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WSN nodes power consumption using multihop routing protocol for illegal cutting forest

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ABSTRACT

The need for an automation system from a remote area cannot be separated from the role of the wireless sensor network. However, the battery consumption is still a problem that influences the lifetime of the system. This research focused on studying how to characterize the power consumption on each sensor node using multihop routing protocol in the illegal logging field, to get the prediction lifetime of the network. The system is designed by using six sensor nodes in a master-slave connection and implemented in a tree topology. Each sensor node is consisting of a sound sensor, vibration sensor, Xbee communication, current and voltage sensor, and Arduino nano. The system is tested using battery 10050 mAH with several scenarios to have calculated how long the battery lifetime can be predicted. The results stated that the master node on the network depleted the power of the battery faster than the slave node since the more slaves connected to the master, the more energy the battery consumes.

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1. INTRODUCTION

Wireless sensor networks (WSN) is a technology that becomes an interesting focus of research in recent years. WSN is a network consisting of many sensor nodes to make direct observations of the environment, in the form of physical phenomena such as sensing, storing, processing, and communicating or collecting data [1]. Some applications that have implemented the WSN technology, placing many sensor nodes that can be found in places that are fixed and predetermined, or even place sensors that are distributed randomly in a very wide geographical observation area [2].

On one node sensors as micro-electro-mechanical systems (MEMS) technology shows in Figure 1, the nodes are consisting of sensing, processing, communication and power units [3]. The sensing subsystem represented to any types of sensors depends on the application. The computing subsystem represented by a collection of the processor that used to compute and process the sense from the sensors. The communication system is the tool that carried out to do communication between sensor nodes through a wireless network. The power subsystem is the tools as a battery that used to give the energy to the system. Based on Figure 1, some parameters must be considered such as position, distance, power consumption in each node and the communication technology between sensor nodes has an unavoidable impact on the network performance [4]. Unfortunately, there are still limitations of WSN. Some challenges such as designing low-power networks, data security, and network architecture have been a concern for researchers in recent years. But, the power consumption due to the limited amount of energy available on the sensor node is one of the most common problems in WSN [5]. Each sensor node is battery operated and has a limited amount of energy. Although there are already has several technologies such as using a solar cell, it still affects the performance of the system and cost application [6–8].

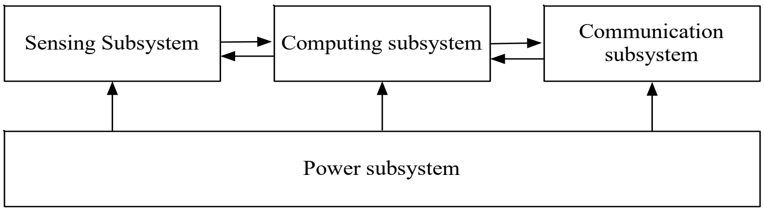

Figure 1. The architecture of sensing node

An application that is used and implemented a WSN in years requires a good battery sensor node that supports the network lifetime because it is very crucial for the life of the application. Usually, the consumption of battery usage on sensor nodes occurs in just a matter of hours without a recharge. Therefore, every researcher who uses WSN in the application must considering to the consumption of batteries and adopt the best technique to reduce power consumption as much as possible, by learning the characteristic of the power consumption and evaluating it due to estimated lifetime application, monitoring time to replace batteries on sensor nodes so that the network is always active and can predictable wireless sensor network life before be doing the network installation.

The energy on a WSN network is used depending on many factors including architecture and network protocols, initiation of data collection, network lifetime, channel characteristic, and energy consumption model [9, 10], also energy efficiency using clustering systems [11] and fuzzy logic in segmentation network [12]. One of the best ways to evaluate power consumption is doing the test on the physical hardware directly, by periodically measuring the remaining batteries, which measures power consumption by using traditional measurement using oscilloscope on one node [13]. Besides, there are also another ways to measure battery capacity by using different operating systems in each node to analyze and compare the consumption of lower current from the sensor nodes during the implementation of an application that runs on different platform operating systems [14] while other studies evaluated the power consumption of the use of POBICOS middleware platform application [15].

In addition, some researchers conduct low power consumption evaluations using modeled such as colored Petri net-CPN application [1] and mathematical queuing model to find optimal solutions to optimize the energy consumption of sensor nodes and to maximize the lifetime of the system [16]. Markovian models also conducted to predicts power consumption [17]. Other studies have been carried out to obtain low power consumption from wireless sensors and collect distributed data in monitoring environmental parameters of the production of greenhouse plants [18] and data fusion [19]. Several studies of energy-efficient also conduct in other various fields such as the telecommunication process [20] and for underwater sensors [21]. According to the similar works and previous studies about analyzing energy consumption it can be summarized that there is a lot of study and research that attempted how to reducing and analyzing energy consumptions since there are many different views in analyzing energy consumptions. The energy consumption parameter divided into several sections, as shown in Figure 2. The energy consumption can be focused on a lot of points of view. In this research, the energy consumption is focused on the hardware units in the physical layer and its topology using a multihop routing protocol [22, 23] which yields power harvesting to supervise the environment.

Meanwhile, illegal cutting is a form of logging or cutting trees without permission that is still widely practiced in the forests throughout the world, and become an issue that causes forest degradation that threatens natural life [24]. WSN is an appropriate technology that supports illegal cutting because it can place many sensors of monitoring nodes and using the multihop routing protocol to reach a large area in the forest. This research contributes to analyzing energy consumption on the sensor node in the WSN that placed to monitor the occurrence of illegal logging. The sensor node consists of a microprocessor, XBee Pro 2C, sound sensor, and vibration sensor. The network consists of six nodes that are attached to a hierarchy in the form of a network topology tree model. Each sensor node forms a master and slave network connection on the WSN. The multihop routing protocol used to reach a large forest area. Energy consumption in the sensor node will be analyzed by approaching the OSI network reference model as an individual constituent at the level of energy consumption at the hardware units per nodes so that it can provide predictive information to implement various algorithms and modeling energy consumption reduction.

This research describes the introduction to chapter one. The next chapter continues regarding research methodology, which covers the basis of literature review, design system, and network modeling. The third chapter determines the test scenario for the sensor node that will be examined for the battery as a network lifetime. Chapter four will be described as a conclusion of the proposed system based on the resulting test.

2. RESEARCH METHOD

The methodology used to be able to complete this research is conducting a literature study to define the basis of the study and comparing the previous research and find similar research. The next step is designing the architecture of the multihop routing protocol network, determining the network hierarchy such as topology, master and slave relationships, number of masters and number of slaves, and what parameters will be analyzed for energy consumption. The next step is doing the experiment on each sensor node and analyzed it, the last part of this paper is represented as a conclusion of the research.

2.1. Study literature

Studying literature studies is an activity that carried out to obtain material and basic knowledge that will be implemented in the system, so it can make a strong basis in analyzing the energy consumption which produced by the WSN in illegal logging application. The study about energy consumption constituent like shows in Figure 2 [25]. The study conducts an energy consumption analysis of the parameters on the sensor node as a hardware unit at the physical layer of OSI and individual sensor energy constituent. The hardware unit which is used on each sensor node, including Arduino Uno, Xbee Pro 2C, gravity sensor, sound sensors, current sensor and voltage sensor that used to calculate power consumption. Besides that, this research also will examine memory usage storage and queuing retrieve data. The last parameter is analyzing the power harvesting as the constituent environment in terms of carrying out the sensing process.

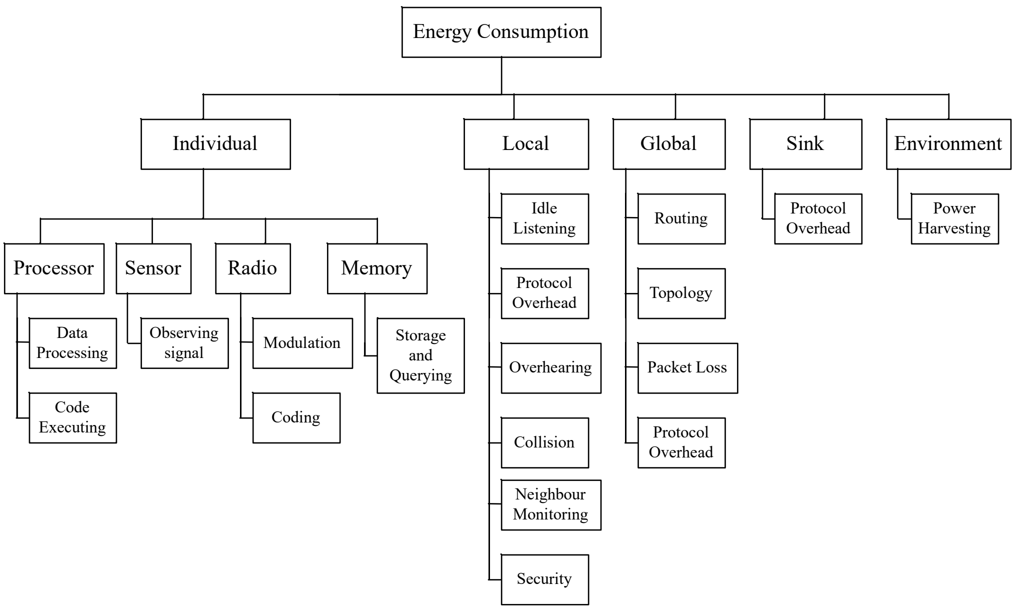

Figure 2. Energy consumption constituent

According to the energy constituent in Figure 2, frequency and the voltage are interconnected in the individual part of the hardware unit. Several things affect the energy consumption when the system is doing supervised the environment, or from the energy consumption that arises from the use of active memory to stored the bit or the energy consumption of the communication between the condition of the active state depends on the number of transmitted and received bit at each sensor node. While energy harvesting involves parameters, in cases where the sensor nodes can extract or harvest energy from the environment, this parameter will be determining the age of the WSN application. Environmental constituent as a sense of component that has positive energy can be formulated as follows:

$$E_{battery}, i\ \Delta t = -H_i\ (t) \quad (1)$$

where Hi(t) is the amount of harvested energy at time t by node i. Calculate energy in transmitting and receiving as one bit is formulated:

$$\text{Energy} = \text{Current} * \text{Voltage} * \text{Time} \quad (2)$$

where current is in ampere, voltage is in volts and time is in second. All the formula is needed to calculate the energy on each sensor node. The energy will be calculated based on the time when the system is running.

2.2. Proposed architecture

WSN was selected for illegal logging applications because it has been mainly used for identification, detection, monitoring application [26] as moving detection or event detection (ED) or tracking system [23, 27–29]. WSN is a suitable technology for an outdoor area in a wide area supervised, can implement more than a hundred sensors in the environment that has mostly be inaccessible by the human and has a long duration of supervision for years. Figure 3 shows the design of each sensor node, which is consists of two sensors of vibration sensor and sound sensor, an Xbee Pro2C, an Arduino Nano, and a current and voltage sensor. The sensors are conducting to sense the sound of the chainsaw and the vibration from the log when the logging occurs. While the Arduino Nano is using to calculate and processing the sensing, the Xbee Pro 2C conducts a communication signal between sensor nodes and the current and voltage sensor is conducting to measure the current and voltage that consumed by the sensor node.

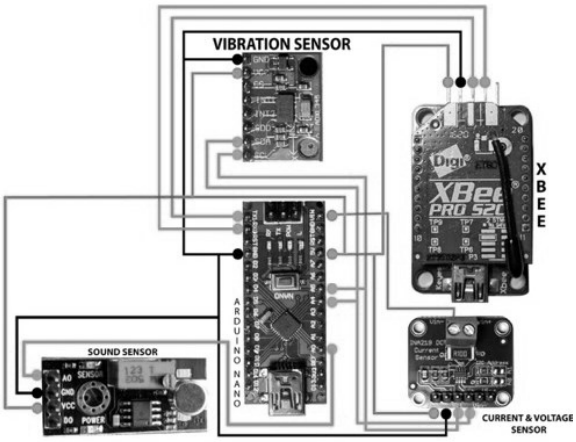

Figure 3. Sensor node design

This research designed six sensor nodes that are hierarchical tree topology as master and slave relationships. The WSN tree topology and the sensor nodes are mapping, as shown in Figure 4. A multihop routing protocol used to support the communication between nodes. The network is divided into two subnetworks, namely Net X and Net Y. In each subnetwork, three sensor nodes are mapping as one master and two slaves. Each subnetwork has a different ID that will be used for tracking applications.

After considering the architecture of the sensor nodes and the topology, the next step is conducting the diagram state of the system while the Xbee Pro 2C is doing sensing the environment. The diagram state shows in Figure 5. The state of the transition diagram consists of awake process, sensing proses, communication process (receiving, transmitting) and the processing process of the processor. The systems state switching consists of receiving, transmitting, processing, and sensing. While in the task transmission state, the awake and sleep state is including in the system. There is also the state switching that running to the same state in the next second, that is triggered in receiving, processing and sensing state in order to supervise the environment continuously.

The diagram systems state will be combined with the work of the system to supervise the illegal cutting activity. The workflow of the system can be seen in Figure 6. When the system is in ON condition, the sensing node starts to supervise and awake the sensor to sniff the environment. The sensor in slave sensor nodes begins awake then doing sensing, processing, receiving and transmitting the data to the master. The sensor node communicated with the master to report the supervised area, alternately. When one slave node does transmit the data to the master, the other slave sensor nodes are in idle radio state. Idle processor and the idle sensor are used when the sensor nodes is not doing sensing and process the data. All the transmitting, receiving, processing and sensing is recorded in the memory every 5 minutes. The system will be running continuously until the system is shutting down.

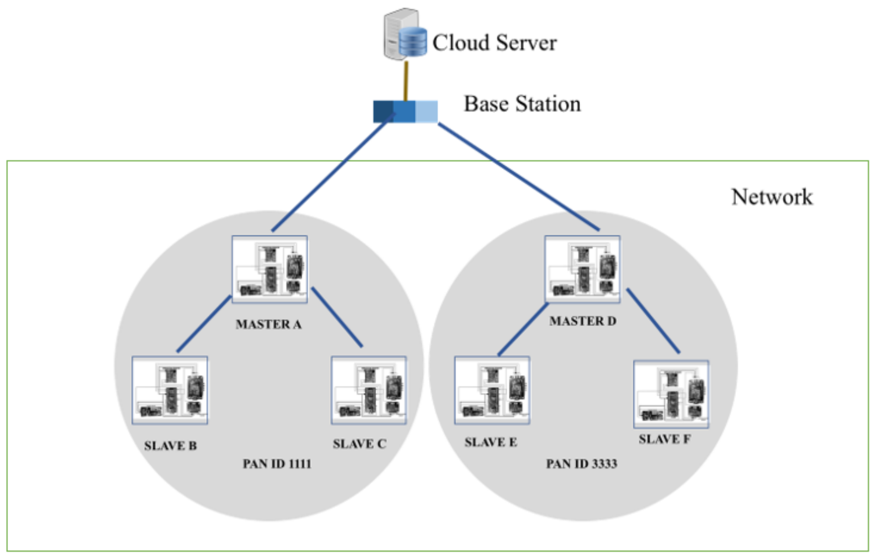

Figure 4. Tree topology network design

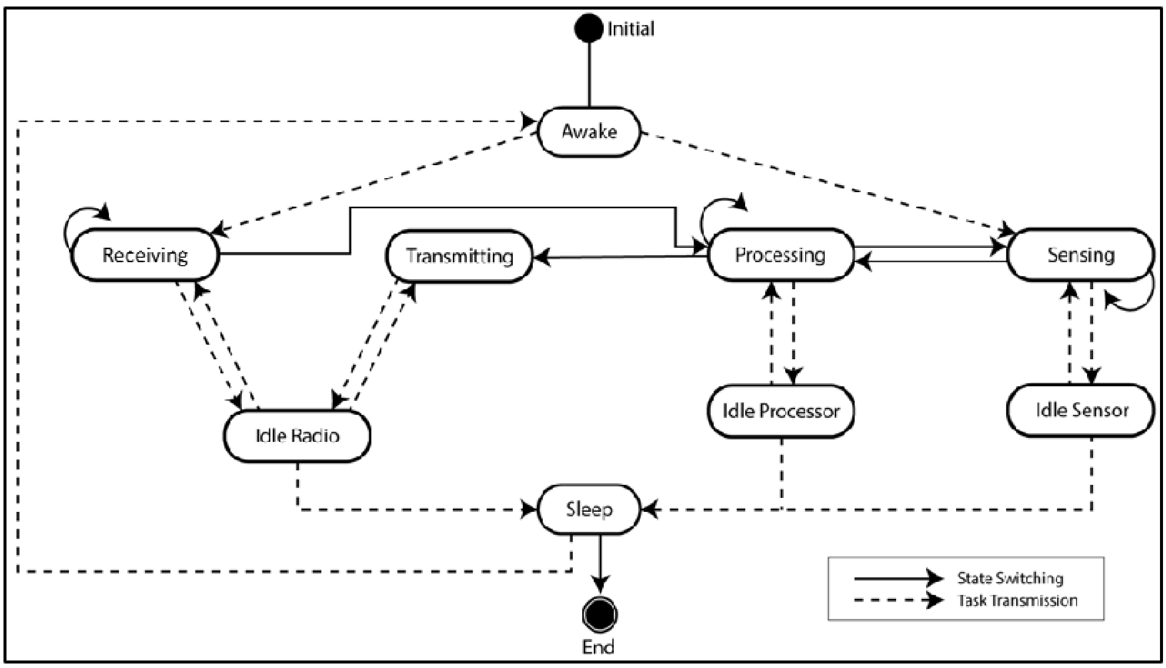

Figure 5. Diagram state supervised system

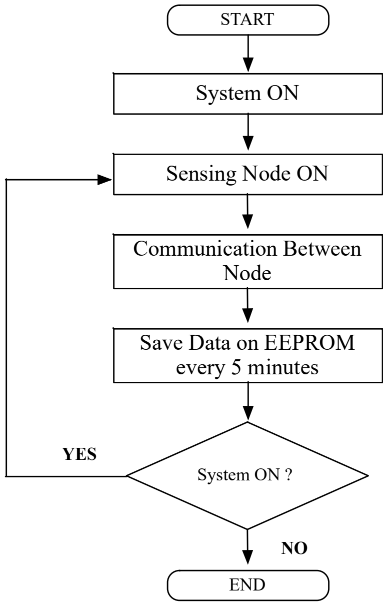

Figure 6. Diagram flow of the system

3. TESTING, RESULT AND DISCUSSION

After conducting a literature study and design the proposed network, a battery resistance test will be carried out in this research. The testing conducts in several scenarios. The first scenario is to test the power consumption in each sensor node and find the trend and characteristic of the use of the battery using extrapolation data [30]. The next scenario is conducting the battery endurance at each node during process sense, as seen in Figure 6. Battery resistance is calculated against time in minutes unit against voltage and power consumption. The result tests are represented in the form of battery resistance extrapolation tables and graphs so that it can predict the lifetime of the network.

The third scenario is conducting measures of the use of memory in the processor. This scenario is intended to measure the usage of EEPROM on the application during the occurrence of sensing by iterating a program as an operating system where the data sensing is stored. Other parameters testing that involves in this research such as distance sensing, distance position between nodes, performance system is not discussed because they have been published in the previous studies which are focused on the performance system [31, 32].

3.1. Power consumption characteristics

Due to the limitations of hardware testing, since the available hardware only has six sensor nodes, the power consumption testing is conducting with a topology tree structure. The system using a new battery with capacity 10050 mAh per battery in each sensor node. The system is connected to a voltage of 5.38 volts. The testing result is shown in Table 1. The battery endurance testing is conducting in a topology tree, shows in Figure 4. The trend of the battery endurance (BE) against power is measuring base on time in unit minutes in order to have an extrapolation graph of each sensor node. The trend column captured every 5 minutes for two hours to have a formula that is affected by lifetime battery.

Table 1. Battery performance testing

Sensor Node	Current (A)	Power (W)	Trend BE Against Power (Minutes)
Master A with 2 slaves	0.038944	0.20	455.9343024
B slave	0.040452	0.21	1086.517917
C slave	0.04044	0.21	1426.247890
Master D with 2 slaves	0.0398268	0.20	906.868064
E slave	0.0400724	0.21	1386.410712
F slave	0.040452	0.21	1170.154334

The graph of power versus the trend of the battery endurance at each sensor node is shown in Figure 7. The different trends at each node determined the lifetime of every battery in each sensor node.

The graph can read the use of power consumption at each node. The master node and slave node showed a significant difference because the master communicates with two slaves; the energy consumption in the master node is greater than the energy consumption at the slave node. According to the trend axis, it can be concluded that the master requires power consumption of more than 2.5 times the power consumption on the slave node. It is also because of the process of the transmitting, processing, receiving and sensing in the master nodes, and the master nodes also doing sensing the environment.

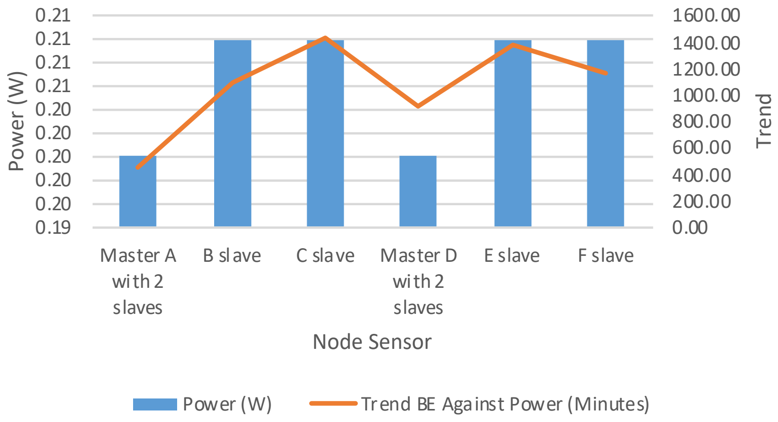

Figure 7. Power versus trend graph

3.2. Battery lifetime

This scenario is conducting the battery lifetime at each sensor node during process sensing. The battery lifetime is calculated against time in every five minutes unit against voltage and power consumption using the formulation (1) and (2). The result calculation of the testing can be seen in Table 2, and the chart of the battery lifetime can be seen in Figure 8. According to the result in the Table 2, the sensor node of Master A that has two slaves will immediately be OFF conditioned within 22.52875 hours, followed by the sensor node of Master D which also has two slaves in 44.81041 hours. The sensor node slave B follows with a lifetime battery of 53.68731 hours and sensor node slave F at 57.81998 hours. Then, sensor node E slave will OFF at 68.50570 hours and sensor node C slave as the longest lifetime battery will OFF in 70.47414 hours.

Table 2. Battery lifetime

Sensor Node	Current (A)	Power (W)	Trend BE Against Power (Minutes)	Battery Lifetime (hour)
Master A with 2 slaves	0.038944	0.20	455.9343024	22.52875
B slave	0.040452	0.21	1086.517917	53.68731
C slave	0.04044	0.21	1426.247890	70.47414
Master D with 2 slaves	0.0398268	0.20	906.868064	44.81041
E slave	0.0400724	0.21	1386.410712	68.50570
F slave	0.040452	0.21	1170.154334	57.81998

3.3. Memory capacity testing

This system is designed with the default of all nodes just to be turned ON. The data is automatically saved to EEPROM. The memory capacity is 512 bytes. Awake process, sensing process, communication process, and processing system are carried out every 300000 ms or equal with 5 minutes. One data stored in the EEPROM requires four spaces of 8 bit for each space. It is equal to 32 bits per activity. All the data on EEPROM will be overwritten after 128 iterations of the program. EEPROM usage can be seen in Figure 9. Memory usage on the chart is the memory usage of two hours when running the system for monitoring and its equal with 50% of the memory usage, while 13% is used for other data, such as operating system programs that stored in the memory to run the system. In the two hours running system, there are still 37% spaces is still empty and can use for other program or continuing the running system.

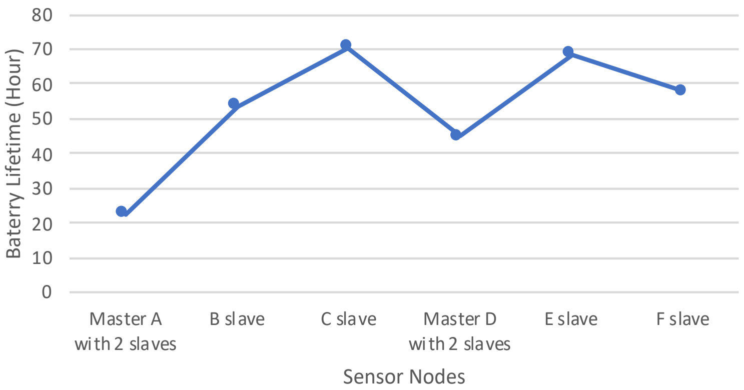

Figure 8. Battery lifetime graph

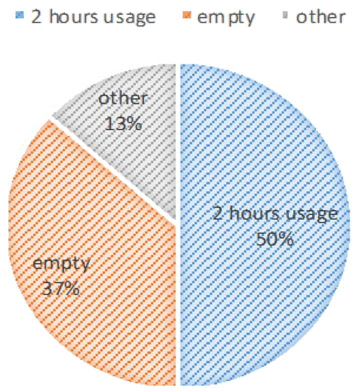

Figure 9. EEPROM usage of the testing system

4. CONCLUSION

WSN implementation on illegal logging applications can be done by placing the sensors to supervised the environment such as sound sensors, gravity sensors or vibration sensors that can detect illegal cutting in the forest. In this research, the multihop routing protocol is implemented in the tree topology and focused on obtaining the characteristics of the battery used as a power consumption system on each sensor node with a master and slave relationship. Two subnetworks contained two masters, and four slaves were applied. With such implemented networks, the master and slave relationships in the topology tree cause the power of the battery on the master position depleted faster. This is due to the communication carried out by the master heavier than the slaves, besides doing sense, the more slaves connected to the master, the more energy the battery consumes, which can expedite the energy depletion of the master. Based on this condition, it can be sure the implementation of the star topology network in the WSN application will also produce unbalanced battery performance because a master was connected with a lot of slaves and the battery power on the master will increase depletion quickly. Therefore, it is recommended that researchers who will conduct applications using WSN considering the use of the topology that will be applied to the application. According to the characteristic of power consumption in illegal cutting trees, the battery life of each sensor also can be determined. So that, power consumption and battery lifetime can be predicted in each node and also can inform the decision to maintain and monitor the battery, remotely. For future work, the application of ring topology and bus topology will be an advantage. By implementing the master replacement algorithm alternately between the sensor node can handle the power consumption eventually distributed on each sensor node. In addition, the use of communication media between nodes and sensor selection to supervise the environment also affects battery life.

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