestion.

II. Related Studies

Kumbhar Hema [8] in this research, proposed a practical implementation of creating WSN using mesh topology with coordinator node, router and end devices using arduino, xbee module and temperature sensors. This study will serve as a model for almost all sensor networks that one would like to build. This is to create setup which will allow to read temperature value form inexpensive temperature sensor placed apart at various location that are mesh networked to gather a stream of input and send to base station.

Doo Seop Yun and Sung Ho Cho [9] in this research, propose to address the problem of data transmission on Zigbee End Device (ZED), which has a power saving feature. Using the method of reducing power consumption in order to reduce network traffic in ZED, due to increased network traffic between the parent node and ZED, results in increased ZED power consumption so that the parent nodes cannot transmit data efficiently and reliably. By applying the proposed method, to recognize the ON-Point time period of the RF ZED Receiver, the parent node cannot receive request data periodically from ZED. So network traffic between ZED and the parent node will decrease. This method is useful for transmitting data efficiently and reliably.

D Pasalic [10] in this research explains how to design and implement Zigbee-based data transmission and monitor wireless smart sensor network integrated with internet. Effective cost implementation requires hardware elements and an integrated programming language. The proposed integration describes the Zigbee WSN system with internet-based technology that is cost-effective, energy efficient and relatively simple, a solution that can be a qualitative channel for data visualization and monitoring. The combination of hardware elements, programming languages and web technologies produces a practical WSN management system as it is presented in the form of diagram visualization so that sensor data flow can be monitored and measured constantly.

Rajeev Piyare and Seong-ro Lee [11] in this research analyze the performance of different network topologies on wireless sensor networks with XBee ZB-based sensor modules. Two network scenarios that are evaluated are direct transmission from End Device to Coordinator and transmission with routers that deliver packets between coordinator and node. For multi-hop transmission with Router, its results show very low network performance in terms of packet throughput and delay. Furthermore, to improve system performance, the number of transmission nodes must be minimized. In addition, the power consumption of End Device using sleep mode can effectively increase the life of the network. Overall, performance analysis shows that the XBee ZB module is more suitable for low-level data applications that have no reliability and very high real-time deadlines.

Ashraf A.M. Khalaf and Mostafa S.A. Mokadem [12] in this research are the two scenarios. First is comparing the three topologies which are star, cluster tree and mesh to see case of node failure as Zigbee coordinator (ZC), Zigbee router (ZR) and Zigbee end device (ZED). Second is comparing the cluster tree topology with a selected ZC and cluster tree topology that has two ZCs. The comparison parameters include data traffic sent, data traffic received, throughput and delay. The result is that the amount of data traffic received and sent to ZC in the case of star topology is very small compared to the cluster tree and mesh topology so it is unreliable when requiring high network data. ZC is important across the topology network but ZC failures result in the entire network failing, The effect of ZR failure on data traffic sent, cross-data received and throughput on ZC is greater than ZED failure in mesh and cluster tree topology cases because RFD does not have the ability to deliver messages so that the impact of failure on ZED is very small in this parameter. The impact of ZED failure on delay in ZC is larger than the impact in ZR because ZR has time to update its routing table in case ZED failure happens.

Research [9], [10] analyzed the transmission of Zigbee End Device and Zigbee Coordinator data in singlehop and multihop way which resulted in increased power consumption that conquered hardware elements and programming languages integrated with the Internet to be more energy efficient. Research [11], [12], analyzed the transmission of Zigbee Router data in multihop way and the results show that network performance on throughput and delay is so low that further research on Zigbee Coordinator and Zigbee End Device on star, mesh and tree topologies is conducted to see the impact of Node failure during data transmission.

Based on the results of analysis on previous studies, there is no discussion about measuring throughput, delay and packet loss parameters on the transmission of Zigbee data on star, mesh and tree topology.

III. METHODOLOGY

A. Hardware Design

Wireless sensor network designed used five xbee 2 series, arduinouno, xbee shield, xbee adapter and LM35. The setting for xbee was done with X-CTU software. This setting is to define xbee as the coordinator, router or end device. Temperature sensor mounted on the end device. Then xbee as the coordinator was installed on the computer to receive data from the router and end device. The processing software was used to create user interfaces with the user so that easy monitoring of temperature and communications was possible. The tools used in the research are in Table 1.

TABLE. I. USED HARDWARE

Hardware	Notes
Xbee S2	As coordinator, router and end device
Arduino Uno	As serial communication with computer
Xbee Shield	As a connector between XBee S2 and Arduino Uno
Xbee Adapter	As a module to set the XBee S2 configuration
LM35	As Temperature Sensor

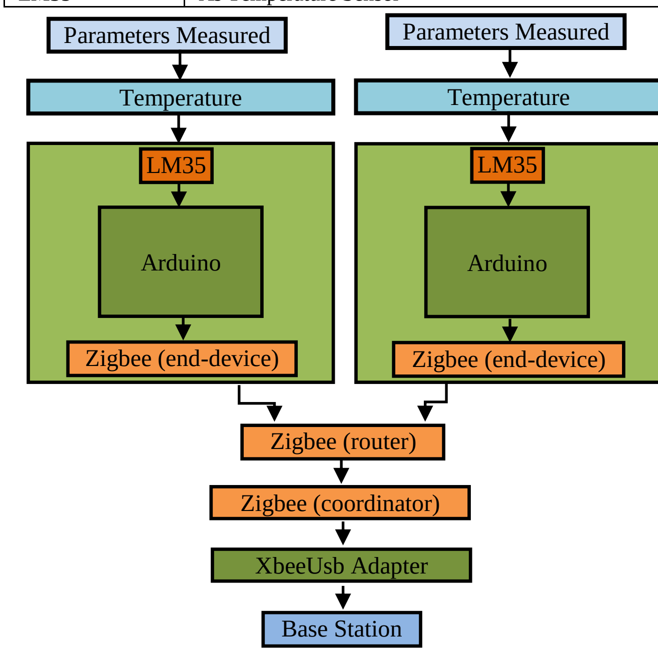

Fig. 1. Hardware design.

Testing was done with star, mesh and tree topology, where arduino and ATMega328 microcontroller which became processing unit connected with software system were equipped with xbee communication device, as in Fig. 1. From Fig. 1, Arduino as ATMega328 microcontroller received input from temperature sensor to be processed into Input data. The reading value was then compared to the set point value and processed by the ATMega328 microcontroller

B. Topology Design

In this study, the measurement and data analysis of zigbee transmission were performed from the wireless sensor network. The test was conducted by measuring the delay, throughput and packet loss parameters. The measurement and analysis used the scenario on star, mesh and tree topologies to determine network performance and reliability level of the zigbee protocol-based wireless sensor network built with xbee.

1) Star Topology Design

In the study, the star topology used is shown in Fig. 2, which was conducted to find out the communication performance between Xbee which were still in the range of Xbee reach. In this test, there were five Xbee used. The first Xbee was configured as a coordinator node to receive the temperature data and the others were configured as the end device nodes to send the temperature data to the coordinator node in unicast. In this test, the distances between nodes were set within a distance range between 10 meters to 100 meters with the condition of Line of Sight.

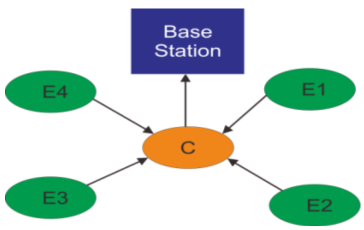

Fig. 2. Star topology.

2) Mesh Topology Design

In this study, the mesh topology used is shown in Fig. 3, which was conducted to find out the communication performance between Xbee which were outside of the range of Xbee reach, so that the communication used routing technique. In this test, the first xbee was configured as a coordinator node to receive data from two router nodes and the other Xbee were configured as the end device nodes to send data to the router nodes. The end device nodes 1 and 2 sent the data to router node 1 in unicast, then the router node 1 sent the data in multicast in which it sent the data to the coordinator node and to router node 2 in which the data were forwarded to the coordinator node. The distances between nodes were set within a range between 10 meters and 100 meters with a condition of Line of Sight.

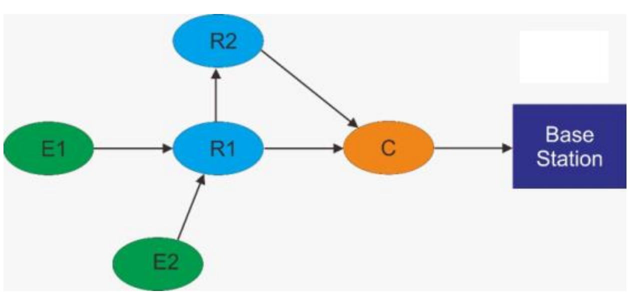

Fig. 3. Mesh topology.

3) Tree Topology Design

In this study, the tree topology used is shown in Fig. 4, which was conducted to find out the communication performance between Xbee which were outside of the range of Xbee reach, so that the communication used routing technique. In the design of this test, the first Xbee was configured as a coordinator node to receive data from two router nodes and two other Xbee were configured as end device nodes to send the data to the router node. In designing this test, the two end device nodes were placed at a distance in which it could not to send data to the coordinator node anymore, then, the router node was placed in between. Each of device nodes 1 and 2 sent its data to router node 1 and 2 in unicast, then, the router nodes 1 and 2 sent the data directly to the coordinator node. The distances between nodes were set within a range between 10 meters to 100 meters with a condition of Line of Sight.

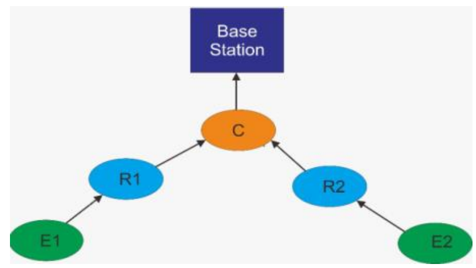

Fig. 4. Tree topology.

C. Data Collection Method

Data collection method in this research was by taking result of data at packet loss which must be under 5% because bigger packet loss resulted in the decreasing quality of a network. Taking the measurement result of the average transmission delay aims to determine the effect of the amount of data packets transmitted to the length of time for transmitting the data packet. The value of the transmission delay is the time it takes to send packets from source to destination. The average measurement result of throughput aims to determine the effect of packet data size on the throughput of the transmissions of the data packets. The average throughput value is calculated every 20 meter. Measurement of the average delay and throughput consists of two types, such as the measurement with variation of data packets with time delivery interval, and variation of data packets with transmission distance. Here is the formulation of data collection methods applied:

1) Delay

Delay is the total delay time of a packet caused by the transmission process from one point to another which becomes the destination.

$$\text{Delay Total} = \frac{\sum_{i=T_t}^{i=T_{t+1}} RT_i - \sum_{i=T_t}^{i=T_{t+1}} ST_i}{\sum_{i=T_t}^{i=T_{t+1}} RP_i};\ 0 \leq t \leq T \quad (1)$$

Notes:

RT_i= Packet Received Time (s)

ST_i= Packet Sending time (s)

RP_i= Number of Received Packets (s)

t = Sampling time(s)

T = Observing time (s)

2) Throughput

Throughput is the number of data packets received per second. Throughput can be referred to as bandwidth in actual conditions. Bandwidth is more fixed, while the throughput is dynamic, depending on the current traffic. Throughput has a unit of bits per second.

$$\text{Throughput} = \frac{\sum_{i=T_t}^{i=T_{t+1}} Pi}{T} \;; 0 \le t \le T \tag{2}$$

Notes:

Pi = Received packet size(bit)

Tt = Sampling time(s)

T = Observing time (s)

Based on *Zigbee* RF Modules by Digi International the throughput value on the *Zigbee* network is worth between 5 Kbps to 35 Kbps.

3) Packet Loss

Packet loss is the number of packets lost during the transmission process from the transmitter to the receiver. Packets loss occurs when one or more data packets passing through a network fail to reach its destination.

$$\text{Packet Loss} = \left(\frac{\sum_{i=T_t}^{i=T_{t+1}} D_i}{\sum_{i=T_t}^{i=T_{t+1}} S_i}\right) \text{x } 100;\ 0 \le t \le T \tag{3}$$

Notes:

D_i= Number of dropped packets (paket)

S_i= Number of sent packets (paket)

T_t= sampling time (s)

T = observing time (s)

IV. Test and Result

The test of zigbee transmission data on wireless sensor network topology was conducted by installing Xbee S2 on Xbee shield, then the Xbee shield was paired with Arduino uno which had been connected with the LM35 temperature sensor as shown in Fig. 5.

A. The Xbee S2 Configuration was performed in three stages

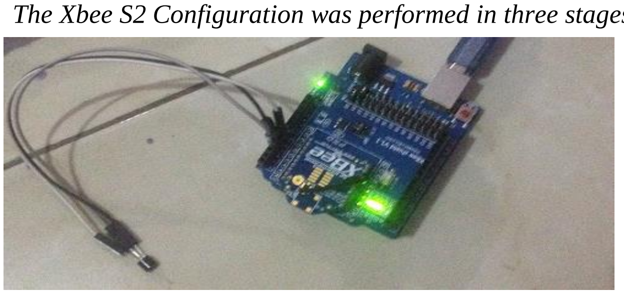

Fig. 5. the implementation of node installation.

1) Xbee S2 Configuration as End Device

Xbee S2 was firstly connected to XCTU software through COM port serial setting, then there were several parameter settings performed, such as; Baud: 9600, Flow Control: none, Data Bits: 8, Parity: none and Stop Bits: 1. Xbee S2 configuration as end device was performed through frameware update as shown in Fig. 6 and the parameters used were specified, they were; Frameware Xbee: End Device Mode AT, PAN ID: 3099 and Baud Rate: 9600.

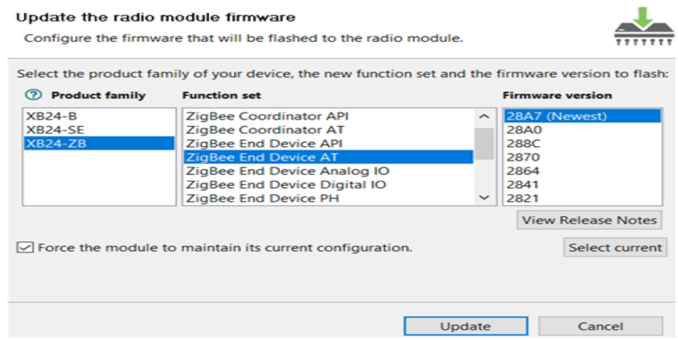

Fig. 6. Xbee S2 configuration as end device.

2) Xbee S2 Configuration as Router

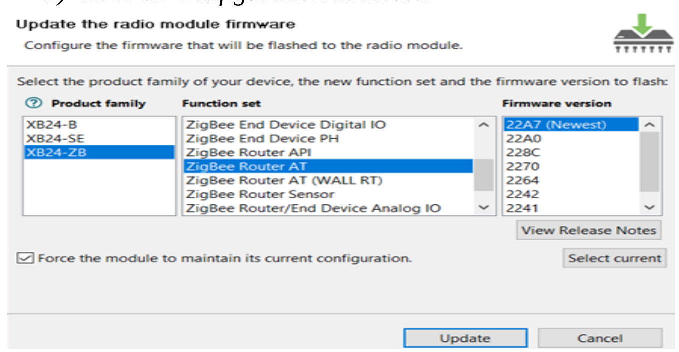

Fig. 7. Xbee S2 configuration as router.

The Xbee S2 configuration as router was performed through frameware update as shown in Fig. 7 and the parameters used were Frameware Xbee: Router Mode AT, PAN ID: 3099 and Baud Rate: 9600

3) Xbee S2 Configuration as Coordinator

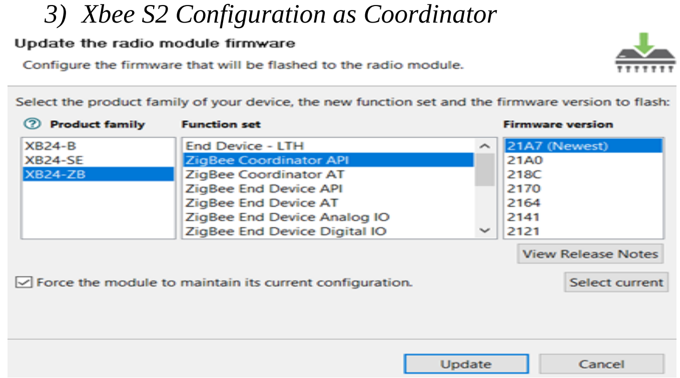

Fig. 8. Xbee S2 configuration as coordinator.

The Xbee S2 configuration as coordinator was performed through frameware update as shown in Fig. 8 and the parameters used were Frameware Xbee: Coordinator Mode API, PAN ID: 3099 and Baud Rate: 9600.

B. Arduino Uno Test

The arduino test was performed by entering the program to Arduino Uno through IDE arduino. The program is to transmit data from end device node to coordinator node, from end device node to router node and from router node to coordinator node.

1) The Test from End Device Node to Coordinator Node

The program of the test result for sending the data from the end device node to coordinator node was uploaded to arduino as shown in Fig. 9.

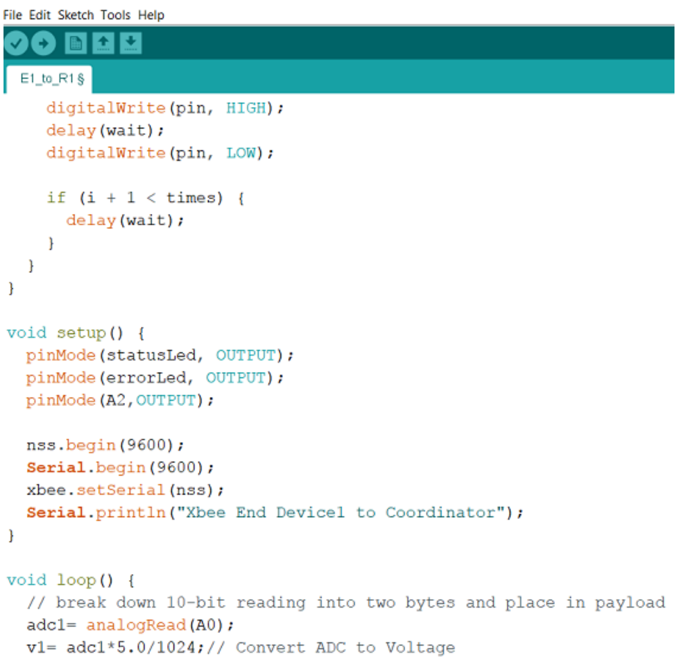

Fig. 9. The upload of the Program of the End Device Data to Coordinator.

The results showed that the data sent were suited to the program command as shown in Fig. 10.

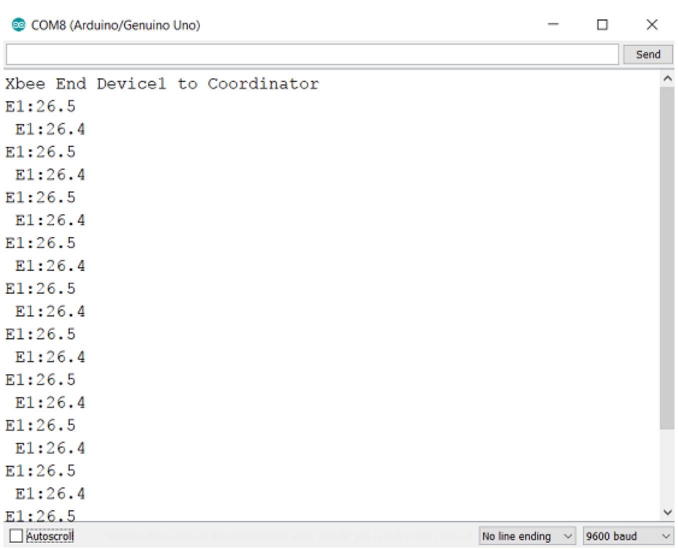

Fig. 10. The Results of the Running Program.

2) The Test from End Device Node to Router Node

The program of test result for sending the data from the end device node to router node was uploaded to arduino as shown in Fig. 11.

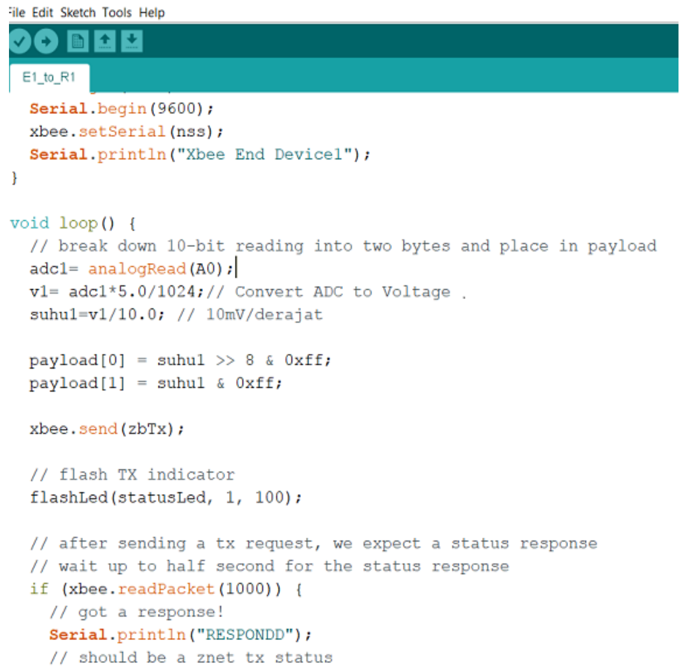

Fig. 11. The upload of the Program of the End Device Data to Router.

The results showed that the data sent were suited to the program command as shown in Fig. 12.

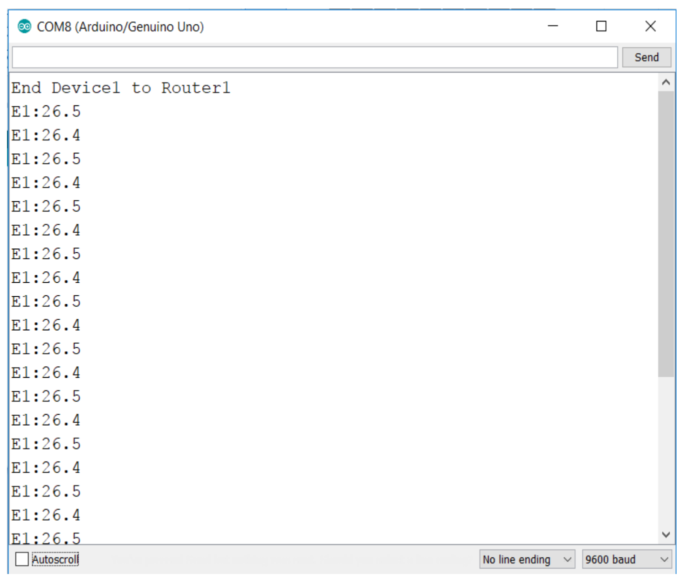

Fig. 12. The Results of the Running Program.

3) The Test from Router Node to Coordinator Node

The program of the test result for sending the data from the router node to coordinator node was uploaded to arduino as shown in Fig. 13.

The results showed that the data sent were suited to the program command as shown in Fig. 14.

Fig. 13. The upload of the Program of the Router data to Coordinator.

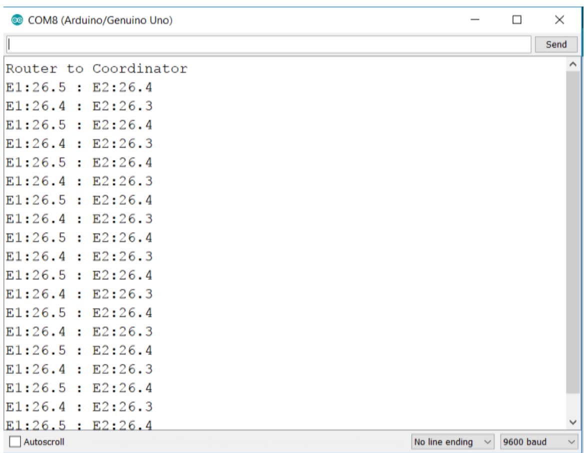

Fig. 14. The Results of the Running Program.

C. Topology Test Results

This test was conducted to find out the communication performance of Xbee S2 in terms of distance (S) in transmitting data using star, mesh and tree topologies.

1) Star Topology

In the results of the test on star topology, the data sent by four end device nodes to coordinator did not have packet loss from a distance between 10 m - 100 m, so that the communication between Xbee S2 could run smoothly and all of the information data sent by the end device could be received well by the coordinator node. The results of the test on star topology are contained in Table 2 below.

TABLE. II. THE RESULTS OF XBEE TEST BY USING STAR TOPOLOGY

S	E1	E2	E3	E4	Coordinator				Delay (s)	Throughput (kB)	Packet Loss %
					E1	E2	E3	E4			
10	26.5	26.4	26.4	26.3	26.5	26.3	26.3	26.1	0	32	0
30	26.4	26.4	26.4	26.4	26.3	26.3	26.2	26.0	0,1	31,82	0,55
50	26.4	26.2	26.3	26.3	26.4	26.2	26.1	26.2	0,1	31,82	0,55
70	26.3	26.3	26.2	26.0	26.2	26.1	26.0	26.3	0,1	31,82	0,55
100	26.2	26.1	26.2	26.1	26.0	25.9	26.2	26.2	0,1	31,82	0,55

2) Mesh Topology

The results of the test on mesh topology showed that the greater the distance of observation, the greater the value of packet loss and delay in data transmission, because the long-distance communication takes time in the process of data propagation through the router node, while the throughput value will be affected by the amount of packet loss, in which the smaller the packet loss, the greater the throughput value and the greater the packet loss, the smaller the throughput value. The results of the test on mesh topology are contained in Table 3 below.

TABLE. III. THE RESULTS OF XBEE TEST BY USING MESH TOPOLOGY

S	E1	E2	R1		R2		Coordinator		Delay (S)	Throughput (kB)	Packet Loss %
			E1	E2	E1	E2	E1	E2			
10	26.5	26.4	26.4	26.4	26.5	26.4	26.5	26.4	0	32	0
30	26.4	26.3	26.5	26.2	26.4	26.2	26.3	26.1	0,1	31,64	1,11
50	26.3	26.4	26.2	26.1	26.1	26.0	25.9	25.8	0,15	31,37	1,94
70	26.4	26.4	26.0	26.0	25.9	25.9	25.8	25.7	0,18	31,11	2,77
100	26.3	26.2	25.8	25.7	25.6	25.6	25.5	25.5	0,20	30	3,05

3) Tree Topology

The results of the test on tree topology almost showed similar results to the results in mesh topology, except on some test results which showed that the tree topology has a smaller average of packet loss and delay than in the mesh topology, because the transmission line in tree topology is unidirectional, while the mesh topology does not have unidirectional transmission line. The results of the test on tree topology are contained in Table 4 below.

TABLE. IV. THE RESULTS OF XBEE TEST BY USING TREE TOPOLOGY

S	E1	E2	R1	R2	Coordinator		Delay (s)	Throughput (kB)	Packet loss %
			E1	E2	E1	E2			
10	26.5	26.4	26.4	26.4	26.5	26.4	0	32	0
30	26.4	26.3	26.5	26.2	26.3	26.1	0,1	31,73	0,83
50	26.3	26.4	26.2	26.0	25.9	25.8	0,11	31,46	1,66
70	26.4	26.4	26.0	25.9	25.8	25.7	0,13	31,28	2,22
100	26.3	26.2	25.8	25.6	25.5	25.5	0,14	31,2	2,5

A. Graphic Results of the Observation

The graphic results of the observation including the observation on star, mesh and tree topologies by seeing the results of the test using delay, throughput and packet loss parameters are discussed below.

1) Delay

From the observation in Fig. 15, it is shown that there are the results of the average value of the delay that the star topology has the smallest time value. Due to the smallest value, the data transmission is better. The different results are shown by the mesh and tree topologies in which the time values are greater because they have to pass through several router nodes before reaching the coordinator.

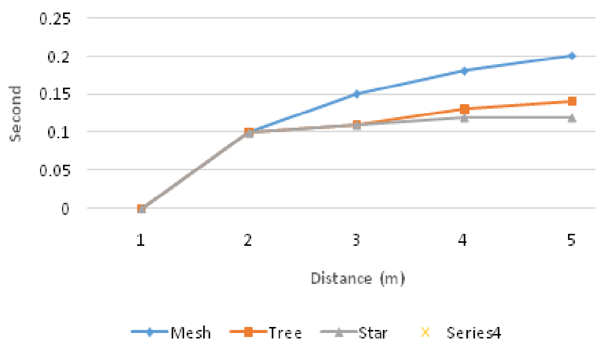

Fig. 15. Delay vs Distance.

2) Throughput

From the observation in Fig. 16, it is shown that there are the results of the measurement on the average value of throughput with different distance settings. It is known that for each type of the size of package data delivered, the average throughput value in the star topology tends to be stable. The different results are shown by the mesh and tree topologies that the data package tends to decrease along with the further distance.

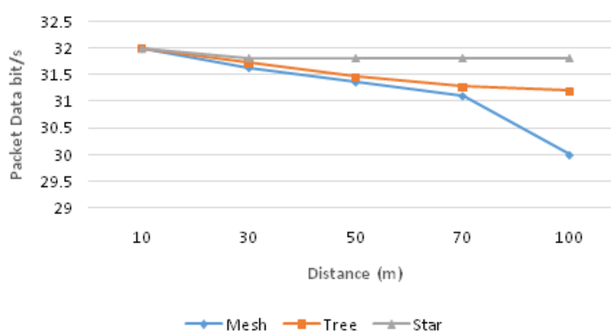

Fig. 16. Throughput vs Distance.

3) Packet Loss

From the observation in Fig. 17, it is shown that there are the results of the percentage of success of packet loss in star topology, where the delivery of data package received is as much as the data package sent, while in the mesh and tree topologies, the data package tends to decrease along with the further distance, in which the data package sent will pass through several router nodes, so that it will take longer time to process the data package in order to reach the coordinator.

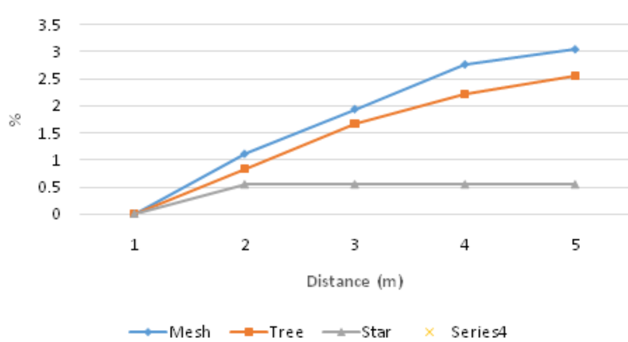

Fig. 17. Packet Loss vs Distance.

V. CONCLUSIONS AND SUGGESTION

Based on wireless sensor network test on temperature data transmission using topology scenario to measure the average value of delay, throughput and packet loss the conclusions are as follows:

1) Star topology had an average value which tended to be stable on the measurement of throughput and packet loss because the star topology did not have any router node, so that the accuracy of data delivery was better.

2) Star topology had the smallest average delay value because the number of nodes was less than in the mesh and tree topologies, so that the advantage of mesh and tree topologies was that they could add more nodes.

3) Mesh and tree topologies had a bad average value on the measurement of throughput and packet loss since they had to pass through many processes that had to pass through the router nodes to transmit the data to the coordinator node, but the advantage of mesh and tree topologies was that the data delivery could go through more distances than in star topology.

4) The next research is expected to measure the distance in the non-line of sight environment.

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