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Energy Efficiency using Data Filtering Approach on Agricultural Wireless Sensor Network

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ABSTRACT

The deployment of Wireless Sensor Network (WSN) Nodes in harsh environments with a lack of energy infrastructure brings some challenges to its design. The battery-powered sensor nodes are typically used in the WSN systems. However, the battery has limitations regarding its lifetime; furthermore, certain techniques are required to improve the battery's lifetime. This paper presents two data filtering approaches to improve energy efficiency on the agricultural wireless sensor network. The first approach is the simple moving average (SMA) that performs filtering on a sensor node with more than one sensor device attached. The second one is based on Threshold Sensitive Energy Efficiency Sensor Network (TEEN) protocol for nodes with only one sensor device attached. Evaluation of the results shows that the two proposed approaches are able to improve the energy efficiency of the agricultural wireless sensor network significantly. Moreover, in the SMA, the level of data accuracy is still high. While in the TEEN approach with hard threshold (ht)=0 and soft threshold (st)=1, the duplicate unsent data is still possible to be predicted on the sink side, if the soft threshold value is greater than 1, the sensor nodes should be in the reactive mode and will only send data when the two sensed data differ.

Keywords: *Agriculture monitoring, WSN, Energy Efficiency, Moving Average, TEEN Algorithm, Data Filtering.*

1. INTRODUCTION

Today, a wireless sensor network (WSN) system is one of the important technologies used to support precision agriculture. The WSN system consists of a number of sensor nodes distributed over the agricultural area to observe the conditions of the field such as temperature and air humidity, soil humidity and pH, leaf wetness, and sunlight intensity. Because the sensor nodes are generally deployed in harsh environments with a limited or unavailable electricity infrastructure such as in remote agriculture farms, the energy source for the sensor nodes typically uses batteries [1][2][3]. Figure 1 shows an example of our sensor nodes with battery power deployed in the paddy field of Gowa regency, Indonesia [4].

Although easy to use as the energy source of the sensor nodes, a battery has limitations on its lifetime. It still requires certain techniques to improve its lifetime, such as the reduction of unnecessary node components, the use low power devices (e.g. low power sensors and communication modules), and the application of some techniques or algorithms to minimize the number of communication activities, including the design of low power communication protocols [5].

Fig. 1. A Battery Powered Sensor Node For Agriculture Monitoring System

According to [6] and [7], the data communication on the sensor networks is a responsible aspect of the energy consumption when compared to sensing and data processing activities. Thus, by reducing the amount of the data communication, the energy consumption of the WSN can be reduced, which in turn has an effect on the longer battery life of the sensor node. As proposed in [8], the Threshold Sensitive Energy Efficient Sensor Network protocol (TEEN) algorithm for energy efficiency of sensor nodes, as well as the use of clustering strategy algorithms [9][10] and a technique to aggregate the data sensor in column-oriented databases [11] can be used. The studies were efforts to improve the energy efficiency through energy-efficient communication protocol mechanisms and data processing. However, several of the techniques are not fully applicable in the sensor network for the agricultural monitoring systems. This paper presents data filtering approaches in accordance with the characteristics of agricultural monitoring systems that are built to improve the efficiency of energy consumption of the sensor node battery. The filtering techniques used in this paper are based on simple moving average (SMA) and the TEEN algorithm.

2. MATERIAL AND METHOD

This section describes the agricultural WSN setup including hardware and software specifications and the filtering approaches that we study.

2.1 Agricultural WSN Setup

The WSN architecture used in this paper has been adapted to the paddy fields of Gowa regency, Indonesia. The system consists of 10 sensor nodes (labeled as SN1 to SN10) that are distributed on the field. Each node is placed in an area of about $1225M^2$. The sensor nodes are equipped with three sensors: temperature, humidity, and soil moisture. 7 nodes (SN1, SN2, SN3, SN6, SN7, SN9, and SN10) serve as sensor nodes, and 3 nodes (SN4, SN5, and SN8) serve as repeater nodes. Sensor node (SN10) in this system is designed to only have a soil humidity sensor. Figure 2 shows the architecture of the system, which we study in this work.

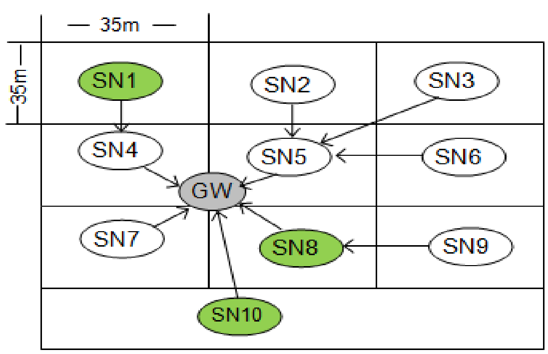


Fig. 2. Agricultural WSN Architecture

To evaluate the filtering scheme, we employ three types of nodes (SN1, SN8, and SN10) on the agricultural monitoring system: sensor nodes (SN1 and SN10), repeater (SN8), and a sink/PC Basestation (GW). The sensor nodes with sensor devices attached will perform several activities such as sensing, data filtering, and sending data to the sink. Repeater nodes provide a multihop mechanism on the network; it will forward data from one node to another one or to sink. The sink node/PC base station collects data from all sensor nodes and stores them or sends the data to the Internet. Sensor nodes in this paper are composed of an Arduino platform as the main board, DHT11 as a temperature and air humidity sensor device, a soil humidity sensor, NRFL2401 communication modules, and a battery. Figure 3 presents the platform for the sensor and Table 1 shows the hardware and software used in this study.

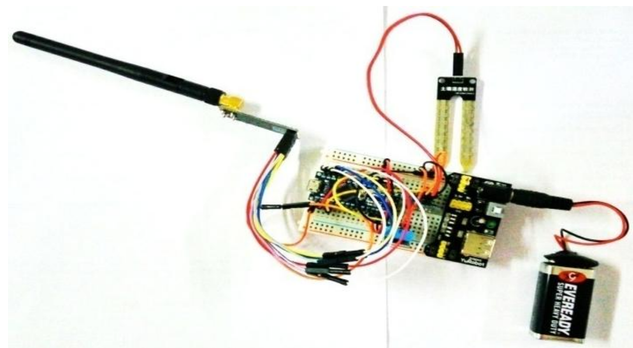


Fig. 3. The Prototype of Sensor Node With 3 Sensors Attached

TableA 1: Hardware and Software Requirements

No	Hardware	Software
1	Arduino Nano	Arduino vers. 1.6.12
2	nRF24L01	
3	DHT11 (Temp & Humid)	DHT Library
4	Soil Sensor Hygrometer	
5	Battery 9V/Li-Ion 3.7V	

2.2 Data Filtering Approach

We apply two filtering schemes for the agricultural wireless sensor network system. The first scheme is simple moving average filtering (SMA), and the second one is based on the TEEN algorithm.

1) Simple Moving Average (SMA) scheme

SMA technique is employed on the sensor nodes that have more than one sensor attached. The technique is commonly used in mathematics or economics to calculate the mean of a dataset or time series. The basic principles of the SMA in this paper are shown in the following formula:

$$M_t = \frac{Yt + Y_{t-1} + Y_{t-2} + ... + Y_{t-n+1}}{n}$$

Where:

Mt = Moving average of t period

Yt = Real value of t period

n = Number of limits in moving average

To perform the SMA technique, firstly, the node initializes n variable, which is used as an index and m variable as the data limit. Then, the node senses the condition of agriculture field (eg. temperature, air humidity, and soil humidity) and stores them in the local buffer of the node. The activity will be repeated m times (e.g. m=10). It then calculates the stored sensed data by doing the SMA formula, and finally sends the average data to the network or sink. Figure 4 shows the SMA mechanism for our sensor nodes.

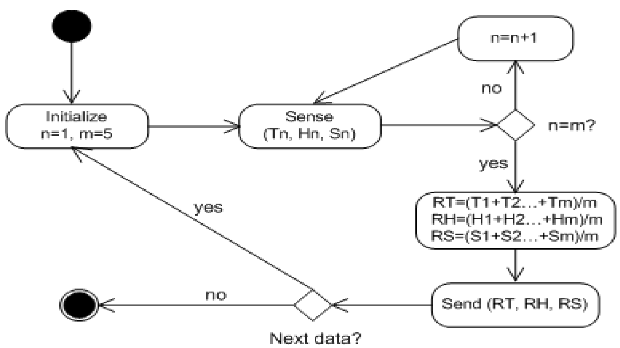


Fig. 4. The SMA Activity Diagram on Sensor Nodes

The application of the SMA is done through two scenarios: In the first scenario, the SMA is placed at each sensor node, while the second is placed on the router/repeater nodes. In the second scenario, any data coming from the sensor nodes will be stored in the local buffer of the repeater, and then the node calculates the average data and sends the average result of each sensor node to the sink. To avoid the decreasing of sensing data, the repeaters in this scheme only perform data processing from the same sensor node without combining or aggregating the sensed data from different sensor nodes.

2) TEEN Algorithm Based Filtering Scheme

In our agricultural WSN system, we employ a sensor node with only one sensor device attached. The node is intended to monitor the presence of water in the soil or to measure the water level in agricultural irrigation. The filtering scheme for this type of sensor node is based on the basic principle of the Threshold sensitive Energy Efficient sensor network protocol (TEEN) [4]. The TEEN is a reactive sensor network algorithm dedicated to real-time computing or time-critical applications. We use the algorithm to avoid the duplication of the data transmission to the sink node. Although sensing is done continuously, the transmission activities that consume more energy can be minimized [8] [12]. In the TEEN algorithm, two variables are used to control the delivery process: hard (ht) and soft threshold (st). A hard threshold is the value of the sensing attribute and the soft threshold is a small change of the sensing value. Figure 5 shows the basic concept of the TEEN algorithm that we modified in this work.

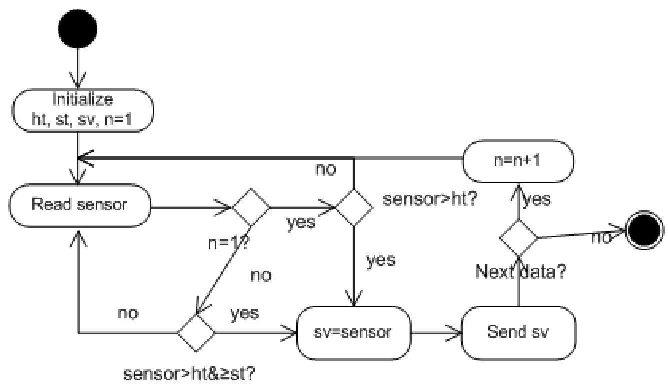


Fig. 5. Basic Principles of TEEN algorithm used in this research [8]

3. RESULTS AND DISCUSSION

3.1 Filtering with SMA Mechanism

To determine the effect of energy efficiency, the battery power parameters of sensor nodes such as voltage drop (Volt) and its current (mA) are quantified during evaluation. In our measurement results, the trend of the voltage drop and the battery energy consumption of sensor node with the SMA mechanism tend to be lower than without SMA. For example with SMA, after the node sent 5 sets of data, the battery voltage dropped is 1 Volt, and its energy consumption was 0.066 Watts. Without SMA, the voltage drop is 1.4 Volt, and its energy consumption is 0.094 Watt. Similarly, after the sensor node was sensed and sent 30 sets of data to the sink, the voltage drop of the battery with SMA was 1.7 Volt and its energy consumption was 0.113 Watts. Otherwise, without SMA, the voltage drop was 8.5 Volts and its energy consumption was 0.563 Watts. The energy consumption rate with SMA was 0.05 Watts and without SMA was 5.83 Watts. This evaluation shows that the use of the SMA approach on the sensor node is able to increase the energy efficiency significantly. The trend of the voltage and energy discharge rate is presented in Figure 6.

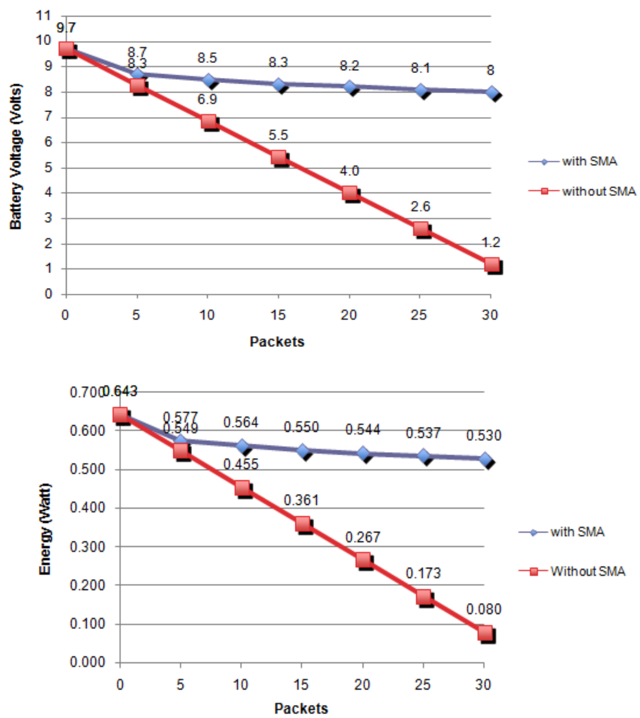


Fig. 6. Battery Voltages and Energy Discharge Rate With and Without SMA on Sensor Node

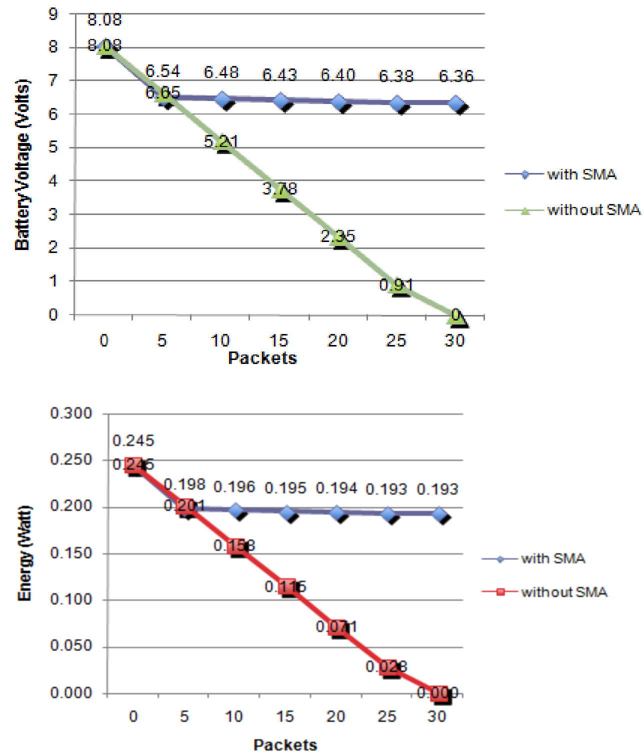


Fig. 7. Battery Voltages and Energy Discharge Rate With and Without SMA on Router Node

On the router node, evaluation results show that after the node sent 10 SMA of data to the sink, the voltage drop of the battery was 1.6 Volts and the battery consumption was 0.049 Watts, and without SMA, the voltage drop was 2.87 Volts and energy consumption was 0.087. After 30 sets of data without SMA were sent, the battery could not be used to power the node due to the lack of battery voltage. The results of the second scenario show us that the voltage drop and energy consumption of the router node with SMA tend to be smaller than without SMA. Figure 7 presents the trend of battery voltage and the energy discharge rate of the router node.

In this evaluation, we also know that the data accuracy level using the SMA filtering mechanism is still high. The results of soil moisture sensing using SMA with m = 5 and m=10 are acceptable, which means the SMA calculation results are still present with a value of 300. Both data show that the soil is monitored under watery conditions. Figure 8 presents the trend of the soil moisture with and without SMA.

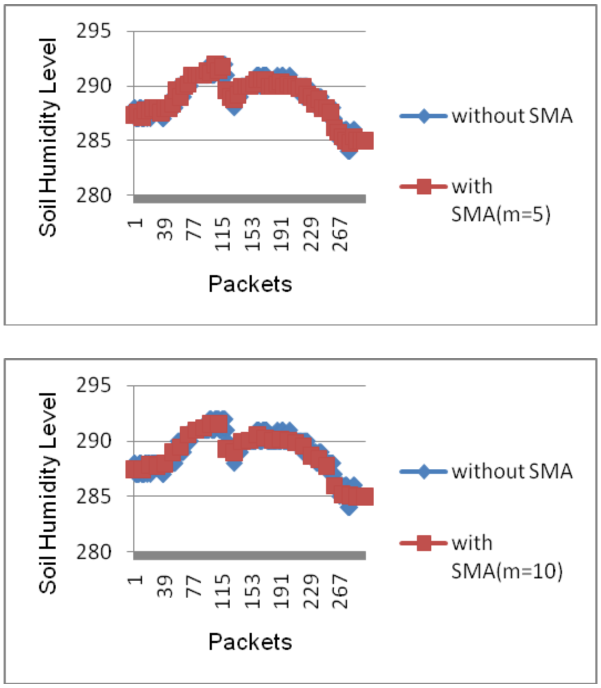
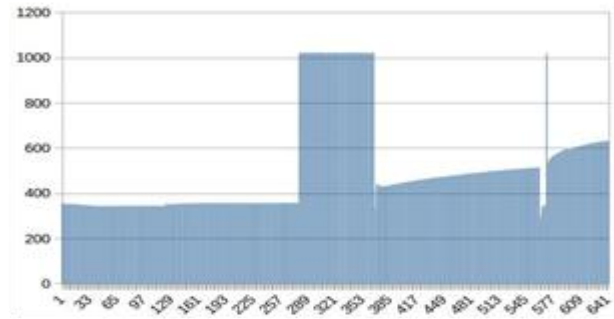


Fig. 8. Soil moisture sensing data with (with m = 5 and m=10) and without SMA

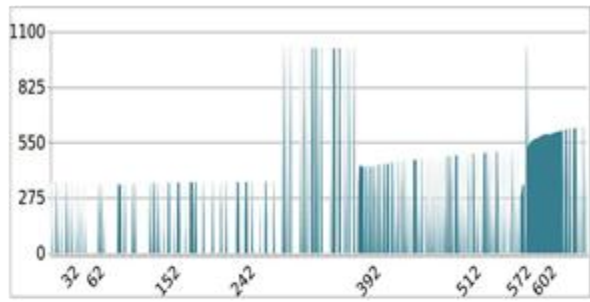
3.2 Filtering with TEEN Algorithm

In the first evaluation, without TEEN, 641 data packets are successfully sent from the sensor node to the sink, while using TEEN (with ht = 0 and st = 1), the sensor node sent 293 data packets to the sink. There are 349 sets of data not sent by the sensor node because they were detected as duplicates from previously sensed data. This result makes our sensor node save about 22789 mA. Moreover, even though the node does not send any duplicate data to the sink, it is possible for us to predict the unsent data from the previously received data. In the second evaluation, we modify the value of ht = 50, and the deviation value st = 2, which indicates two sensor nodes sent 71 data packets. However, without TEEN, the nodes sent 4000 data packets. The reduction of the packet numbers sent is acceptable due to the agricultural field conditions such soil conditions or irrigation that do not change drastically. But, the unsent data is not possible to predict in the sink side. The value of ht and st in this configuration will be very suitable for the reactive node where only sends data (or notification) if two sensed data packets differ significantly.

From the evaluations, we know that the use of the TEEN algorithm in the sensor node is important to improve the energy efficiency. Figure 9 shows the received soil moisture data on the sink with and without the TEEN algorithm.



(a) Soil moisture sensed data without TEEN



(b) Soil moisture sensed data with TEEN

Fig. 9. Soil moisture sensed data without TEEN (a) and with TEEN (ht = 0 st = 1) (b).

4. CONCLUSIONS

In this paper, we have implemented two filtering approaches for energy efficiency on the agricultural wireless sensor network. The first approach is the simple moving average that performs filtering on a sensor node with more than one sensor device attached. The second one is the TEEN based algorithm for nodes with only one sensor device attached. Evaluation results present the two approaches are able to improve the energy efficiency of the agricultural wireless sensor network significantly. In the SMA, the level of data accuracy is still high. While in the TEEN scheme with ht=0 and st=1, the duplicate unsent data is still possible to be predicted on the sink side, but if the deviation value (st) is more than 1, the sensor nodes should be the reactive mode that only sends data when the two sensed data packets differ. For future work, we consider applying an algorithm to validate and predict the sensor values on the sink side, especially to analyze and predict unsent data when the sensor nodes using the TEEN algorithm.

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