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OPTIMIZATION OF ENERGY CONSUMPTION IN SENSOR NODE BASED ON RECEIVED SIGNAL STRENGTH INDICATOR (RSSI) AND SLEEP AWAKE METHOD

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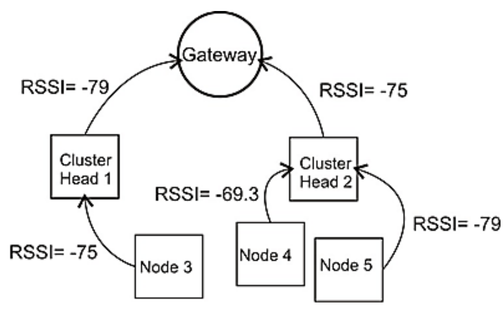
Graphical abstract



Abstract

The transmission power management in Wireless Sensor Networks (WSN) is a critical problem. This research investigated optimizing power consumption based on transmission power (Tx Power) level according to RSSI and periodic transmission time. We investigated the RSSI value by varying Tx Power Level to get the optimum Tx Power Level. We found the optimum periodic transmission time by transmitting the data with various transmission times. By varying the Tx Power Level, we found the optimum Tx Power Level, resulting in the power consumption decreasing by about 42% and the power supply's lifetime increasing by about 71% in the 280 m distance between the sensor node and gateway, with a 108 Wh power supply. By varying the periodic transmission time, we found that the optimum periodic transmission time is 8 seconds. Combining the optimum Tx Power Level and periodic transmission time, we found that the power supply's lifetime is 40 times longer. This result is helpful for WSN applications in remote areas.

Keywords: Wireless Sensor Network, Tx Power, RSSI, Sensor Node

1.0 INTRODUCTION

Recently, there have been many reports about the application of Wireless Sensor Networks (WSN) in remote area applications such as small windmills [1], [2], ecologist purposes [3], [4], [5], water quality [6], [7], [8], disaster management [9], [10], and intelligent home [11]. In this issue, limited energy resource becomes a problem in making the sensor nodes work. Some researchers have published the results to overcome the energy limit in the sensor node; for example, Hayfa et al. employed IEEE 802.15.4 for the analysis of low-power and Low Rate Rate Wireless Personal Area Networks (LRWPANs). The other work on energy saving is the simulation of an algorithm to reduce consumed energy by nodes [12]. Srbinovska et al. investigated battery lifetime by managing periodical transmitting time. They used WSN for the greenhouse [13], [14], [15]. Simultaneously, Philipose and Rajesh applied WSN to the railway system. They investigated energy consumption by managing the sleep time of the sensor node [16]. Marwa et al. applied WSN for an intelligent home. Their research used WSN to cluster sensors and actuators and collect data in a central location [17]. In terms of communication quality in WSN, it is introduced Received Signal Strength Indicator (RSSI) as a parameter for the localisation-positioning of sensor nodes and deciding the direction of the node to send the data [18], [19], [20]. From the above research, the RSSI value is not an indicator to decide transmission power which is usually defaulted by the processor module.

In this research, we investigated factors influencing power consumption in sensor nodes. The quality of sensor communication is defined and measured based on the value of the Received Signal Strength Indicator (RSSI). We used RSSI as an indicator when we experimented by changing the distance between the node and gateway, changing the programmable Tx Power Level, and changing the periodic transmission time using the sleep-awake method. We investigated the RSSI value in the variated distance between the sensor node and gateway from 55 to 5 meters. For each distance, we investigated the influence of the Tx Power Level on RSSI value by gradually changing the Tx Power Level from 23 as the highest level to 5 as the lowest level for each distance. In this investigation, we start the investigation of each distance by measuring the initial RSSI value with Tx Power 23. After that, we gradually decreased the

Tx Power Level until we derived the minimum Tx Power Level. The last, we investigated the influence of sleep-awake time on power consumption by analysing transmitted and received data. Finally, we plotted all data for analysing. In this experiment, we measured temperature as a sample.

2.0 METHODOLOGY

2.1 Received Signal Strength Indicator (RSSI)

RSSI is a method to measure how strongly a wireless module can receive a signal. Equation 1 is the formula to measure RSSI.

$$RSSI(d) = P_t(d_0) - P_L(d_0) - 10n_p \log_{10}(\frac{d}{d_0}) + X_\sigma \quad (1)$$

P_t is power transmission, P_L is path loss based on reference distance, and n_p is path loss depending on the transmission medium. The model of RSSI variation used a Gaussian random variable with X_σ=N $(0,\sigma^2)$. The value of n_p and σ can be tuned based on the propagation environment.

2.2 Sleep Awake Method

Due to the limited energy and typically non-rechargeable nature of sensor nodes, sleep/wake scheduling is one of the core issues in wireless sensor networks. By extending nodes' time in sleep mode while maintaining packet delivery efficiency, sleep/wake-up scheduling aims to maximize each node's lifetime while conserving energy [21]. The time schedule of the method is depicted in Figure 1.

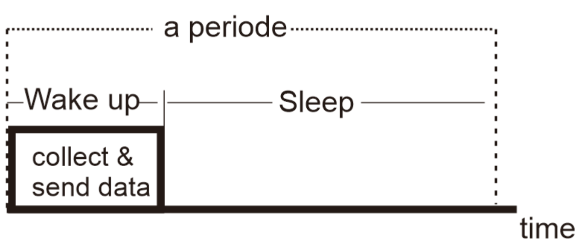


Figure 1 Sleep Awake's time diagram

2.3 Experiment Setup

In the experiment, the setting of the sensor node gateway used configuration as depicted in Figure 2.

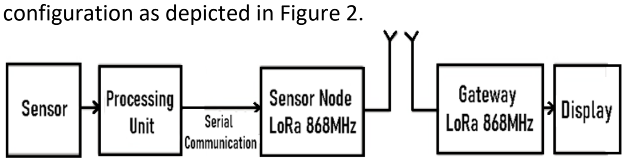


Figure 2 Block Diagram of the Experiment

As the working voltage is 5V, the current sensor INA219 is employed to measure the power consumption, as depicted in Figure 3.

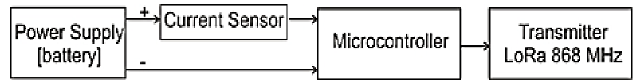


Figure 3 Deployment of the Current Sensor

After completing the power measurement system, we measured RSSI by changing the distance between the node and gateway (Figure 4). In this experiment step, we also investigated the minimum programmable power setting (Tx Power Level) by decreasing the power value (in the range from 23 to 5) until the lowest Tx Power Level, when the gateway can still receive the data. The flowchart (Figure 5) shows the procedure.

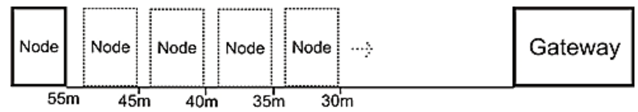


Figure 4 RSSI Measurement by Changing the Distance

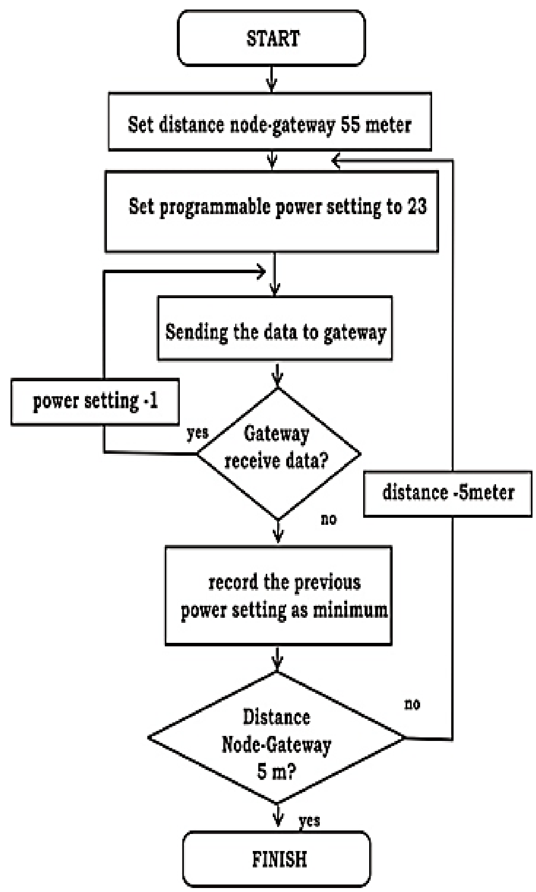


Figure 5 Flow Chart to Find Minimum Power Transmission

The last experiment addressed the periodic transmitting time (sleep-awake). In this part, as depicted in Figure 6, both data are set in the same computer so the plotting data can be analyzed.

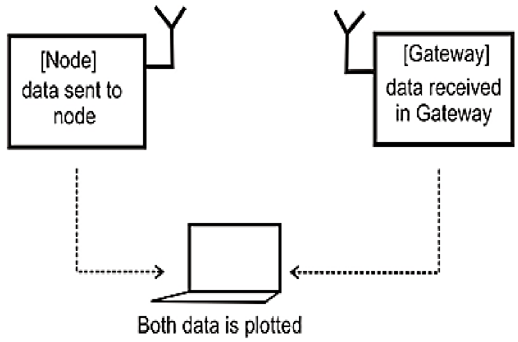


Figure 6 Sleep-Awake Experiment Setup

3.0 RESULTS AND DISCUSSION

3.1 Experiment Result

The first experiment investigated the correlation between programmable power settings and power consumption. The result is shown in Figure 7 and Table 1. It shows that the lower the value of the Tx Power Level, the lower the power consumption.

Table 1 Correlation Between Power Setting and Power Consumption

Tx Power Level	Voltage (V)	Current (mA)	Power (W)
5	4.77	62.50	0.29
6	4.77	62.50	0.31
7	4.77	67.90	0.32
8	4.77	69.80	0.33
9	4.78	72.90	0.34
10	4.79	74.69	0.35
11	4.82	77.90	0.37
12	4.82	82.90	0.39
13	4.82	86.30	0.41
14	4.80	91.90	0.44
15	4.75	97.30	0.46
16	4.67	103.80	0.48
17	4.61	116.40	0.53
18	4.59	118.80	0.54
19	4.67	126.00	0.58
20	4.55	134.20	0.61
21	4.72	140.00	0.66
22	4.50	146.50	0.65
23	4.52	149.20	0.67

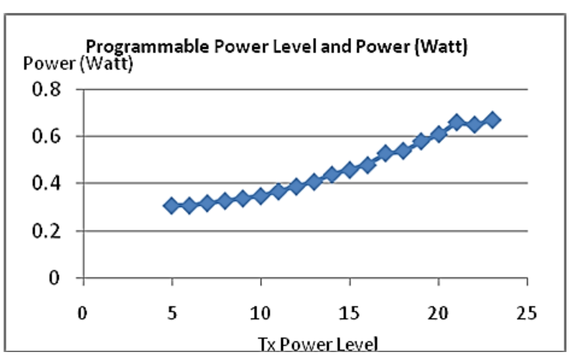


Figure 7 Power Setting and Consumed Power

We also investigated the influence of programmable power level setting (Tx Power Level) for the Received Signal Strange Indicator (RSSI) value. Figure 8 and Table 2 show the experiment result. It also shows that the pattern of RSSI value is strong while the power setting level is high.

Table 2 Correlation Between Power Setting and RSSI

Tx Power Level	RSSI			
	Trial 1	Trial 2	Trial 3	Average
24	-79	-81	-87	-82.33
23	-79	-82	-90	-83.67
22	-86	-83	-80	-83.00
21	-90	-85	-83	-86.00
20	-83	-90	-83	-85.33
19	-84	-86	-88	-86.00
18	-85	-86	-84	-85.00
17	-89	-82	-84	-85.00
16	-86	-94	-88	-89.33
15	-87	-83	-92	-87.33
14	-88	-80	-93	-87.00
13	-83	-83	-89	-85.00
12	-82	-83	-88	-84.33
11	-81	-92	-88	-87.00
10	-84	-85	-89	-86.00
9	-86	-85	-89	-86.67
8	-90	-85	-89	-88.00
7	-89	-87	-94	-90.00
6	-89	-86	-89	-88.00

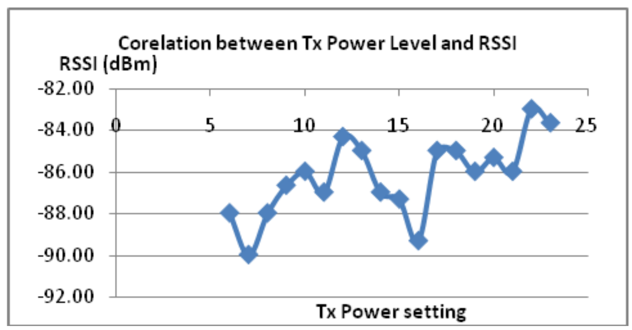


Figure 8 Power Setting and RSSI Value

Table 2 shows the measurement results to recognize the correlation between Tx Power Level and RSSI, carried out thrice for each Tx Power Level. These results show that there are different data for each Tx Power Level. In addition, the data shows fluctuation in the RSSI value, as shown in Figure 8. Those anomalies referred to the RSSI measurement phenomenon, where environmental conditions strongly influence. In addition, there is a contribution from the hardware's accuracy in responding to the change of Tx Power Level through the software's programmatic instruction.

The distance between a node (transmitter) and gateway (receiver) was also varied to investigate the changing of RSSI. Figure 9 and Table 3 show their correlation. In the research of WSN, although the data shows the node's position to the gateway is like a straight line, it can still be used as an indicator for the routing in WSN with a considerable number of nodes.

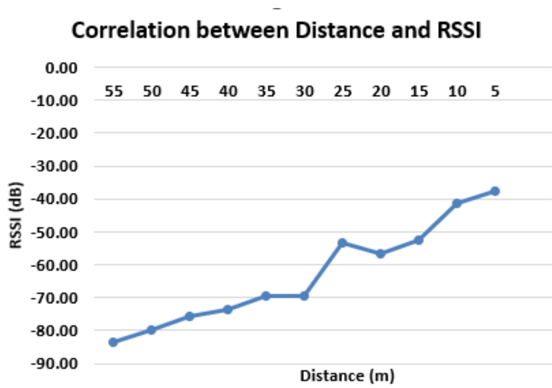


Figure 9 Distance and RSSI

Table 3 Correlation Between Distance and RSSI

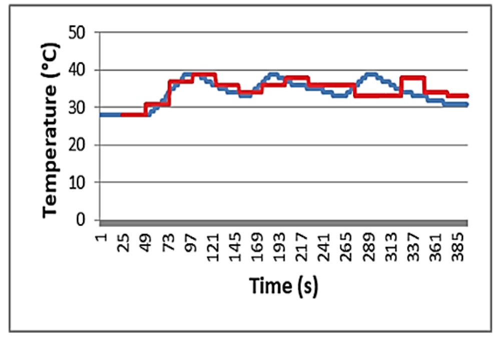
Distance (m)	Tx Power Level	RSSI (dBm)			
		Trial 1	Trial 2	Trial 3	Average
55	23	-79	-82	-90	-83.67
50	23	-82	-78	-79	-79.67
45	23	-72	-78	-78	-75.67
40	23	-78	-77	-70	-73.67
35	23	-73	-73	-66	-69.33
30	23	-66	-71	-71	-69.33
25	23	-57	-52	-51	-53.33
20	23	-55	-61	-54	-56.67
15	23	-53	-54	-50	-52.33
10	23	-42	-40	-42	-41.33
5	23	-40	-36	-37	-37.67

In this research, searching for the minimum power in the transmission process, the minimum Tx Power Level was investigated. The procedure was conducted by first setting the node for such distance, and then the power level setting was set to the maximum level (23). We repeated this procedure for varied distances. We achieved the lowest power to receive the transmitted data by decreasing this power level. Table 4 shows the initial-minimum setting and the changing of RSSI.

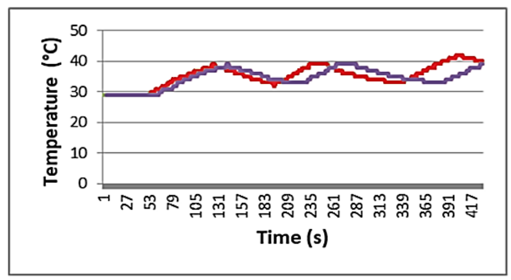
Table 4 Minimum Power Transmitter for Different Initial Values

Distance (m)	Initial		Minimum	
	Tx Power	RSSI (dBm)	Tx Power	RSSI (dBm)
280	23	-97.6	12	-98.0
170	23	-87.3	9	-95.0
55	23	-82.0	6	-88.0
50	23	-79.0	6	-90.0
45	23	-75.6	6	-89.3
40	23	-85.6	6	-73.6
35	23	-69.3	6	-70.0
30	23	-69.3	6	-72.0
25	23	-53.3	6	-55.0
20	23	-56.6	6	-57.0
15	23	-52.5	6	-55.6
10	23	-40.0	6	-41.0
5	23	-37.6	6	-37.0

The last experiment was to investigate the power consumption according to the periodic signal transmission (sleep-awake period). In this investigation, the sample used is temperature. Figure 10 is the profiles of transmitted data (blue line) and received data (red line) periodically several times with various sleep times. From Figure 10, we concluded that the maximum sleep time for the received signal to be still read is 8 seconds. This result shows graphically that the signal transmission period influences the received data.



(2 seconds)



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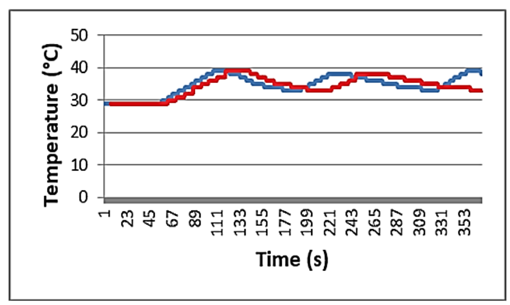
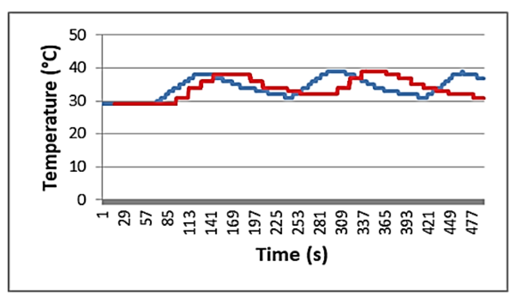


(8 seconds)



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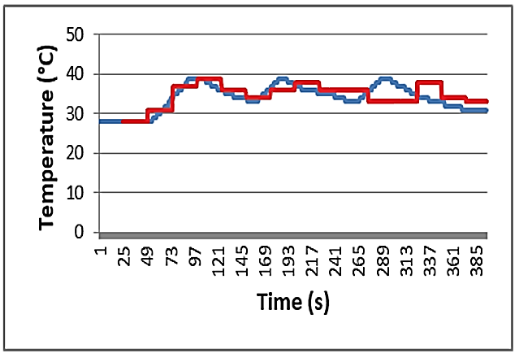
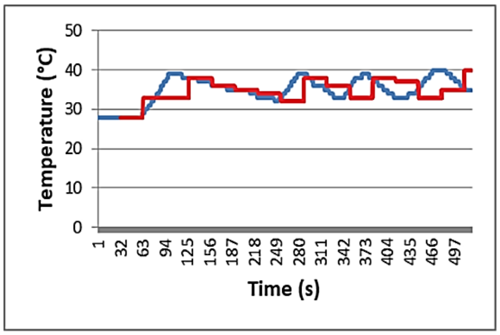


(25 seconds)



(32 seconds)

Figure 10 Profiles of Transmitted Data (Blue Line) and Received Data (Red Line) with Varied Sleep Times

3.2 Discussion

The investigation of the varying distance between the sensor node and gateway shows that the increasing distance can decrease the RSSI value (Table 3). The investigation of varying Tx Power Level for a certain distance show that an initial RSSI value can derive from the optimum Tx Power Level (Table 4). Furthermore, the variation of data transmission time with the sleep-awake method shows that the gateway can still read the data appropriately with a signal transmission period of 8 seconds. Those results show that changing the Tx Power Level setting and periodic signal transmission time can derive the minimum power consumption.

Table 4 shows the measurement results for various distances, where at 280m distance, the recognized initial RSSI is -97,6 with initial Tx Power Level 32. By decreasing the Tx Power Level to 12, the recognized RSSI value is -98 or relatively similar. On the other hand, Table 1 shows that the power consumption reduced from 0.67 to 0.39 watts, related to the decreasing Tx Power Level from 32 to 12.

According to eq2., using Tx Power Level 12, the system's lifetime is 276,9 when the power supply capacity is 108Wh.

$$Lifetime = \frac{108}{0.39} = 276.9\ hours \tag{2}$$

Therefore, using Tx Power Level 12, the power supply's lifetime is 115 hours or 71% longer than the power supply's lifetime by using Tx Power Level 23. Using Tx Power Level 23, the sensor node's energy consumption is 0.67 watts, and the power supply's lifetime is 161.19 hours.

The above power supply's lifetime calculations are for processors that typically work or without a specific transmission method. The measurement shows that the typical working cycle of the processor is 0.2 seconds. Thus, the data transmission period is 0.2 seconds. By applying the sleep-awake method with a data transmission period of 8 seconds, the power supply's lifetime becomes 40 times longer or 11076 hours, which is 461.5 days.

Another example case is the configuration of the WSN depicted in Figure 11. With the Tx Power Level setting 23, the total power consumption, based on Table 1, is 3.35 W. Table 4. Shows that we can change all power level settings from 23 to 6. Hence the total power consumption can be decreased to 1.55 W.

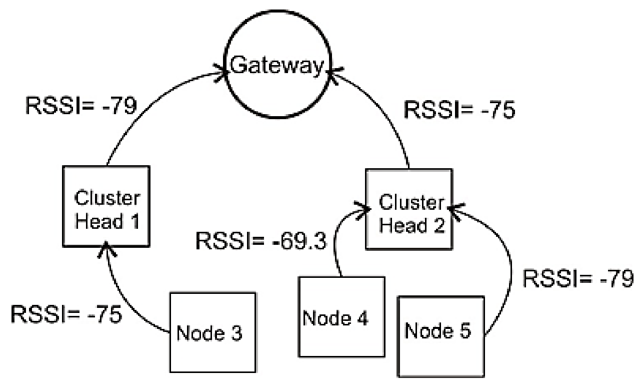


Figure 11 Initial RSSI Value with Power Setting 23

4.0 CONCLUSION

This research investigated two essential factors influencing power consumption in the sensor node. Transmission power and periodic transmission time have been analyzed based on the value of RSSI and the periodic transmission time. In the first factor, to find the minimum Tx Power Level, we experimentally measure the initial value of RSSI by changing the distance between the sensor node and gateway. The initially used Tx Power level is 23, with the initial RSSI value for each distance. We decreased this initial TX Power Level step by step until we derived the lowest Tx Power Level, which transmits the data correctly. In the transmission time investigation, the periodic transmission time was changed from 2 to 32 seconds and analyzed graphically for transmitted and received signals so that the received data could still represent the information. The results show that the sensor node does not need to use the highest Tx Power Level for any initial RSSI. It will adaptively change the Tx Power Level based on the initial RSSI. Hence power consumption can be automatically decreased. In the distance 280 m with an initial RSSI -97.6, the Tx Power level can be changed to 12 with RSSI -98. Thus, power consumption could decrease from 0.67 to 0.39 watts or about 42%. If the power supply of the sensor node is 108 Wh, the power supply's lifetime with Tx Power Level 12 is 276.9 hours or 71% longer than Tx Power Level 23 with the power supply's lifetime of 161.19 hours. For the periodic transmission time, with a sleep time of 8 seconds, the power supply's lifetime is 40 times longer than a transmission using the processor cycling time of 0.2 seconds. Combining this periodic transmission time with the obtained optimum TX Power Level, the estimated power supply's lifetime is 11076 hours, 461 days. The research result can benefit WSN applications, especially in remote areas.

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