A novel energy-efficient dynamic programming routing protocol in wireless multimedia sensor networks

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ABSTRACT

Wireless multimedia sensor networks (WMSNs) have characteristics that may influence the routing decisions, such as limited energy resources, storage and computing capacity. Therefore, a routing optimization needs to be done to match the characteristics of the WMSNs. Existing routing protocols only consider energy efficiency regardless of energy threshold, maximum energy, and link cost collectively as the primary basis of routing. In this work, the energy-efficient dynamic programming (EEDP) protocol is proposed to optimize routing decisions that take into account the energy threshold, the maximum energy, and the link cost. Then, the protocol is compared with the dynamic programming (DP), and the ant colony optimization (ACO) protocol. The simulation results show that the EEDP protocol can improve energy efficiency of nodes and network lifetime of the WMSNs. Then, the EEDP protocol is also implemented into a network topology of 10 NodeMCU ESP32 devices. As a result, the EEDP protocol can work very well by selecting routes based on nodes that have the remaining energy above 50 and has the shortest distance. The average delay in sending data for the entire route for the 10 iterations of sending data is 3.99 seconds.

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1. INTRODUCTION

Devices used in wireless multimedia sensor networks (WMSNs) have limited resources, low processing speed, small storage capacity, and limited bandwidth communications. In addition, the WMSNs must also operate for long periods of time, but they only have battery-powered nodes. Therefore, the available energy resources limit the operation of the overall network. Another characteristic of the WMSNs is that the nodes must have significant processing power as a group. The nodes should be able to organize and manage the network together [1]. This is much more difficult than controlling the device individually. Furthermore, changes in the physical environment, in which the network is used, create the nodes to experience variations in network connectivity and affect routing protocols. Multimedia data transmission via the WMSNs can also reduce the energy capacity of a node [2]–[4].

WMSNs have a multi-hop network topology and bandwidth channels that vary with time. Multimedia applications, when sent over a multi-hop network in WMSNs, can experience degradation regarding throughput, delay, and packet loss. The multimedia application may also fail to reach the destination node because of the energy capacity factor of the intermediate nodes that are exhausted for forwarding multimedia application packets [5]. The special needs of WMSNs such as energy efficiency and quality of service (QoS) pose new challenges for optimizing the WMSNs routing protocol. Optimization of routing protocols is a process to improve the performance of existing routing protocols so that they have good quality and high work output. Multimedia data, including audio, video, image and scalar data, and the transmission process in real time and not real time require different QoS metrics based on the type of application. Therefore, routing protocol optimization techniques designed for WMSN must have the ability to facilitate application-specific service quality assurance and energy efficiency of nodes and networks [6]–[11].

Most of the energy consumption in the WSNs and WMSNs is spent on three main activities, namely: sensing, data processing and communication. All these factors are important and should be considered when developing a routing protocol to the WMSNs. Communication between nodes is a major component of energy consumption. Recently ongoing research in the WSNs and WMSNs has been largely concentrated on designing an energy-efficient routing protocol for nodes communication and has not considered the energy threshold, the maximum energy, and the link cost as the main base routing decisions. The main task of the routing protocols in the WMSNs is not only to transmit data from source to destination but also to consider the energy threshold of the nodes and improve overall network lifetime. The routing protocol operation will greatly affect the energy used for data transmission in the WMSNs. Continuous use of the paths with low energy often causes energy depletion of the nodes along the existing paths. Ultimately this will also cause dead nodes, and break up the network partition [12]–[17].

The most difficult issue with wireless communication systems is routing. Only a few survey articles on WMSN routing protocols have been released. For WSNs, a brand-new energy-efficient and reliable ant colony optimization (ACO)-based routing protocol (E-RARP) has been proposed. The protocol developed a new probability function that took into account numerous new impact parameters, including residual energy and hop count, in addition to pheromone [18]. Research by Benmansour and Labraoui [19], there is a thorough explanation of how to develop and construct smart routes to support QoS-aware applications. This work presents a thorough review that focuses on identifying and delineating all current SI-based routing techniques for WMSNs. The suggested technique dynamically chooses the best path based on the cost function with the shortest distance and the least energy loss using a genetic algorithm (GA)-based metaheuristic optimization. The algorithm improved the network's energy dissipation by introducing a cost function that takes the distance to the event area's center and base station, as well as the node's remaining energy, into account when selecting CH [20]. Every node in a wireless sensor network has been assigned a threshold energy parameter using a model based on swarm intelligence-based efficient routing in order to manage energy conservation and balancing. This threshold setting is crucial in ensuring that every node nearby a node of concern participates in packet forwarding on a regular basis. This led to outstanding energy conservation and optimal energy balancing amongst all of the included nodes, increasing the network's lifespan [21]. The Dijkstra's shortest path routing and sleep-wake scheduling (DSRSS) uses the Dijkstra's protocol related to the routing optimization of network lifetime of nodes. However, this protocol does not consider the QoS requirements for multimedia applications [22]. However, the above protocols have not considered routing metrics such as maximum energy, energy threshold, and delay as the basis for making routing decisions simultaneously.

The dynamic programming (DP) method has been used in WSN but it only focuses on and calculates the multi-hop time synchronization, network configuration, energy efficiency, and distance of nodes [23]. A problem of optimal paths between nodes has been investigated in the wireless network. Therefore, the DP method is used to solve the problem in terms of the energy efficiency [24]. The multi-decision sequential routing protocol (MDSR) based on the DP is proposed in the wireless mesh network (WMN). The simulation results show that the protocol has a better performance in terms of throughput and end-to-end delay [25]. A cross-layer based routing protocol is suggested that can make use of medium access control (MAC) layer QoS-based scheduling for more effective routing mechanisms in WMSNs in order to deliver QoS assurance and energy efficiency [26]. To guarantee QoS and reduce energy usage, the cross-layer multipath routing (CLMR) architecture is presented. The purpose of CLMR is to select the proper multipath and distribute multimedia packets according to their significance. To get the best routing decision, the cross-layer design between the application, network, and physical layers is changed [27]. However, all these protocols have not been implemented to investigate the issues of energy efficiency and network lifetime.

A routing protocol optimization is a process to improve the performance of existing routing protocols to have a good quality and high working results. To achieve the optimization of routing protocols on the WMSNs, the energy-efficient dynamic programming (EEDP) protocol is proposed based on the DP protocol [28]. The EEDP protocol takes into account the energy efficiency of nodes and the network lifetime of the WMSNs for routing decisions. This protocol uses three routing metrics comprising the energy threshold, the maximum energy, and the link cost. Then, the protocol is compared with the DP, and the ACO protocol. Therefore, the results of this work can contribute to solving problems of routing needs based on specific needs, namely energy efficiency of nodes and network lifetime of the WMSNs.

The rest of this paper is organized as follows: section 2 explains the proposed method. Section 3 explains the results and discussion. Finally, the conclusions are presented in section 4.

2. THE PROPOSED METHOD

The EEDP protocol as shown in Figure 1 considers three routing metrics consisting of the energy threshold, the maximum energy and the link cost collectively as the primary routing decisions. When a node wants to send a multimedia application, the node must determine whether routes are available or not to neighboring nodes. If these routes are already available, the node calculates the number of energy threshold and link costs of the neighboring nodes traversed. If all the neighboring nodes that will be passed to have the amount of energy above the energy threshold, then the routing protocol will select a neighboring node with maximum energy. If all neighboring nodes have the same amount of energy, then the routing protocol will select a neighboring node with the smallest link cost. The decision in selecting nodes that will be passed by the multimedia application can vary depending on the condition of the energy level of the node and the link cost from the adjacent nodes (such as distance and delay). Therefore, the protocol always chooses the node with energy threshold and maximum energy. Thus, the energy efficiency of nodes and the network lifetime of the WMSNs will be maintained continuously [29].

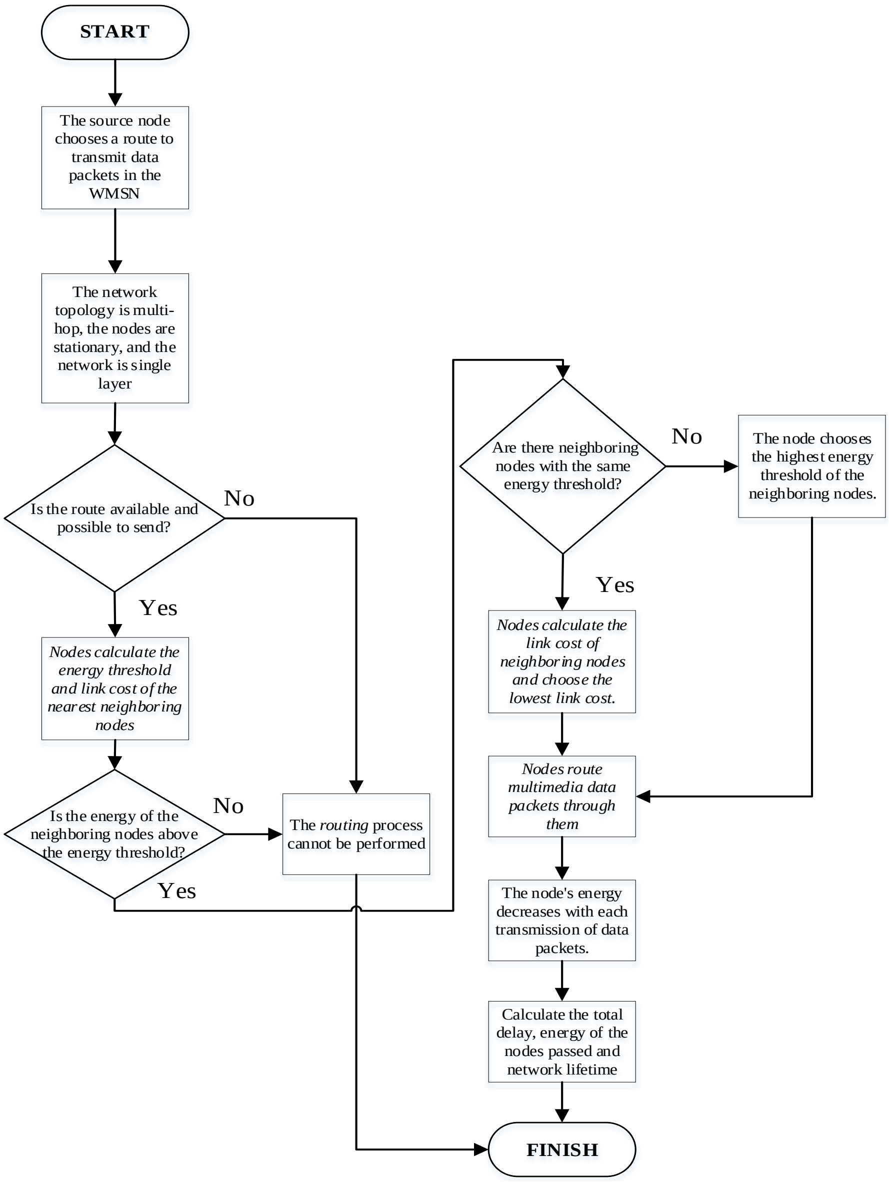

Figure 1. The EEDP protocol

We compare the performance of the EEDP protocol with the DP, and the ACO protocol. We use the MATLAB simulation model as shown in Table 1 to test the EEDP protocol. Tests are conducted to determine the performance of the EEDP protocol in terms of total link cost and the total energy required when submitting k bits of data from node 1 to node 45 as shown in Figure 2. To calculate the total link cost from node 1 to node 45, the distances between adjacent nodes are created randomly between 1 and 4. Thus, the total amount of energy is required to transmit the number of k bits from node 1 to node 45 based on (1):

$$\text{Total Energy} = \sum_{i=1}^{n} E_i - \begin{bmatrix} \left((E_{tx} + E_d) * k\right) \\ +\left(E_{fs} * k\right) \end{bmatrix} \tag{1}$$

Table 1. Simulation parameter

Parameter	Value
E_i=the initial energy of node i	Random, between 1 and 2 (in Joule)
E_{tx}=the radio dissipates energy	50 nJ/bit
E_{fs}=the transmit amplifier types	10 pJ/bit/m^2
E_d=the data aggregation energy	5 nJ/bit
n=the number of nodes	45
k=the number of bits	50 kbit
The number of rounds	250

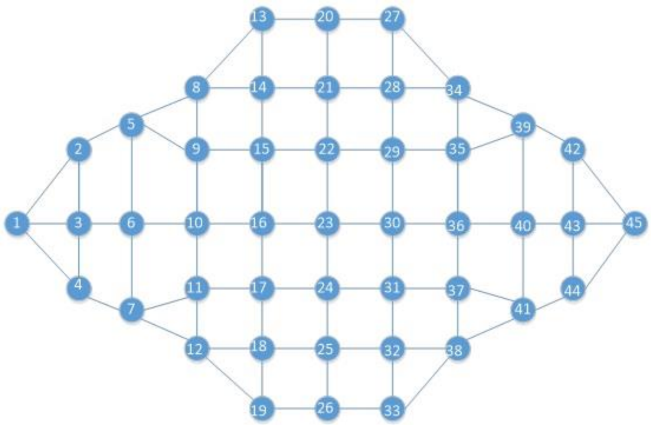

Figure 2. Network topology for 45 nodes

3. RESULTS AND DISCUSSION

This section displays and explains the MATLAB simulation results from the EEDP protocol when compared to the DP and the ACO protocols. Then this section also discusses the prototype of NodeMCU ESP32 devices that have been paired with the EEDP protocol.

3.1. Simulation results

Figure 3 shows a comparison of the process of selecting the optimal path from node 1 to node 45 based on the DP, the ACO, and the EEDP protocol. The DP protocol has the smallest round to reach the optimal path from node 1 to node 45 than other protocols. While the EEDP protocol has the second smallest round. It indicates that the DP protocol has a simple computation. It does not need to compute all available paths, but it only computes paths related to the sending nodes directly.

Figure 4 shows the total energy from node 1 to node 45 based on the EEDP protocol. The EEDP protocol always looks for nodes that have a residual energy above the energy threshold for each round. If the nodes have the same energy level, the EEDP protocol will select a node with the greatest energy level. Until the last round, the energy efficiency of nodes is always maintained above the energy threshold so that the energy of the node is not draining quickly. Additionally, this also causes the network lifetime of the WMSNs well maintained continuously.

Figure 5 shows the total delay from node 1 to node 45 based on the DP, the ACO, and the EEDP protocol. The DP protocol has the smallest total delay compared to the ACO and the EEDP protocols. The DP protocol divides the total delay issue into decision stages. Therefore, the DP protocol does not need to check all possible delays of the existing nodes. However, the DP protocol only checks the delay metric of neighboring nodes that have a direct link with the sending node for each decision stage. Then based on the amount of delay that exists from neighboring nodes, the DP protocol chooses a lower total delay value. The optimal decision results from each decision stage produce a set of optimal decisions as a whole, namely the lowest total delay value. The EEDP protocol has the largest total delay because this protocol chooses the energy threshold and maximum energy metrics of the nodes over the delay metric as the basis for routing decisions.

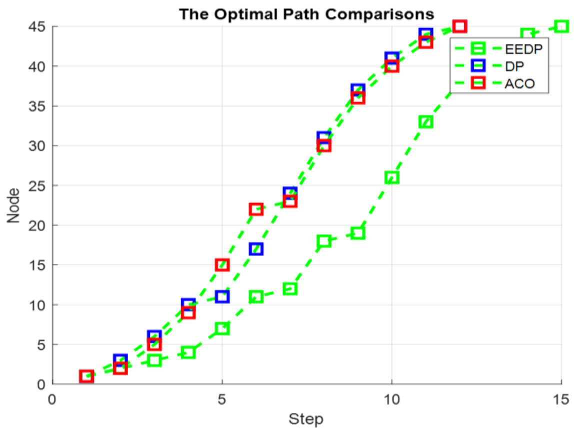

Figure 3. A comparison of the process of selecting the optimal path from node 1 to node 45 based on the DP, the ACO, and the EEDP protocol

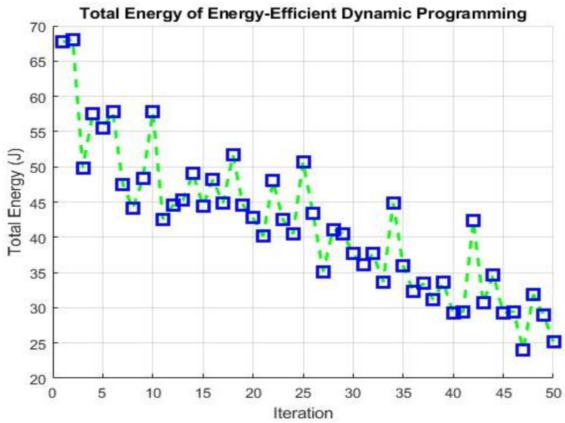

Figure 4. The total energy from node 1 to node 45 based on the EEDP protocol

Figure 6 shows a comparison of the total energy from node 1 to node 45 based on the DP, the ACO, and the EEDP protocol. The total amount of energy of the DP, and the ACO protocol continue to drop until the last round. This drop occurs because of the same links are used continuously. Therefore, the energy level of nodes that passes will be reduced quickly. Additionally, these protocols do not provide other link alternatives to prevent the nodes with less energy to be passed. The EEDP protocol always looks for nodes that have maximum energy and above the energy threshold for each round. If the nodes have the same energy level, the EEDP protocol will select a node with the greatest energy level. Until the last round, the energy efficiency of nodes is always maintained above the energy threshold so that the energy of the node is not draining quickly. Selection of the nodes that have maximum energy and above the energy threshold of the EEDPprotocol causes network lifetime longer until the last round and prevent the nodes from losing energy quickly when being passed. Furthermore, the selection of the nodes that have the maximum energy and above the energy threshold also leads no hole, partitions or broken network in the WMSNs.

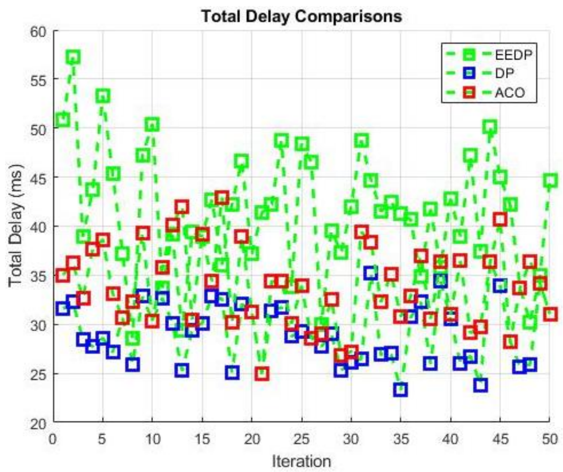

Figure 5. A comparison of the total delay from node 1 to node 45 based on the DP, the ACO, and the EEDP protocol

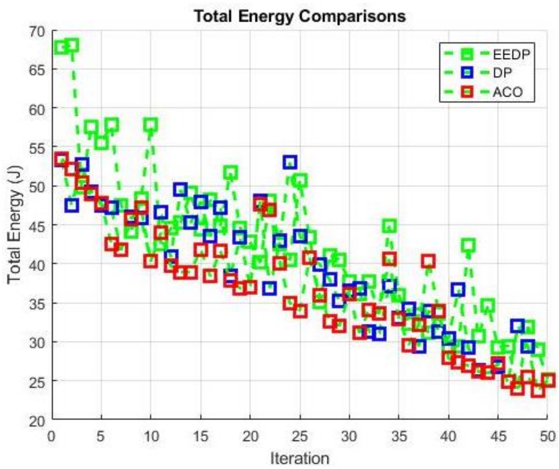

Figure 6. A comparison of the total energy from node 1 to node 45 based on the DP, the ACO, and the EEDP protocol

3.2. Prototype

We have implemented the EEDP protocol into a network topology of 10 NodeMCU ESP32 devices. We have modified the ESP-mesh protocol to comply with the EEDP protocol [30]. The distances between the nodes and the energy stored in the nodes are randomly generated as shown in Figure 7. The higher the value of the number indicates the farther the distance and the greater the stored energy. When node 01 will send text data to its neighboring nodes, namely node 02, node 03, and node 04, first node 01 will check all distances to its neighboring nodes. After that, node 01 will check all stored or remaining energy from its neighboring nodes. We have determined that a neighbor node can receive and forward text data if the remaining energy of the node is greater than 50. Then, node 01 will choose a neighboring node that has the remaining energy above 50 and has the shortest distance, namely node 03. Finally, node 01 sends its data to node 03 that has fulfilled these two conditions.

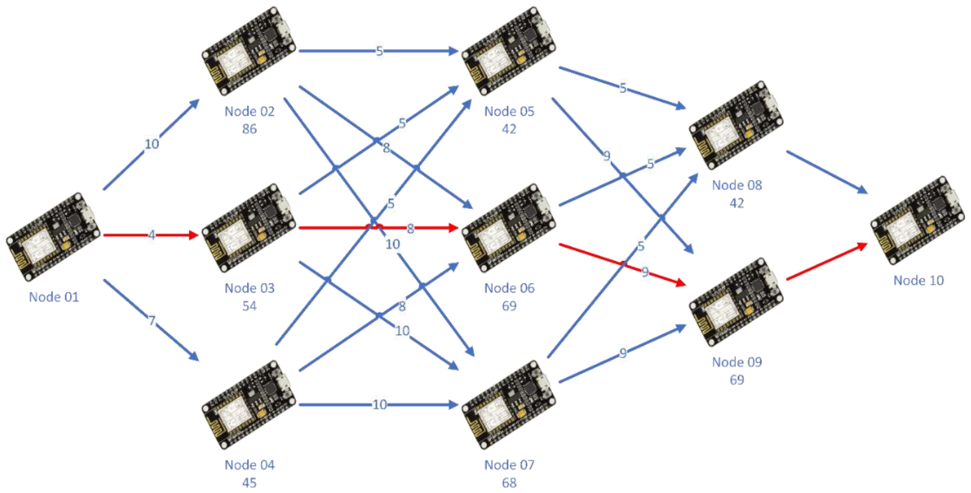

Figure 7. Route of sending data from node 01 to node 10 for iteration 1

All route options for sending data from node 01 to node 10 for 10 iterations of sending data can be seen in Figure 8. All of these routes have considered the remaining energy above 50 and the shortest distance when sending data from node 01 to node 10. The entire delay in sending data from node 01 to node 10 for 10 iterations of sending data can be seen in Figure 9. The average delay in sending data from node 01 to node 10 for the 10 iterations of sending data is 3.99 seconds.

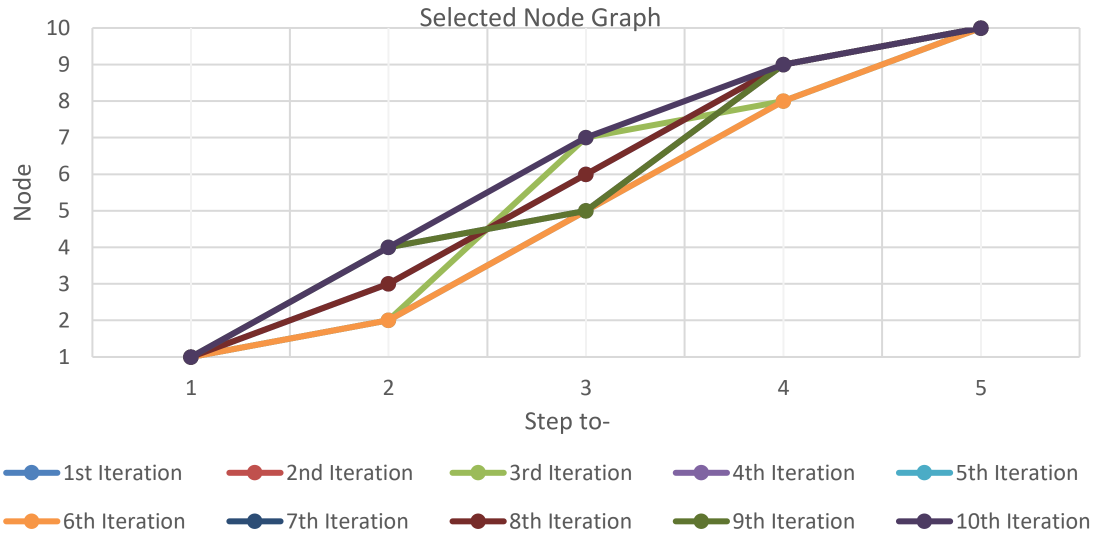

Figure 8. The steps for sending data from node 01 to node 10 for iterations 1 to 10

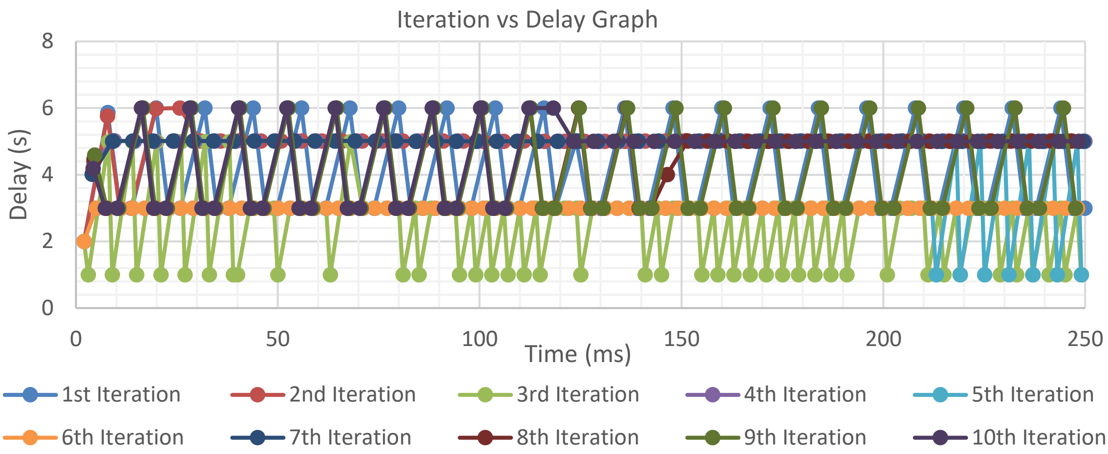

Figure 9. Route delay in sending data from node 01 to node 10 for 10 iterations of sending data

4. CONCLUSION

A routing optimization in the WMSNs that focuses on the energy threshold, the maximum energy and the link cost has been achieved by using the EEDP protocol. The simulation results show that the EEDP protocol outperforms the ACO protocol in terms of energy-efficiency of nodes and network lifetime of WMSNs. Then the EEDP protocol has also been successfully implemented into a network topology of 10 NodeMCU ESP32 devices. As a result, the EEDP protocol can function very well by selecting routes based on the shortest distance and the stored energy or the remaining energy from its neighboring nodes.

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