

Temperature and Humidity Optimization of Air Conditioner for Saving Electrical Energy Using Wireless Sensor Network Method

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Abstract— The consumption of electrical energy from year to year continues to increase. This is caused by the use of electrical energy and electrical equipment that inefficient. Hence, it is necessary to make efforts to save electricity efficiently. One of the efforts that have been made is research on the PPC (Programmable Power Controller) which functions as a controller for the use of electrical energy in the AC (Air Conditioner) device. Optimization of AC is also an effort to save electrical energy. This research focuses on technological efforts in the form of a room condition monitoring system design (temperature and humidity monitoring), AC mode setting scenarios, and room characterization for efficient use of electrical energy using the WSN (Wireless Sensor Network) method. The performance of the WSN sensor node as a monitoring device for room conditions which includes temperature and humidity has been successfully created using a temperature sensor, humidity sensor, signal conditioning circuit, and a programmed microcontroller. WSN sensor node results show that the DHT21 temperature and humidity sensor, which has a temperature range is 15°C-90°C, minimum humidity of 20% RH, and a maximum of 90% RH, testing works well. Meanwhile, the average time needed to carry out the node selection process until it is connected to the selected node when there is a default node, and no default node is 9.068 seconds and 9.968 seconds. Moreover, the implementation result of this device in the room area is in general, during working hours from 09:00 to 17:00, humidity conditions range from 30% - 75%, and temperatures range from 20°C - 40°C close to normal limits according to ASHRAE standard 55. In the next research, we focus on using the WSN relay to completely aim the function of the WSN sensor as a tool to reduce the electrical energy for monitoring and controlling the temperature and humidity AC.

Keywords— Electricity efficiency; programmable power controller; air conditioner; wireless sensor network; temperature; humidity.

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I. INTRODUCTION

AC (Air conditioning) is the process of changing the properties of air (especially temperature and humidity) to a more pleasant condition, usually aimed at distributing air-conditioned to an inhabited room such as a building or vehicle to improve temperature comfort and indoor air quality. In general, AC is a technology that modifies air conditions (heating, cooling, dehumidification, cleaning, ventilation, or air movement). IAQ (Indoor Air Quality) I-BEAM (I-Building Education and Assessment Model) is the quality of air in a building which is expressed by the concentration of pollutants and thermal conditions (temperature and relative humidity), which affect the health, comfort, and performance of its occupants [1].

Temperature is one of the basic IAQ measurements that directly affects feeling comfort and promotes concentration and productivity. According to the ASHRAE standard 55, the

recommended temperature range for "comfort" is 73 to 79°F (22.8 to 26.1°C) in summer and 68 to 74.5°F (20.0 to 23.6°C) in winter [2]. Measurements should be made periodically over several areas of the building to ensure that the air is evenly distributed, and the temperature is consistent.

Too low humidity indoors can cause static effects and people will feel their skin feeling dry. Too high in humidity, people will feel "sticky". According to ASHRAE standard 55, indoor humidity levels must be maintained between 30% and 65% for optimal comfort. Humidity can be measured in several ways. Typically, references such as relative humidity, wet bulb temperature, dry bulb temperature, humidity ratio and absolute humidity are used. Regardless of the method chosen, measurements should be made periodically and spread throughout the room to ensure that the air is evenly distributed and that humidity levels remain. The data of temperature and humidity from the measurement are the parameters to control AC.

WSN (Wireless Sensor Network) has emerged as new research in distributed computing environments in many applications today. Based on the topology, there are various applications. A survey on various WSN topologies has been performed. The advantages and disadvantages are also listed out. Besides, comparisons between various topologies such as cluster tree, star, mesh, and ring are listed. This topology plays a very important role to support various applications [3-7]

II. MATERIALS AND METHOD

The method applied to analyze the potential for energy savings with environmental condition monitoring technology based on WSN in a building needs to use a model representing all objects and energy use in the building that is the object of research. A good model must calculate the total energy consumption in a building that is not too far from the actual reality, with a maximum difference of about 5% [8].

The variables that will be sensed by the WSN sensor node in this research are room temperature and humidity. There are several types of measuring instruments for this variable, including hygrometers and electronic sensor systems. One of the popular electronic sensors used is the DHT21 sensor which can measure relative humidity and temperature with a calibrated digital output. This system uses an integrated temperature-humidity sensor with a digital output to take measurements. From the sensor datasheet, it is known that the output is not linear, so it needs compensation in the software to get accurate data. The method of obtaining linear values from the sensor follows the formula [9]:

$$RH_{linear} = c_1 + c_2 \times SO_{RH} + c_3 \times SO_{RH} (\%RH) \quad (1)$$

Likewise, for temperature compensation, the following formula is for converting a digital reading (SO_T) to a temperature value, with the coefficients given to the signal requiring compensation:

$$T = d_1 + d_2 \times SO_T \quad (2)$$

One sensor data reading unit on a WSN is called a sensor node. Its function is as a network builder consisting of five main parts, namely the sensor interface, which is a detector and measuring certain physical parameters, the analog circuit is a signal conditioning circuit, the microcontroller functions to process and manage data from sensors, the radio as the sending and receiving medium data, and a battery that serves as a power source [10]. With this capability, the sensor node can be called a smart sensor, as shown in Fig. 1.

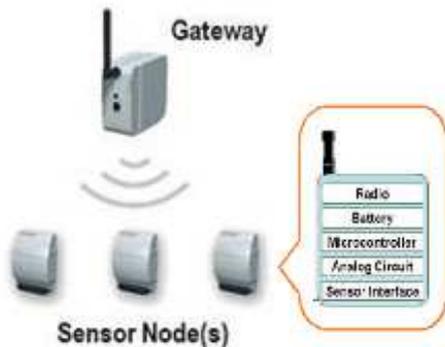


Fig. 1 WSN Sensor Node Structure

Monitoring is done by collecting data from these nodes to be processed and displayed on the server. The interconnected nodes will form a WSN architecture, as shown in Fig. 2 [11-15].

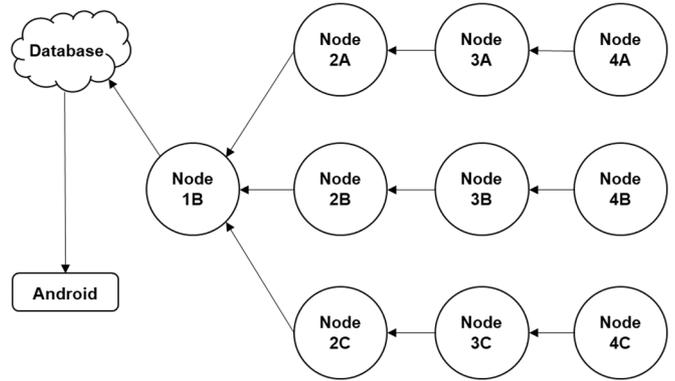


Fig. 2 WSN architecture

Each node is labeled as an SSID (Service Set Identifier) according to its predetermined location. The labeling is entered into non-volatile memory on the ESP8266. Where there is a sink node (1B), and other nodes are sensor nodes (2A, 3A, 4A, 2B, 3B, 4B, 2C, 3C, 4C). The number of sensors used is 9 sensors. The system starts by reading each sensor node's temperature and humidity values, then the temperature and humidity data are sent to the sink node before finally being forwarded to the database until it can be displayed on Android [16] [17]. By default, the data transmission path is formed according to the block diagram shown in Fig. 3 [18]. The data transmission path can be re-formed based on the RSSI (Received Signal Strength Indicator) if there is a damaged sensor node.

A test-bed was developed to verify the estimation results, analysis, and discussion in this study, as shown in Fig. 4. Fig. 5 describes the integration scenario; WSN controls several different WSN Gateways [19]. Apart from WSN at this layer, there is also hardware that is equivalent to WSN Gateway, namely PPC devices. Each client is programmed to access and schedule sensor readings at each node.

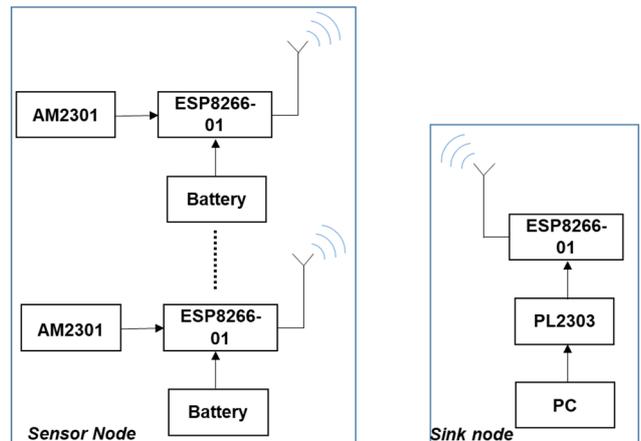


Fig. 3 Block diagram of sensor nodes and sink node

A large number of sensor nodes needs to be supported by a reliable and efficient communication protocol in accommodating data. Communication between sensor nodes

and WSN Gateway uses UDP Protocol (User Datagram Protocol). UDP is a protocol and datagram that is more compact than TCP. Meanwhile, the communication between WSN Gateway and PPC uses the TCP-IP protocol because it requires high bandwidth and reliable data transportation.

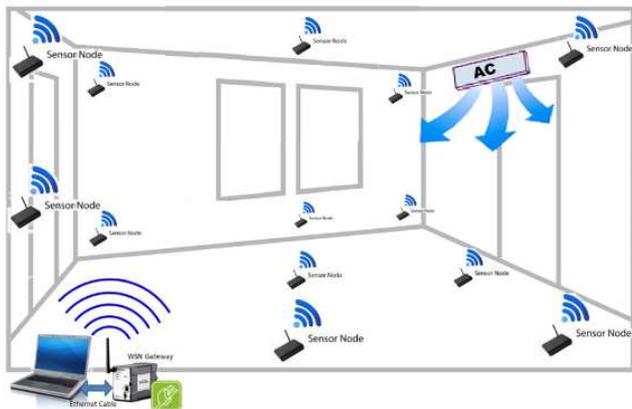


Fig. 4 Test Bed research

The functionality of the WSN can be grouped into three categories: (i) Hardware management, (ii) Discovery, (iii) Control hardware. System implementation consists of hardware implementation and software implementation. Hardware implementation is the activity of manufacturing hardware devices that are assembled for the distributed sensor system measurement process. Meanwhile, software implementation is an activity of programming for this WSN [20][21]. The hardware implementation consists of the microcontroller module ESP8266, temperature and humidity sensors, relay, IR sensor, and a hall-effect sensor. There are two types of nodes, namely sensor nodes and the sink node. Sensor nodes are used to detect room temperature and humidity and send the data to other nodes. While the sink node functions to receive data from sensor nodes reading, then forward it to the database. The used hardware includes temperature and humidity sensors AM2301, ESP8266, USB-TTL PL2303, and batteries. These devices are assembled into an initial prototype for the WSN nodes model application built as shown in Fig. 5 [20].



Fig. 5 The initial prototype of the WSN node

Each node is labeled as an SSID (Service Set Identifier) according to its predetermined location. The labeling is recorded into the non-volatile memory on the ESP8266. Node 1B is a sink node, while the other nodes are sensor nodes. The

number of sensors used is 9 sensors. The system starts by reading the temperature and humidity values that come from each sensor node, then the temperature and humidity data are sent to the sink node before finally being forwarded to the database until they can be displayed on Android. By default, the data transmission path is formed according to the block diagram shown in Figure 6. But if there is a damaged sensor node, the data transmission path can be re-formed based on the RSSI (Received Signal Strength Indicator) [21].

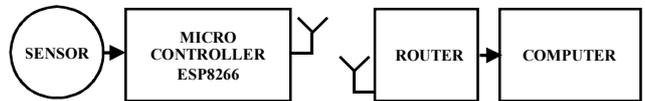


Fig. 6 WSN node electronic system block diagram

The first stage in WSN implementation in monitoring room conditions is recording actual conditions that include recording temperature and humidity over a certain period of time. These temperature and humidity readings are recorded at any time for 24 hours to SD CARD memory using a data logger that consists of a microcontroller system connected to the SHT-11 temperature and humidity sensor. The stored data will be analyzed later. The electronic system used for data recording is composed of several series, namely the DHT21 temperature and humidity sensor, microcontroller ESP8266 with radio communication circuit/WIFI module between the microcontroller and the internet [22][23]. The block diagram of the electronic data retrieval system of the WSN node Electronic System is shown in Fig. 6 [24-26].

The microcontroller used in this system is the ESP8266 which is one of the ESPRESSIF microcontroller chips. In this circuit, a DIP Switch is set to set the addressing node and DHT21 sensor pins for sensing temperature and humidity and connecting the LED pins indicators. The model of the microcontroller circuit is shown in Fig.7.

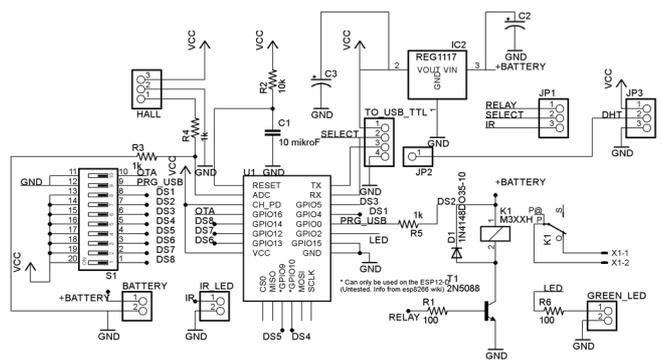


Fig. 7 The model of ESP8266 microcontroller circuit

The system test results consist of the transmitter and receiver. The DHT21 temperature sensor is tested with temperature detection at several places in the room, then the result of the output reading obtained is compared with the temperature value listed on the room thermometer. The room thermometer used in this study has a scale of 0° to 150°C. Researchers have carried out the recording of temperature and humidity since March 2020. Data is recorded and stored in a 2GB SD Card memory from March 1, 2020 to July 17, 2020.

III. RESULTS AND DISCUSSION

A. Graph of Temperature and Humidity Changes

The data samples were collected on March 1, 8, 15, 22, and 29, 2020. From these samples, we can see a graph of changes in temperature and humidity during March 2020, as shown in Fig. 8.

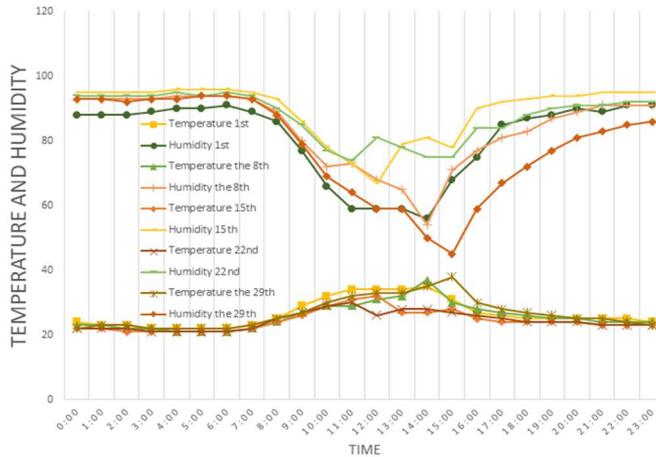


Fig. 8 Graph of changes in temperature and humidity during March 2020

From Fig. 8 it is known that in the range of week 2 to week 4 changes in temperature and humidity from 20:00 to 09:00 is relatively the same, which is between 22-24°C and humidity above 90%. The temperature on the first Sunday of March looks lower than the end of the month. At the end of March, it appears that the temperature rises, and the humidity falls in the range of 40-50% during the day. Further data sample collection was gathered on April 1, 8, 15, 22, and 29, 2020. From these samples, it can be seen that the graph of changes in temperature and humidity during April 2020 is shown in Fig. 9.

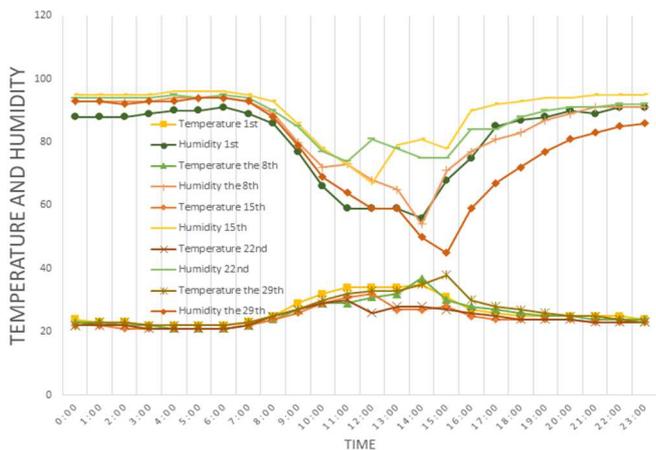


Fig. 9 Graph of changes in temperature and humidity during April 2020

Fig. 9. shows that the highest temperature occurred on April 22, 2020 at around 15:00 with temperatures around 38°C. While the lowest humidity occurs on April 29, 2020 at around 15:00 with a humidity value of nearly 40%. Furthermore, both humidity and temperature change in average every day from 08:00 to 16:00, that is, for humidity changes in the range of 40% - 80%, while the range of temperature changes is between 20°C to 40°C.

The third data collection was done on May 1, 8, 15, 22, and 29, 2020. Same with the previous trends, it can be seen that the graph of changes in temperature and humidity during May 2020 is shown in Fig. 10.

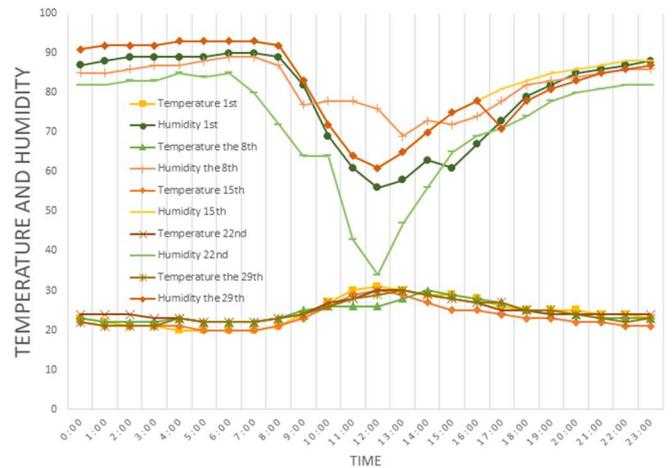


Fig. 10 Graph of changes in temperature and humidity during May 2020

Fig. 10 shows that the lowest humidity occurred on May 22, 2020 at 12:00 with value of 30% and the highest is on May 29, 2020 between 00:00 and 08:00 above 90%. Meanwhile, the highest temperature around 30°C and the lowest around 18°C occurred on May 1, 2020, at 12:00 and 06:00, respectively. Researchers determined data sampling on June 1, 8, 15, 22, and 29, 2020. From these samples, we can see the graph of changes in temperature and humidity during June 2020, as shown in Fig. 11. In Fig. 11, it can be seen that the average changes every day in June 2020, both humidity and temperature are relatively stable.

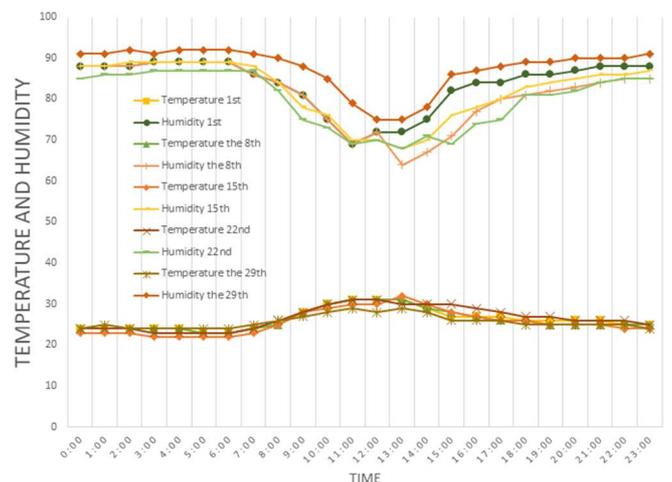


Fig. 11 Graph of changes in temperature and humidity during June 2020

Researchers determined sampling data collection on 1, 8, 15, 22, and 29 July 2020. From these samples, the graph of changes in temperature and humidity during July 2020 as shown in Fig. 12. It shows that the characteristics of changes in humidity and temperature in July 2020 are similar to May 2020 in Fig. 10.

From the data sample taken from March to July 2020, the results show that the trend of data in March is the same as in April, likewise, the data for May is the same as in July while in June the trend for data is different, which has almost the

same characteristics in humidity and temperature for sample data taken on 1, 8, 15, 22, and 29 June 2020.

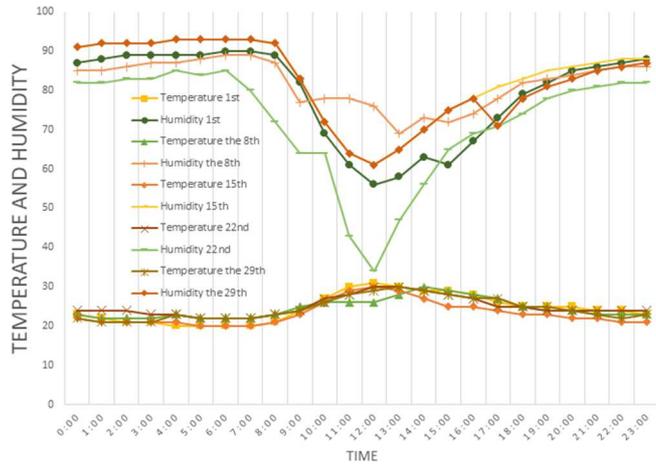


Fig. 12 Graph of changes in temperature and humidity during July 2020

Overall, the sample data taken in March, April, May, June, and July 2020 shows that in general, during working hours from 09:00 to 17:00 humidity conditions range from 30% - 75% and temperatures range from 20°C - 40°C close to normal limits according to ASHRAE standard 55. This shows that the WSN Electronic System node or WSN sensor works well because it is able to condition temperature and humidity during working hours according to the set standards, so there is no extra work from AC.

Besides, the RSSI showed the sensor nodes and sink node ranges from -49 dBm to -71 dBm still much less than the energy-hours used to turn on the AC (225 until 920 Watt or 32.35 dBm until 32.96 dBm). This shows that the application of WSN sensor only requires very little energy but is able to support system reliability in the form of energy reduction and efficiency if it collaborates with WSN relay programmed and scheduled, such as when the temperature rises, the AC is automatically turned on and when it is night and there are no people and the temperature is cold, the AC is automatically turned off. Indeed, the combination of WSN sensor and WSN relay work makes the room system design reduce energy use and efficiency. Then, the next research we apply the WSN relay to turn on and off AC and WSN sensor to monitor as well as control the temperature and humidity AC in the room system design.

Because of in this research, we are still discussing temperature and humidity monitoring and have not entered the direction of the WSN relay to turn on and off AC, so the calculation of the energy that can be saved is still not clarified. If the WSN sensor and WSN relay work together in a programmed and scheduled manner, we can calculate how much energy can be saved.

The monitoring display is visible through an android application made using the Thinkable App Builder. The application contains information on the form of temperature and humidity data readings that derives from each sensor node and the condition of each node whether it is active (blue) or inactive (grey). The maximum number of sensor node data that can be displayed is nine sensor nodes. The android application display is shown in Figure 13.

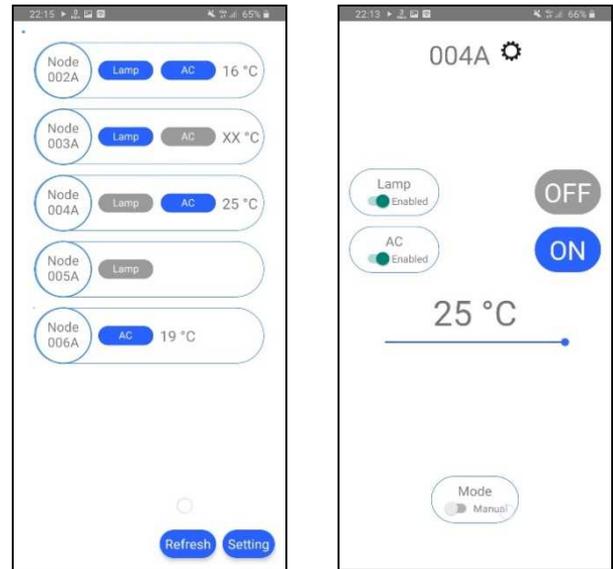


Fig. 13 WSN monitoring application

Routing algorithm testing is carried out at each sensor node. This test aims to determine the success rate of selecting the node to be connected along with the time required to carry out the node selection process until it is connected to the selected node. The test is carried out on two conditions, namely when there is a default node and when there is no default node, provided that the sink node is always present. The default node is the priority node to be connected by the sensor node according to the block diagram shown in Fig. 2.

TABLE I
TESTING THE ROUTING ALGORITHM WHEN THERE IS A DEFAULT NODE FOR NODES 4A, 4B, 4C, AND 3A

Test Node	Detected Nodes		Selected Node	Time (seconds)
	SSID	RSSI (dBm)		
4A	4B	-58		
	4C	-60		
	3A	-56		
	3B	-63		
	3C	-67	3A	8,559
	2A	-62		
	2B	-63		
	2C	-66		
	1B	-68		
	4A	-56		
4B	4C	-59		
	3A	-57		
	3B	-70		
	3C	-63	3B	10,566
	2A	-68		
	2B	-61		
	2C	-57		
4C	1B	-68		
	4A	-69		
	4B	-56	3C	8,571

	3A	-63		
	3B	-64		
	3C	-51		
	2A	-66		
	2B	-55		
	2C	-70		
	1B	-71		
	4A	-56		
	4B	-62		
	4C	-65		
	3B	-68		
3A	3C	-63	2A	8,758
	2A	-60		
	2B	-64		
	2C	-57		
	1B	-69		

Table I shows that the test results show that the selected node is always the default node of the sensor node being tested, with the average time needed to carry out the node selection process until it is connected to the selected node, which is 9.068 seconds.

Fig. 14 is an example of a route that is formed when the default node is not active. Alternative routes are automatically formed under different conditions.

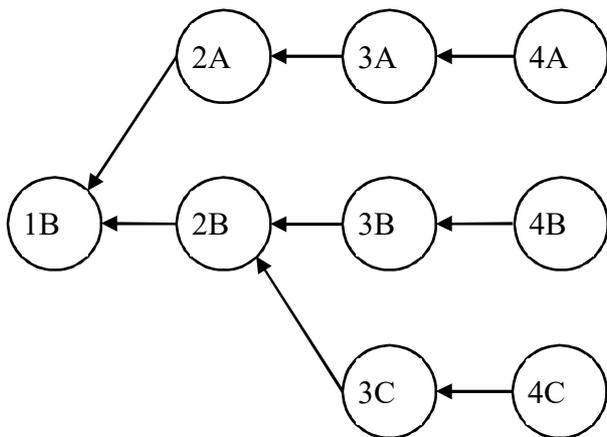


Fig. 14 The route formed when node 2C does not have a default node

TABLE II
TESTING THE ROUTING ALGORITHM WHEN THERE IS NO DEFAULT NODE
FOR NODES 4A, 4B, 4C, 3B AND 3C

Test Node	Detected Nodes		Selected Node	Time (seconds)
	SSID	RSSI (dBm)		
4A	4B	-57	3B	9,570
	4C	-57		
	3B	-57		
	3C	-59		
	2A	-66		
	2B	-65		
	2C	-69		
	1B	-80		
4B	4A	-53	3A	8,548

	4C	-57		
	3A	-62		
	3C	-68		
	2A	-70		
	2B	-64		
	2C	-79		
	1B	-72		
	4A	-68		
	4B	-51		
	3A	-68		
	3B	-60		
4C	2A	-67	2B	8,583
	2B	-57		
	2C	-65		
	1B	-69		
	4A	-49		
	4B	-55		
	4C	-49		
	3A	-55		
3B	3C	-59	2A	8,759
	2A	-54		
	2C	-57		
	1B	-61		
	4A	-64		
	4B	-61		
	4C	-57		
	3A	-61		
3C	3B	-53	2B	8,529
	2A	-62		
	2B	-60		
	1B	-65		

From Table II it can be seen that the test results show that the selected node is always the node with the strongest signal strength and is located closer to the sink node than the location of the node being tested, with the average time needed to carry out the node selection process until it is connected to the selected node, namely 9.968 seconds.

IV. CONCLUSION

This research was conducted to analyze environmental variables in a room, including temperature and humidity, using a wireless device with a Wireless Sensor Network configuration. The performance of the WSN node as a monitoring device for room conditions which includes temperature and humidity has been successfully created using a temperature sensor, humidity sensor, signal conditioning circuit, a microcontroller programmed according to the design that has been made. DHT21 temperature and humidity sensor testing works well for measuring room temperature and humidity, according to the DHT21 sensor datasheet, the temperature range is 15°C-90°C, minimum humidity 20% RH and maximum 90% RH. The default node of the sensor node being tested has the average time needed to carry out the node selection process until it is connected to the selected node, i.e., 9.068 seconds. The node with the strongest signal strength that is located closer to the sink node than the location of the

node being tested has the average time needed to carry out the node selection process until it is connected to the selected node, namely 9.968 seconds.

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