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# Benchmarking in QoS and Energy Consumption SAW and TOPSIS Algoritm in Low Cost Microcontroller for Wireless Sensor Network Routing Application

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***Abstract*—The Wireless Sensor Network technologies have provides us with cheap and unique solution to deal with telecommunication infrastructure problem that don't exist in extreme and isolated area. To guarantee the quality of service of Wireless Sensor Network wireless data transmission, a lot of researchers propose to employ a routing algorithm, such as SAW and TOPSIS from MCDM algorithm. A lot of routing algorithm in Wireless Sensor Network was based on these algorithms. In this paper we propose to do simulation and real time energy measurement in order to determine the best MCDM algorithm to be use in Wireless Sensor Network routing. In QoS 3x4 node simulation Both algorithm has provide low delay 31 millisecond and low packet loss 16 bit. This good performance in QoS however has disadvantage which has higher hop quantity. In term of energy consumption SAW has less energy consumption (better) compare with TOPSIS for each microcontroller development platforms that we have test. Although it was small but we have difference in energy consumption between SAW and TOPSIS, for ESP32 it has difference 39 microJoule, for ESP8266 it has difference 129 microJoule and for ATMEGA328P it has difference 2 microJoule.**

***Keywords*— Algorithm, Energy Consumption, Routing Wireless Sensor Network, SAW, TOPSIS.**

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## I. Introduction

The Wireless Sensor Network has been classified as the next generation network in 2010 by ITU [1]. This network contain interconnected sensor nodes that exchanging sensed data using wireless technologies such as LoRa [2], zigbee [3], and many others [4]. Using its unique solution which is node to node communication (adhoc network) it has low cost for deploying it [5], and it can be used everywhere from mountain [6], forest [7], cities [8], even in underwater application [9]. Even though Wireless Sensor Network has this advantage, this network also has many advantages such as limited energy and data transmission problem such as interference [10], delay [11], packet loss [12], and others [13].

To guarantee the quality of service in wireless data transmission in Wireless Sensor Network, a lot of researchers propose to employ a routing algorithm [14]. Routing is behavior of a network that controlled by an algorithms. This algorithm will decide how every node in Wireless Sensor Network should be communicated between each other's. this algorithms has single purposes which to delivers observation data using point to point node communication, from the farthest node to the base station closer node with minimum error.

To combat limited energy and data transmission problem we propose to investigate SAW and TOPSIS routing algorithm in term of power consumption efficient and in term of quality of service (QOS) highest performance parameter. The SAW and TOPSIS algorithms are two methods commonly used in multi-criteria decision making [15]. The SAW and TOPSIS algorithm can be applied in the context of routing in Wireless Sensor Networks to select the optimal communication path based on several criteria [16]. These two algorithms were special because it was a foundation of incoming routing algorithm in wireless sensor network and other routing application.

## II. Literature Review

Kim et al use SAW algorithm as a protocol to improve routing in WBANs by considering mobility and temperature sensitivity. This holistic approach can lead to more efficient and reliable data transmission within the network, specifically to the challenges posed by WBAN environments [17]. Kim also use SAW algorithm to improve routing efficiency and effectiveness in MANETs by utilizing geographical routing and employing a sophisticated decision-making method [18]. This approach is particularly suitable for dynamic and resource-constrained environments typical of MANETs, where traditional routing protocols may not perform optimally. Choudhary et al use TOPSIS to propose hybrid fuzzy-genetic algorithm aims to enhance the performance of Cyber Physical Wireless Body Area Networks by leveraging the strengths of fuzzy logic and genetic algorithms to optimize various performance metrics critical to WBAN operation and application in healthcare and monitoring scenarios [20], Mehta et al propose TOPSIS to address the challenges of energy consumption and network efficiency in WSNs by leveraging hierarchical organization, fuzzy logic for adaptable clustering, and bio-inspired routing algorithms to prolong network lifetime and improve performance metrics. [22].

## III. Method

### *A. SAW (Simple Additive Weight) Algorithm*

This algorithm is also known as weighted addition method [23]. This algorithm concept is to seeing for all weighted sum on each alternative on all attributes. This algorithm was developed by Fishburn to show arranged product sets using priority orderings and assignments [24]. The SAW algorithm steps were shown from Equation 1 to 3.

*Normalize Criteria Matrix*

The Matrix of weighted Criteria for all every alternative and all attributes which is $N_{ij}$. This $N_{ij}$ needs to be normalization so that it can be compared all criteria that has different value. Normalize matrix for each alternative was given by [25].

$$rij = \begin{Bmatrix} \left(\frac{Nij}{\mathrm{Max}\,Nij}\right) \mid \in Benefit \\ \left(\frac{\mathrm{Min}\,Nij}{Nij}\right) \mid \in Cost \end{Bmatrix} \quad (1)$$

Where :

r = Normalize weighted number of alternatives, i=1,2,….,m, and j =1,2,….,n.

*Preference Criteria Matrix*

Preference for each alternative was given by:

$$\sum_{j=1}^{n} w_j\, r_{ij} \quad (2)$$

Where :
$W_j$ = weighted value for alternatives, i=1,2,….,m, and j =1,2,….,n

*B. TOPSIS Algorithm*

System was develop by Zadeh in 1965 [26]. It was expected to solve real-world problems using approximate reasoning based on unprecise information [27]. At first system was meant to become decision making algorithm [28] however until now a lot of new methods intend to solve other problem such as robot movement [29], [30], speed [31], and many others [32]–[34]. To solve data transmission problem in Wireless Sensor Network from far node to gateway node, TOPSIS was need to be employ as data transmission routing algorithm. With this algorithm it can chose the best ideal node alternative and worst node alternative. The TOPSIS algorithm from Equation 3 until equation 9.

*Normalize Matrix Decision*

For every criterion, the normalization needs to be done. This step was to limit the criterion between 0 and to 1[25].

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} {x_{ij}}^2}} \quad (3)$$

Where :

r = Element of normalize decision matrix,

x = Decision matrix of alternatives and criteria, i=1,2,….,m was number of alternatives and j =1,2,….,n number of criteria

*Weighted Normalize Matrix Decision*

The normalized matrix must be weighted. This weight was to show the criteria that has the biggest value for the decision making system. The weighted Criteria Matrix can be expressed below.

$$N_{ij} = rij.wij \quad (4)$$

Where :

N = Weighted Normalize of alternatives.

r = Normalize number of alternatives, i=1,2,….,m and j =1,2,….,n

*For Positive Ideal Solution*

The Weight of the normalize matrix decision can be seen as a positive ideal solution as in Equation (5).

$$A_b = \begin{Bmatrix} \left(\min\left(t_{ij} \middle| i = 1,2,\ldots,m\right) \middle| j \in J-\right) \\ \left(\max\left(t_{ij} \middle| i = 1,2,\ldots,m\right) \middle| j \in J+\right) \end{Bmatrix} \equiv \left\{ t_{bj} \middle| j = 1,2,\ldots,n \right\} \quad (5)$$

Where :

Ab = best ideal Solution alternatives, J+ = {j=1,2,⋯.,n | j} criteria that having a positive impact.

*For Negative Ideal Solution*

The Weight of the normalize matrix decision can be seen as a negative ideal solution as shown in Equation (6).

$$A_w = \begin{Bmatrix} \left(\max\left(t_{ij} \middle| i = 1,2,\ldots,m\right) \middle| j \in J-\right) \\ \left(\min\left(t_{ij} \middle| i = 1,2,\ldots,m\right) \middle| j \in J+\right) \end{Bmatrix} \equiv \left\{ t_{wj} \middle| j = 1,2,\ldots,n \right\} \quad (6)$$

Where :

Ab = worst ideal Solution alternatives, J- = {j=1,2,⋯.,n | j} criteria that having a negative impact

*Distance for Positive Ideal Solution*

This alternative shows as the nearest with the best:

$$d_{ib} = \sqrt{\sum_{j=1}^{n} (t_{ij} - t_{bj})} \quad (7)$$

Where :

dib = near the best ideal solution alternatives, i = 1,2,….,m

*Distance for Negative Ideal Solution*

The alternative shows the nearest with the worst

$$d_{iw} = \sqrt{\sum_{j=1}^{n} (t_{ij} - t_{wj})} \quad (8)$$

Where :

diw = near the worst ideal solution alternatives, i = 1,2,….,m

*Closeness Coefficient*

With the best alternative and the worst alternative distance, hence we can calculated closeness coefficient to show the best of the performance of the nodes alternatives, as shown in equation 9:

$$CC = \frac{d_{iw}}{d_{iw} + d_{ib}} \quad (9)$$

Where :

CC = Closeness Coefficients of alternatives, i = 1,2,….,n

In order to find out not only effective algorithm but also efficient in energy consumption in Wireless Sensor Network routing algorithm, therefore In this paper we propose to do simulation and also real time energy consumption measurement.

### C. 3x4 Nodal Simulation

In this simulation we do will do twice simulation using each respective algorithm. The simulations contain 3x4 WSN nodes, with QOS parameter such as delay (millisecond), packet loss (bit), and hop quantity. The QOS parameter value will be add randomly for every random WSN node. Figure 1 show WSN node simulation configuration.

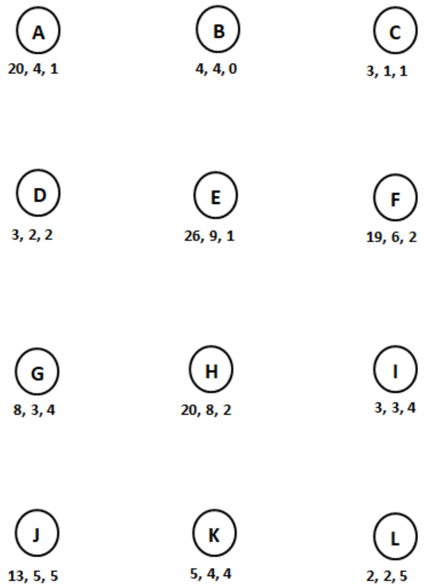


Figure 1. 3x4 WSN nodes, with random delay and packet loss

### D. Microcontroller Hardware

In order to do real time measurement, we propose to implement both algorithms into 3 different microcontroller development platforms. We like to see whether there is a different in energy consumption if we are using 3 distinct microcontroller development platforms. The first microcontroller development platforms that we would like to use would be Lolin D32 that based on microcontroller ESP32 wrover. Lolin D32 is one of popular microcontroller development platform to be use as main processing unit for fast prototyping wireless sensor network nodal. It happen because Lolin D32 is a low cost microcontroller [35], has Wi-Fi and bluethooth feature embedded [36] and also has higher processor clock speed 240 MHz and also deep sleep feature [37]. With those feature it makes Lolin D32 very popular for every wireless communication application such as wireless sensor network and IoT application.

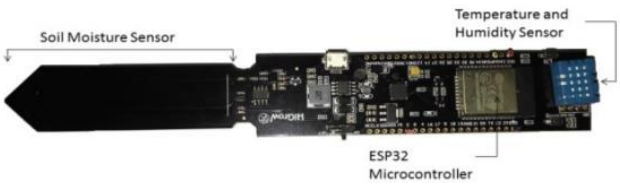


Figure 2. ESP32 for wireless sensor network nodal for agriculture application [35].

Another microcontroller development platforms that we would like to test is Wemos ESP8266 D1R2 mini that based on microcontroller ESP8266EX. This platform is also one of popular microcontroller development platform to be use as main processing unit for fast prototyping wireless sensor network nodal [38]. It has Wi-Fi feature embedded and also has higher processor clock speed up to 160 MHz and also deep sleep feature [39]. With those feature it makes Wemos ESP8266 D1R2 mini very popular for every wireless communication application such as wireless sensor network and IoT application.

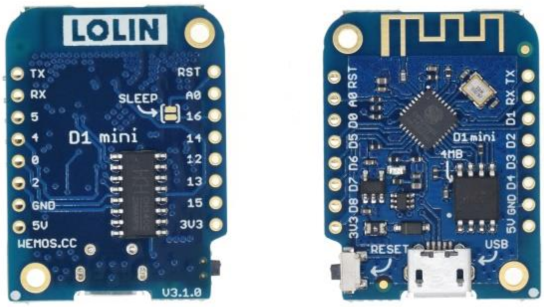


Figure 3. Wemos (lolin) ESP8266 D1R2 mini picture taken from wemoc.cc.

The last microcontroller development platforms that we would like to test is Arduino Mini Pro that based on microcontroller ATMEGA328P. It has low power consumption, processor clock speed 8 MHz, and also deep sleep feature [40] making it popular for fast prototyping wireless sensor network nodal [41].

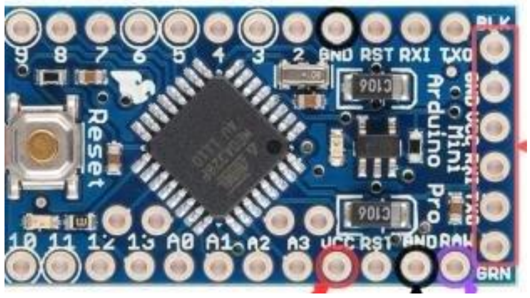


Figure 4. Arduino Mini Pro

## IV. Result and Analysis

In this section we do comparison between TOPSIS and SAW algorithm both in simulation with 3x4 WSN node and also in real time measurement using microcontroller ESP32, ESP8266, and ATMEGA328P.

### A. Simulation Routing

In TOPSIS algorithm, delay and packet loss was considered as a benefit, while hop quantity was consider as a cost. However delay and packet loss was QOS parameters that need to be low as possible. Therefore in benefit we are using minimum function in positive ideal solution and maximum in negative ideal solution, while for hop quantity we are using maximum function in positive ideal solution and minimum in negative ideal solution. In this routing simulation the highest node routing value will be selected as the next node path. Table 1 shows TOPSIS routing selection path.

Table 1. Topsis Routing

| Routing Step | Node Routing Value Alternatives | | | Routing Path |
|---|---|---|---|---|
| Step 1 | Node H 0.476 | Node J 0.617 | Node L 1 | Node K to Node L |
| Step 2 | Node I | | | Node L to Node I |
| Step 3 | Node H 0.634 | Node F 1 | | Node I to Node F |
| Step 4 | Node E 0.416 | Node C 1 | | Node F to Node C |
| Step 5 | Node B | | | Node C to Node B |

In SAW algorithm, delay and packet loss was considered as a benefit, while hop quantity was consider as a cost. However delay and packet loss was QOS parameters that need to be low as possible. Therefore in benefit we are using minimum function, while for hop quantity we are using maximum function. In this routing simulation the highest node routing value will be selected as the next node path. Table 2 shows SAW routing selection path.

Table 2. Saw Routing

| Routing Step | Node Routing Value Alternatives | | | Routing Path |
|---|---|---|---|---|
| Step 1 | Node H 1.35 | Node J 2.51 | Node L 6 | Node K to Node L |
| Step 2 | Node I | | | Node L to Node I |
| Step 3 | Node H 5.15 | Node F 6 | | Node I to Node F |
| Step 4 | Node E 1.56 | Node C 6 | | Node F to Node C |
| Step 5 | Node B | | | Node C to Node B |

We can see in table 1 and table 2 TOPSIS and SAW, that both algorithm has manage to do routing from node K to node B. Both algorithm routing has avoided the shortest path and chose to go around node L, I, F, and C to get to node B from node K. To give clear picture in routing performance, we would like to compare TOPSIS and SAW algorithm routing performance in simulation with shortest path (straight path or no routing) performance. Figure 3 shows comparison between TOPSIS, SAW, and also shortest path in Quality of service parameter.

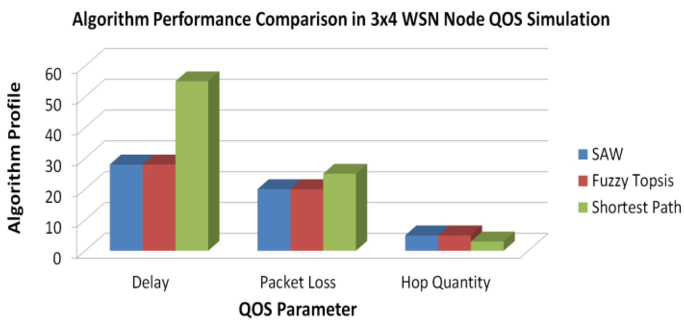


Figure 5. Routing comparison performance in QoS parameter between TOPSIS, SAW, and shortest path.

As we can see from figure 5 in routing comparison performance between TOPSIS, SAW, and shortest path, TOPSIS and SAW algorithm has manage to do routing and avoided bad performance routing from node K to node B. both algorithm are using node L, I, F, and C instead of shortest path which is using node H, E. if we compare this both algorithm routing QoS parameter were low as possible we delay was only 31 millisecond and packet loss was only 16 bit, compare with shortest path were delay 50 millisecond packet loss 21 bit. However this good performance routing has cause higher hop quantity. If we see also from figure 3 shortest path have 3 hop only compare with both algorithm that have 5 hop, this higher hop means higher total power consumption in data transmission.

*B. Real Time Energy Consumption Measurement*

According to Ruberg and colleagues total energy consumed by the microcontroller for each base expression is calculated using equation [42]:

$$E = V_{dd} x\, I_{Average} x\, T_{operation} \qquad (10)$$

where :

E = is energy unit, Joules

$V_{dd}$ = is microcontroller voltage operation, Volt.

$I_{average}$ = is average microcontroller current consumption during its operation, Ampere

$T_{operation}$ = is time duration of microcontroller operation, Second

Based on equation 10 we need to find all three parameter in order to calculated energy consumption from each microcontroller development platforms that run TOPSIS and SAW algorithm. According their respected microcontroller datasheet ESP32 [37], ESP8266EX [39], and ATMEGA328P [40], all three microcontroller was running on 3.3 volt power source for their operation. Therefore we only need to measure current consumption and time consumption for each microcontroller development platforms.

To find time consumption for each microcontroller development platforms, we have set the TOPSIS and SAW algorithm routing simulation for 100 looping. After finished 100 loop, each microcontroller development platforms will sent report contain time consumption for 100 loop. Also when each microcontroller development platforms was running TOPSIS and SAW algorithm routing simulation we also measure its current consumption using SANWA digital multimeter CD800A. Figure 6 below show report from microcontroller and we capture it using Arduino IDE serial communication port. To make visualization easy, we wrote measurement result on table 3 that show us time consumption measurement, and on table 4 we wrote measurement result for current measurement from each microcontroller development platforms that runs 2 different algorithm routing simulation (TOPSIS and SAW).

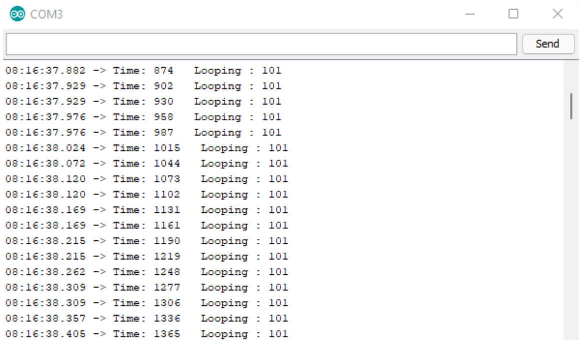


Figure 6. Real time routing simulation and time consumption using ESP32 microcontroller.

Table 3.TOPSIS and SAW Algorithm comparison in Microcontroller Time Consumption in milisecond

| Algorithm Routing | Microcontroller Time Consumption (milisecond) | | |
|---|---|---|---|
| | **ESP32** | **ESP8266** | **ATMEGA328P** |
| TOPSIS | 29.1717 | 29.6869 | 28.6907 |
| SAW | 29.1717 | 29.1700 | 28.6771 |

Table 4. TOPSIS and SAW Algorithm comparison in Microcontroller Current Consumption in miliAmpere

| Algorithm Routing | Microcontroller Current Consumption (miliAmpere) | | |
|---|---|---|---|
| | **ESP32** | **ESP8266** | **ATMEGA328P** |
| TOPSIS | 52.9 | 75.4 | 12.52 |
| SAW | 52.5 | 75.4 | 12.50 |

If we use equation 10 and data measurement from table 3 and table 4, we could visualize the routing algorithm energy consumption profile for each microcontroller development platforms. This energy consumption profile can be seen on figure 7 below.

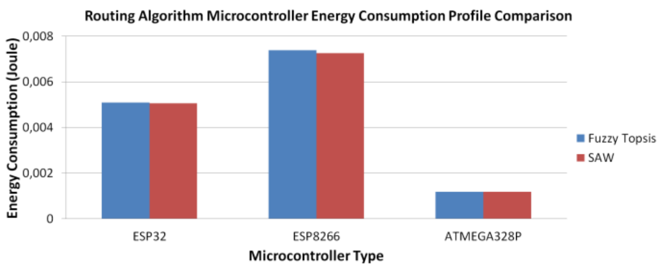


Figure 7. microcontroller development platforms energy consumption profile in running routing algorithm (TOPSIS and SAW)

based on figure 7 we can say that SAW algorithm indeed less consume power (better) compare with TOPSIS, however the the difference wasn't significant. The difference in energy consumption for each microcontroller development platforms was 39 microJoule for ESP32, 129 microJoule for ESP8266, and 2 microJoule for ATMEGA328P.

## V. Conclusion

Using both simulation and real time energy consumption measurement, we have managed to identify the best MCDM algorithm for routing in Wireless Sensor Network Application. Using 3x4 Wireless Sensor Network nodal configuration we conclude that both TOPSIS and SAW algorithm have perform well and both have same value in simulation for QoS parameter such as delay was only 31 millisecond and packet loss was only 16 bit. However in term energy consumption SAW has less energy consumption (better) compare with TOPSIS for each microcontroller development platforms that we have test. Although it was small but we have difference in energy consumption between SAW andTOPSIS, for ESP32 it has difference 39 microJoule, for ESP8266 it has difference 129 microJoule and for ATMEGA328P it has difference 2 microJoule. We conclude that both SAW and TOPSIS has good performance in Wireless Sensor Network routing Application, with slightly better for SAW algorithm in energy consumption compare with TOPSIS.

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