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Energy Efficiency Optimization for Intermediate Node Selection Using MhSA-LEACH: Multi-hop Simulated Annealing in Wireless Sensor Network

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Abstract

Energy usage on nodes is still a hot topic among researchers on wireless sensor networks. This is due to the increasing technological development increasing information requirements and caused the occurrence of information exchange continuously without stopping and impact the decline of lifetime nodes. It takes more effort to manually change the energy source on nodes in the wireless sensor network. The solution to such problems is to use routing protocols such as Low Energy Adaptive Clustering Hierarchy (LEACH). The LEACH protocol works by grouping nodes and selecting the Cluster Head (CH) in charge of delivering data to the Base Station (BS). One of the disadvantage LEACH protocols, when nodes are far from the CH, will require a lot of energy for sending data to CH. One way to reduce the energy consumption of each node-far is to use multi-hop communication. In this research, we propose a multi-hop simulated annealing (MhSA-LEACH) with an algorithm developed from the LEACH protocol based on intra-cluster multi-hop communication. The selection of intermediate nodes in multi-hop protocol is done using Simulated Annealing (SA) algorithm on Traveling Salesman Problem (TSP). Therefore, the multi-hop nodes are selected based on the shortest distance and can only be skipped once by utilizing the probability theory, resulting in a more optimal node path. The proposed algorithm has been compared to the conventional LEACH protocol and the Multi-Hop Advance Heterogeneity-aware Energy Efficient (MAHEE) clustering algorithm using OMNeT++. The test results show the optimization of MhSA-LEACH on the number of packets received by BS or CH and the number of dead or alive nodes from LEACH and MAHEE protocols.

Keywords: multi-hop communication; LEACH Protocol; Intermediate Nodes; Simulated Annealing

1. INTRODUCTION

Energy is a power that is used to perform various processes of activity. Along with the development of technology, energy consumption on a device in the network also increased. This is due to the increasing need for information which results in continuous data exchange without stopping and makes the lifetime of the device become decreased. One of the main issues on the network that is still a conversation is about energy consumption. It takes more effort to manually replace batteries on nodes in the wireless sensor network. The existence of these problems attracted the attention of researchers to overcome these problems using routing protocols such as Low Energy Adaptive Clustering Hierarchy (LEACH) [1] - [5], Home Energy Efficient Design (HEED) [6] - [9], Power-Efficient Gathering in Sensor Information Systems (PEGASIS) [10] - [15] and others [16], [17].

Routing protocols are divided into three types namely flat routing, hierarchical routing or cluster-based routing, and geographic routing. Flat routing works with all nodes passing data to the base station (BS), hierarchical routing works by grouping nodes and selecting cluster heads (CH) in charge of delivering the data to the BS, and geographic routing or geo-based routing is introduced to overcome the limitations of topology-based routing protocol and relies on the physical location information of the nodes in the WSN obtained from location services. One of the routing protocols often adopted for wireless sensor network is the LEACH protocol. This is because this protocol utilizes a hierarchical network strategy as a fully decentralized scheme [1]. Rasyid et al. [4] proposed the development of the LEACH protocol to produce a better network lifetime on wireless sensor networks. The cluster head is chosen directly by the base station to lower the energy consumption of each clustering node. The test results of this scheme show that the proposed method has better performance in the lifetime of the network than the LEACH protocol in general.

One way to lower the energy consumption of each clustering node is to use multi-hop communication [18] - [20]. In this communication, several nodes are needed to be the path between the source (cluster head) and destination (base station). Ayoub et al. [19] proposed a clustering algorithm where the cluster head is selected based on the advanced algorithm. Cluster heads are selected based on remaining energy and distance from the base station. This algorithm proposes two multi-hoping criteria namely distance based on multi-hoping and load balancing based on multi-hoping. In the first criterion, this algorithm chooses the shortest path for transmission and avoids unnecessary overhead in data. Whereas the second criterion, the optimum path is chosen according to the traffic load at the intermediate node. The test results state that the proposed algorithm can increase network life as network stability.

In this work, we propose the development algorithm of the LEACH protocol based on multi-hop communication. Cluster head selection is selected by considering the remaining energy of each node to avoid nodes

that have low energy being the cluster head. Besides, multi-hop communication is used to lower the energy consumption of each node. The selection of nodes on multi-hop is done using the Simulated Annealing (SA) algorithm on the Traveling Salesman Problem (TSP). The SA algorithm is a search algorithm that utilizes probability theory, while TSP is an optimization problem to determine the shortest distance and ensure that the path can only be crossed once [21]. So that the nodes in multi-hop are chosen based on the shortest distance and can only be skipped once by utilizing probability theory.

This research is organized as follows: Section II presents a review of previous research on the algorithm used in multihop between nodes in the cluster. Section III presents a review of the authors' contributions and originality to the study. Section IV explains the review in determining parameters, performing LEACH algorithm simulation and applying the proposed method. Section V discusses the performance of the proposed algorithm. The conclusions summarized in Section VI.

2. RELATED WORKS

Several researchers discuss the energy efficiency of CH selection, multi-hop on WSN and specifically multi-hop on LEACH using different algorithms.

Zhou et al. [6] proposed to overcome the decrease in network performance caused by failure of network nodes in unexpected environments in wireless sensor networks (WSN), a multipath routing protocol that is fault-tolerant and energy-efficient based on the idea of a hybrid clustering protocol, energy-saving (HEED), called HEED fault-tolerant (HEED-FT). The HEED-FT algorithm is proposed to improve routing reliability and energy balance between CH. Then the results from the simulation show that HEED-FT has less energy consumption, higher reliability and longer network survival than the HEED algorithm.

Sabor et al. [18] proposed in multi-hop routing CH near the base station, it acts as a liaison or relay for CH that is far from the base station. Because CH is far away which will spend energy very quickly. So they introduced a new clustering algorithm called the Unequal Multi-hop Balanced Immune Clustering (UMBIC) protocol to solve hot spot problems and increase the life span of small and large scale or homogeneous and heterogeneous wireless sensor networks with different densities.

Ayoub et al. [19] proposed a Heterogeneity-aware Energy Efficient (MAHEE) clustering path planning algorithm for wireless sensor network that can communicate between nodes within a cluster. So that the energy that has been used can be consumed more efficiently. Then in this algorithm, CH selection can be chosen where the node has higher energy as CH. Besides, multi hop routing between clusters with the assistance of advanced CH selection can increase network lifetime and stability.

Biswas et al. [20] proposed the shortest path data collection algorithm that is distributed to connect the target targets with a broad scope. This is

due to maximizing WSN lifetime associated with static multi-hop. So tracking the target in WSN can get more efficient energy.

Alnawafa and Marghescu [22] proposed a new approach to dividing the entire sensor network into several levels. So that each node will act according to its position and status. Besides, to the new approach, there are two techniques developed, namely static and dynamic. This technique is used to route data between levels. The result study of Improved multi-hop technique (IMHT-LEACH) shows that the proposed technique prolongs life, increases stability and increases network throughput compared to LEACH and multi-hop technique (MHT-LEACH) protocols. Next, the two techniques described, Static and Dynamic Techniques, were developed.

3. ORIGINALITY

In this part, we developed the algorithm of LEACH protocol based on intra-cluster multi-hop communication. Therefore, intra-cluster multi-hop communication has many nodes in the cluster. Thus, the results of the data can be obtained more optimal than inter-cluster communication. We use the LEACH protocol because this protocol utilizes a hierarchical network strategy by grouping nodes and selecting CH to convey information to BS. Cluster head selection is chosen by considering the residual energy of each clustering node to avoid nodes that have low energy being the cluster head. Besides, multi hop communication is used to lower the energy consumption of each clustering node leading to CH. The selection of nodes in multi-hop is performed using the algorithm Simulated Annealing (SA) on Traveling Salesman Problem (TSP). The SA algorithm in the TSP used was adopted in the research of Rao et al.[21] who compared the SA-TSP and GA algorithms on the Supply Chain Network. In this paper, nodes in multi-hop will be selected based on the shortest distance and can only be skipped once by utilizing probability theory, thus producing a more optimal node path.

4. SYSTEM DESIGN

In this research, we divided the system into 3 phases including the following: (1) Determine the required parameters, (2) Perform a simulation of LEACH and MhSA-LEACH algorithms which are simulated in OMNeT++, (3) Test the algorithm and display the experiment graph. Figure 1 shows the system design of this study, where each step in the design will be explained in more detail in sections 4.1-4.3.

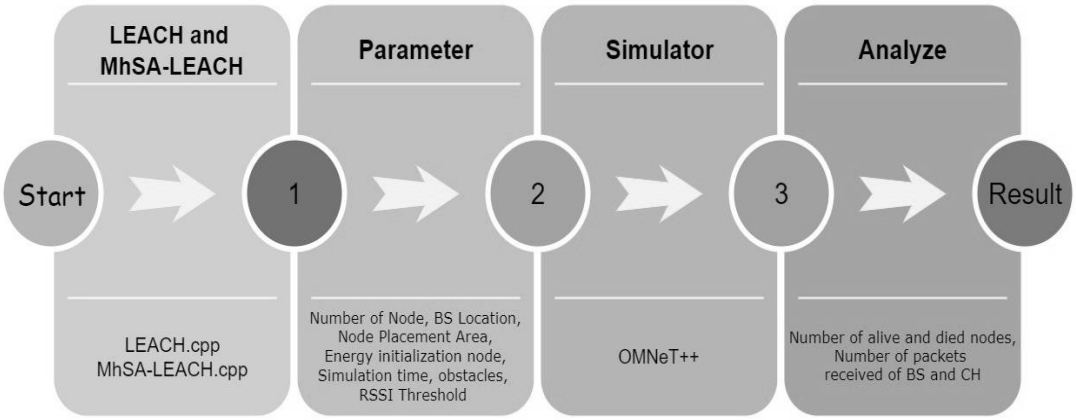

Figure 1. Research system design

4.1 Determine the required parameters

The first step is to determine the parameters required in the LEACH and MhSA-LEACH algorithms. Among the parameters needed are node placement, location of BS, node placement area, energy initialization for each node, number of nodes, simulation time, hindrance, and RSSI threshold. The initialization of the parameters used is shown in the table 1:

Tabel 1. The value of the parameters used

Simulation parameters	**Value**
Node Placement	Random
Location of BS	Center
Node Placement Area (meter)	1000 X 1000 m.
Energy initialization for each node (joule)	5 J
Number of nodes	100
Simulation time (round)	5000
Hindrance	No
RSSI Threshold	-60dbm

4.2 Perform a simulation of the LEACH and MhSA-LEACH algorithm which are simulated in OMNeT++

4.2.1 LEACH

LEACH is a hierarchical-based routing method that aims to energy efficiency in the network by dividing nodes into clusters. The LEACH algorithm starts by selecting a node as Cluster Head (CH) then by clustering algorithm selects the non-CH node as a member so that it forms a cluster. This mechanism saves energy because only the CH transmits data to BS, then each node only sends data to the respective CH. As a result, energy consumption is reduced so that the network lifetime is optimal. A block diagram of the wireless sensor network system on the built LEACH can be seen in Figure 2.

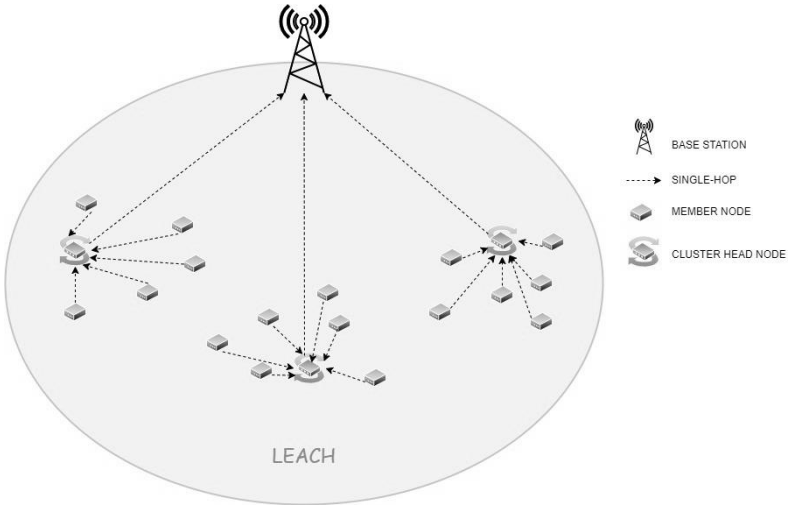

Figure 2. System block diagram on LEACH

The system consists of one BS and 100 sensor nodes or so-called nodes. The node has the function to scan data from the environment and transmit sensor readings data to BS. Besides, the node also acts as a relay in the network whose job is to forward data from the node to BS. In this case, referred to as Cluster Head (CH). Each node has identical properties. The BS acts as the center of data aggregation of all the nodes on the network. Each node communicates wirelessly using the XBee module with a range that is still within range. The process of forming a network using the LEACH protocol consists of two phases, namely the setup phase and the steady state phase. The setup phase is a cluster formation phase where CH is chosen in this phase. Each node has the same opportunity to become CH. The determination of CH is determined based on random numbers generated by each node. The node will be the cluster head if the random value raised on it is smaller than $P_i(t)$.

$$P_i(t) = \begin{cases} \frac{k}{N - k * \left(r \bmod \frac{N}{k}\right)} & : C_i(t) = 1 \\ 0 & : C_i(t) = 0 \end{cases} \quad (1)$$

Nodes have a small random value of $P_i(t)$ will only be selected to be CH in the previous delivery round (r) or those that have a value of $C_i = 0$. Thus, each node will become CH once every N/k round. Where N is the number of nodes in a network and k is the number of clusters. If the probability of cluster formation is b, then k can be found by the following equation:

$$k = N \; x \; b \quad (2)$$

That way equation 2 can be simplified into:

$$P_i = \frac{p}{1 - b \; x \bmod \left(r, \frac{1}{b}\right)} \quad (3)$$

After CH is selected in each cluster, each node chooses to follow CH based on the signal power it receives. After the set-up phase is finished, the process continues to the steady-state phase. In steady-state phase, the nodes that are joined to each cluster start scanning the environment. Scan data obtained by each node is forwarded to CH. Then CH gather data from each clustering node and sends the data to the BS.

After all the data from the generation of nodes to sending data from node to node, the next is describing radio energy or calculating energy usage in the simulation. This radio energy model is used to estimate the energy usage of each clustering node. The biggest energy consumption is when sending data from the node to BS. The energy used is directly comparable to the distance node to BS, the farther distance BS, the energy needed to send data will be even greater.

4.2.2 Proposed Method

The proposed MhSA-LEACH protocol discusses the issue of sending data from the node to CH, then CH to BS. The problem of transmitting data by optimal selection has a significant impact on overall energy waste. Initially, the packet is sent between nodes in the cluster which contains the characteristics of the node as follows: remaining energy, initial energy, location of the node with status (dead or alive). In the CH selection algorithm, N_k shows the number of iteration nodes to be CH. Then generate efficient cluster information to choose the optimal CH. To calculate the remaining energy (E_r), it can be calculated as follows in equation 4:

$$E_r = \sum_{k=1}^{N} E_k\,(r)\; x\; \frac{1}{N_k} \tag{4}$$

(E_k) is an initial energy each round that changes according to the variable value (k). The number of cluster heads needed can be calculated in equation 5:

$$C_{opt} = C_k \frac{E_k}{E_r} \tag{5}$$

C_{opt} indicates the desired value as CH, similarly the threshold will be shown in equation 6 for the final decision of choosing CH with the following probabilistic equation (P):

$$P = \begin{cases} \dfrac{C_{opt}}{1 - C_{opt} * \left(r \bmod \frac{1}{C_{opt}}\right) x\, D} \\ 0 \end{cases} \tag{6}$$

For the current round r during D, indicate the distance from node to BS. Each node on a random number will produce a number that will be compared with the threshold value. If the threshold value (P) is greater than a random number, this node will become a member. If it is not greater, then CH is chosen for the current round r. Distance D support in the selection of the current CH. The condition on the equation 6 of probability is final decision of choosing CH where after CH optimal is selected with probability. Nodes at the minimum distance from the BS will be combined with the largest CH energy calculation. Thus, choosing CH with node distance to the closest BS distance will extend the lifetime of the node.

1. Set-up phase

   This phase aims to create a cluster and find the CH of each cluster. CH selection is based on the MhSA-LEACH algorithm. During the set-up phase, each node sends its location and energy level information to the BS. In the MhSA-LEACH algorithm the optimal CH determination, BS ensures that the energy load is distributed to all nodes. BS also calculates the average energy of each node and the CH selection is done by selecting the most remaining energy from each node to avoid the node that has low energy becomes CH. Besides, multi-hop communication is used to lower the energy consumption of each node.
2. Steady-state phase

   After the cluster is formed and CH is selected, the node closest to CH directly sends the data to CH but the node farthest from CH requires a lot of energy for sending data to CH. In the MAHEE protocol, CH is chosen based on the highest energy and multi-hop usage of each node in the cluster is better than LEACH. The following figure 3 results from the Multi-Hop Advance Heterogeneity-aware Energy Eficient Path Planning Algorithm for WSN (MAHEE):

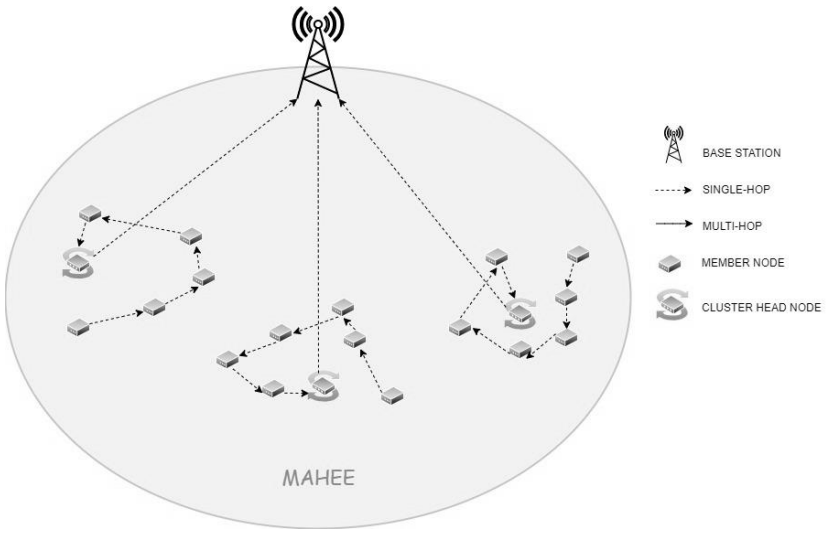

Figure 3. Multi-Hop Advance Heterogeneity-aware Energy Efficient Path Planning Algorithm for WSN (MAHEE)

Figure 3 above shows that the selected CH may still be far from BS even though CH has the highest energy of each cluster. In the proposed MhSA-LEACH protocol, CH selection does not only look at the highest energy but nodes that are close to BS. Then the selection of nodes in multi-hop is done in a cluster between nodes with the nearest neighbor node up to CH using the Simulated Annealing (SA) algorithm for Traveling Salesman Problem (TSP). So that the energy used for nodes far from CH can be more efficient and the network lifetime can be longer than the steady state phase in LEACH. SA for TSP is an algorithm with a searching method that utilizes probability theory to find the minimum global optimization problem. Simulated Annealing also seeks to find solutions by moving from one solution to another, and if the new solution being tested has a smaller energy function value, then the solution being tested will replace the old solution. Generally, the new solution chosen is a solution that is near or around the old solution. This method is an adaptation of the Metropolis-Hasting algorithm, which is a type of Monte Carlo method, to create the required sample state. The SA flowchart for TSP in multi-hop problem is shown in Figure 4:

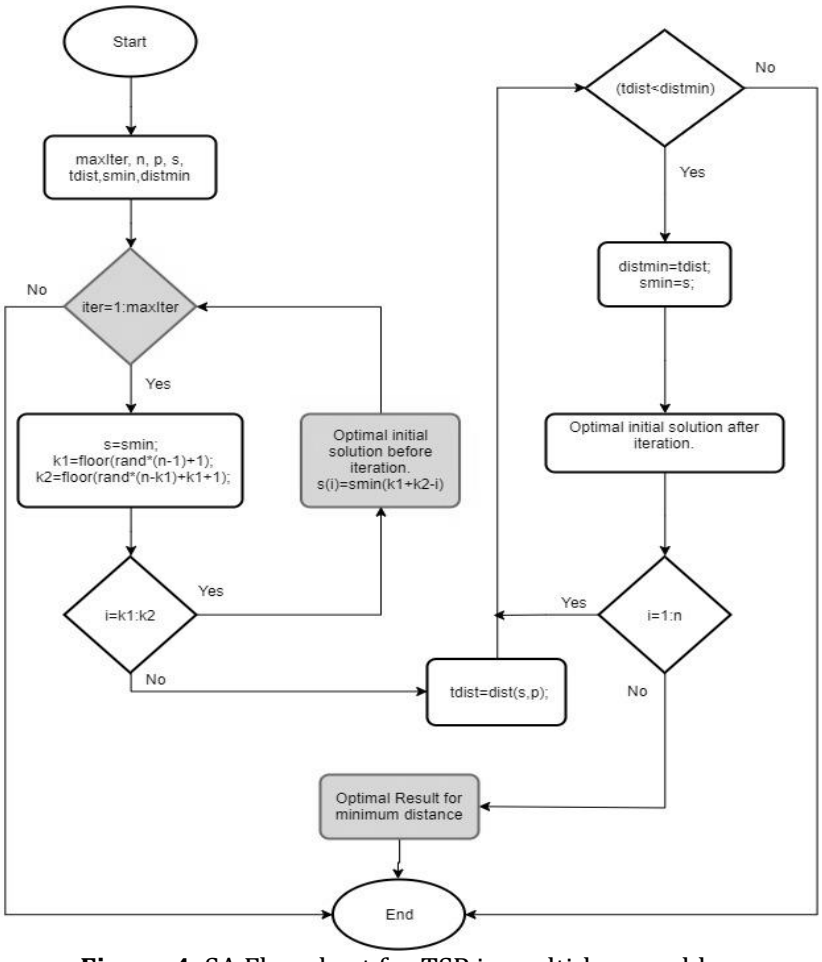

Figure 4. SA Flowchart for TSP in multi-hop problem

In Figure 4, we add the maximum number of iterations to checking the number of nodes in each cluster. After selecting the maximum number of iterations, the next optimal path is chosen from the other paths. This takes a long time compared to the MAHEE protocol but the results obtained are more optimal in multi-hop problems. In SA, a solution is known as a state. A state needs to have a measure of whether or not the state is good. good measure of whether or not the state is expressed with energy. Because SA is designed for the case of minimization, the final energy must be less than the initial energy. The following proposed algorithm of SA for TSP is explained in Figure 5.

```
Create initial state
set initial Energy Tstart
while Enow > Eend
      repeat n times
            generate newState
            EnergyChange = (new energy – old energy)
            if EnergyChange < 0
                  currentState = newState
            elseif rand (0,1) < exp (- EnergyChange / E),
                  currentState = newState
            endif
      end repeat
      decrease E
end while
```

Figure 5. SA Algorithm for TSP

This step consists of building a solution from the input of random nodes on its placement then getting the solution by default then getting the optimal solution with the lowest distance shown in Figure 6:

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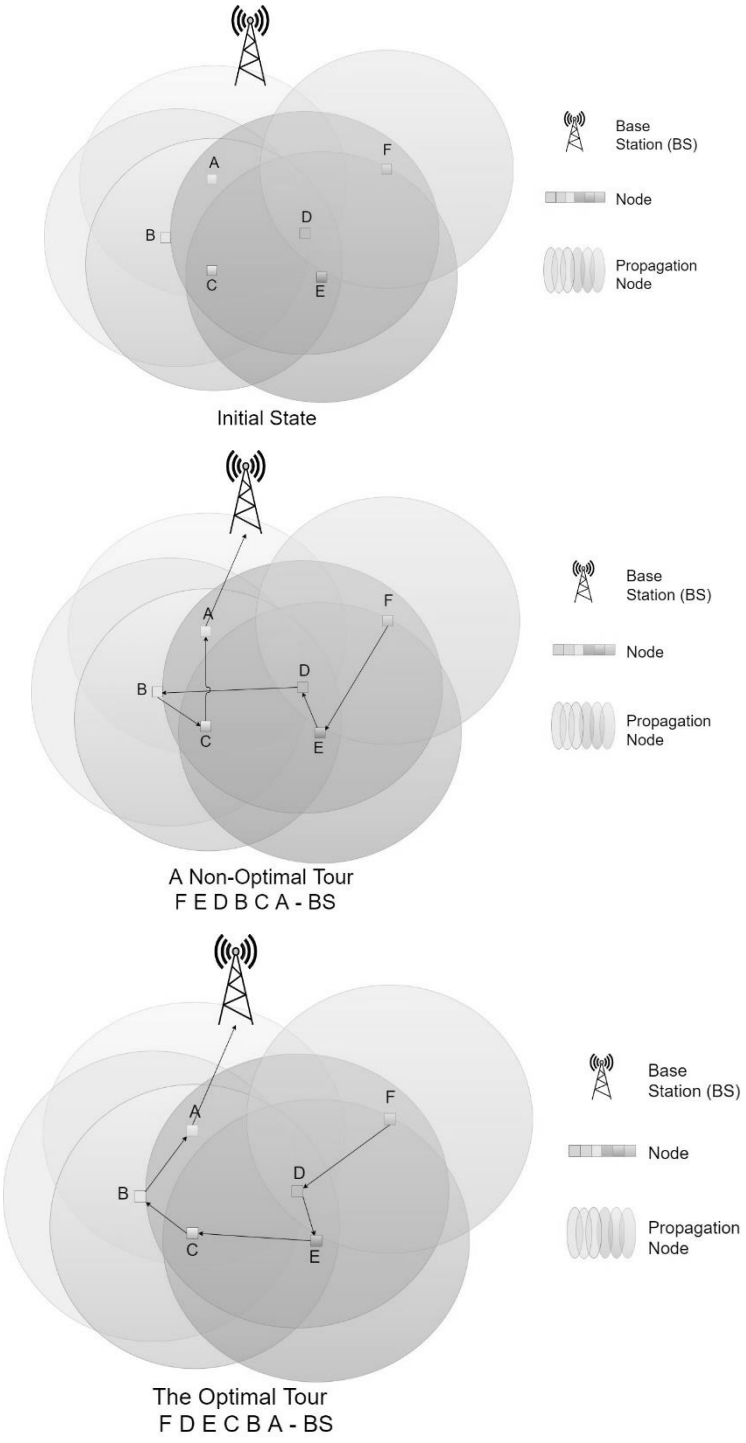

Figure 6. The optimal solution steps of SA for TSP

After the optimal solution steps are obtained by Figure 6, the algorithm is implemented in multi-hop for intra-clusters in the CH members. CH has been selected based on the highest energy of each

clustering node. The following figure 7 results from Multi-hop Simulated Annealing for TSP LEACH (MhSA-LEACH).

The illustration shown in Figure 7 shows that the node having the farthest distance from CH requires an intermediate node to send data to CH. The data sent will pass through several nodes to reach the closest node to CH. So that data from the farthest node can get to CH with lower energy consumption than without going through an intermediate node (single-hop).

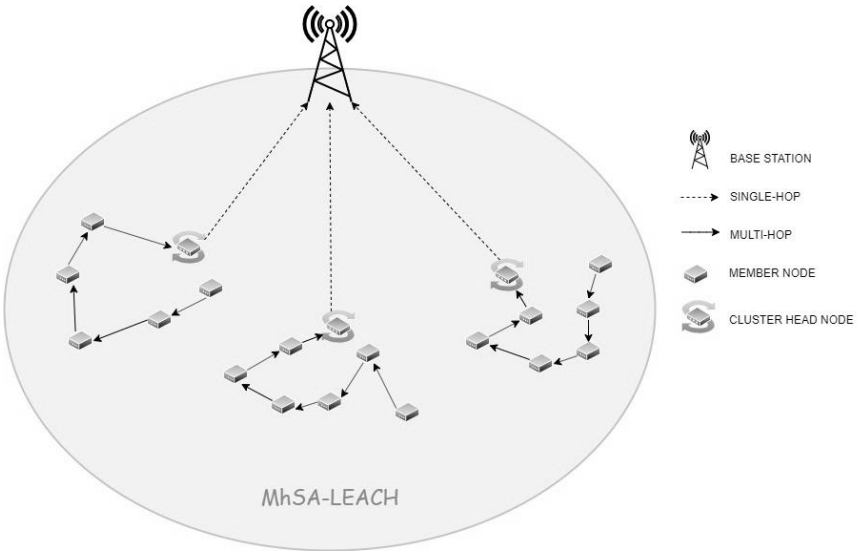

Figure 7. Multi-hop Simulated Annealing for TSP LEACH (MhSA-LEACH)

4.3 Test the algorithm and display the experiment graph

This step of the LEACH, MAHEE, and MhSA-LEACH algorithm will be simulated. In this research using OMNeT++ to simulate them. LEACH, MAHEE, and MhSA-LEACH algorithms that have been simulated will get results. And the results will be further processed. After the compilation results are obtained, the graph includes the number of dead nodes, the number of alive nodes, the number of packets received by BS, and the number of packets received by CH.

5. EXPERIMENT AND ANALYSIS

In this section, we will explain the protocol analysis shown by MhSA-LEACH compared to the LEACH protocol and Multi-Hop Advance Heterogeneity-aware Energy Efficient Path Planning Algorithm for WSN (MAHEE). In table 2, some attributes are used in the comparison of LEACH, MAHEE, and MhSA-LEACH algorithms. The following comparison of LEACH, MAHEE, and MhSA-LEACH algorithms is shown in table 2.

Table 2. Comparison LEACH, MAHEE, and MhSA-LEACH algorithm

Algorithm	**LEACH**	**MAHEE**	**MhSA-LEACH**
Communication Scheme	Single-hop	Multi-hop	Multi-hop
Complexity	Low	Medium	High
Cluster Head Selection	Random	Choose node has the highest energy **or** nearest BS	Choose node has the highest energy **and** near BS
Scalability	Poor	High	High
Load Balancing	No	Yes	No
Number of Dead Nodes	Lots	Medium	Few
Number of Packets Received by BS or CH	Little	Many	Very Many
Number of Alive Nodes	Short	Long	Very Long
Advantages or Disadvantages of Computation	Fast Computation Time from MAHEE and MhSA-LEACH	Fast Computation Time from MhSA-LEACH	Slow Computation Time
Optimal Results	Low	High	Very High

In the research using OMNeT++ to simulate it, several tested parameters are the number of dead nodes, number of packets received by BS, number of alive nodes and number of packets received by CH.

5.1 The Number of Dead Nodes

The number of dead nodes in the test is used to test the reliability of the LEACH, MAHEE, and MhSA-LEACH algorithms. With the results of a dead node, it indicates that the node that has run out of energy can no longer send data on the next round. The results of the dead node are shown in Figure 8 at each turn:

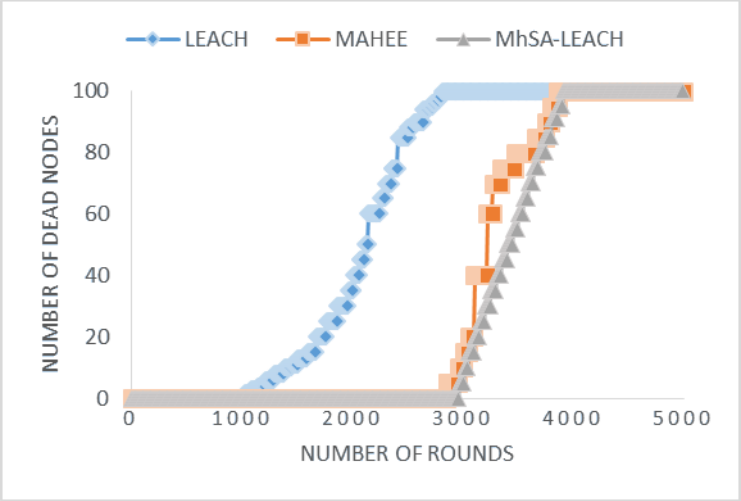

Figure 8. Number of Dead Nodes

The illustration shown in Figure 8 shows that the number of dead nodes for LEACH starts at some nodes after 1030, 1400, and 2100 rounds. The nodes die when 2820 turns. For MAHEE, the node dies when in round 2860, as for the protocol we propose (MhSA-LEACH) the node dies when in round 2970. After several subsequent rounds, the results obtained for MAHEE and MhSA-LEACH almost have in common the number of dead nodes. However, MhSA-LEACH is more optimal than MAHEE.

5.2 Number of Packets Received by Base Station (BS)

The number of packets received by BS is used to test the number of packages in the LEACH, MAHEE, and MhSA-LEACH algorithms. The number of packets received by BS shows that the number of packets received by BS from each node has a longer network lifetime. The results of the number of packets received by the BS are shown in Figure 9 at each turn:

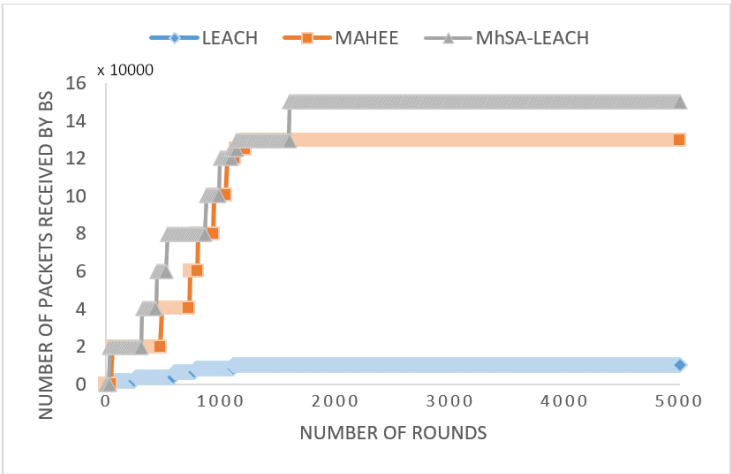

Figure 9. Number of Packets Received by BS

The illustration shown in Figure 9 shows that the number of packets received by BS for LEACH is far less than the others. Comparison of MAHEE and MhSA-LEACH showed MhSA-LEACH is better than MAHEE starting at 310 rounds. At 1600 rounds for the number of packets received by the BS start to differ from the previous round with a significant difference.

5.3 The Number of Alive Nodes

The number of live nodes in subsequent tests after testing the dead nodes is also used to see more optimal results from the LEACH, MAHEE, and MhSA-LEACH algorithms. for alive nodes, indicating that nodes that have more energy consumption can continue to send data at the next round. The results of the live node are shown in Figure 10 at each turn:

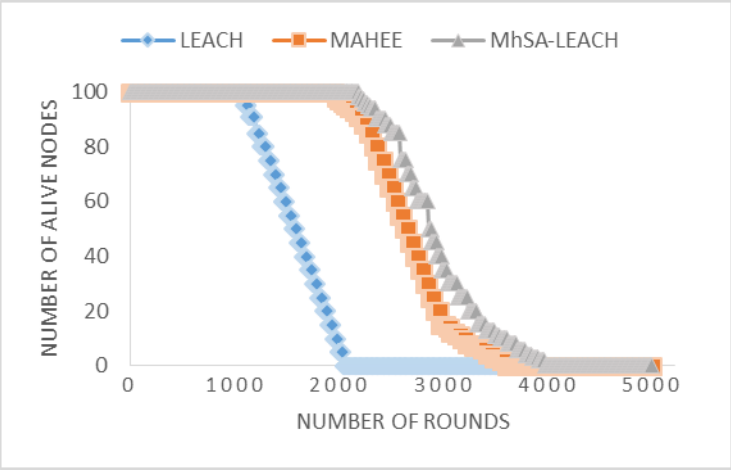

Figure 10. Number of Alive Nodes

The illustration shown in Figure 10 shows that the sum of all live nodes for LEACH only reaches rounds after 1090 rounds. The nodes die when 2030 rounds. For MAHEE, all nodes only alive to 1960 rounds. For the MhSA-LEACH protocol, all nodes only alive to 2170 rounds. After the next few rounds, the results obtained for MAHEE and MhSA-LEACH almost have another similarity for the number of alive nodes. However, MhSA-LEACH is more optimal than MAHEE.

5.4 Number of Packets Received by Cluster Head (CH)

The number of packets received by CH is used to test how many packages or data it sees on the LEACH, MAHEE, and MhSA-LEACH algorithms. The number of packets received by CH shows that the number of packets received by CH from each node has a longer network lifetime in the cluster. The results of the number of packages received by CH are shown in Figure 11 at each turn.

The illustration shown in Figure 11 shows that the number of packets received by CH for LEACH is less compared to others. Comparison of MAHEE and MhSA-LEACH, showed MhSA-LEACH is better than MAHEE starting at

610 rounds. At 2780 rounds the number of packets received by BS differed from the previous round with a significant difference because some nodes in MAHEE protocol have died compared to MhSA-LEACH.

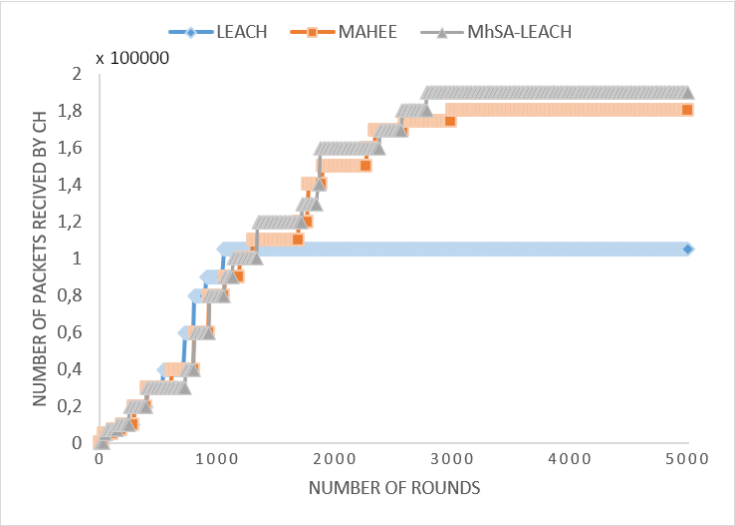

Figure 11. Number of Packets Received by BS

The MhSA-LEACH in number of packet received by BS or CH and number of alive or dead node considers all the nodes (member) in the network to communicate with another node and CH. In this way, the member node is located so far from the CH and cannot communicate directly because it can remotely send information to the CH by communicating with the member node of another cluster. In the proposed algorithm each cluster has CHs and member nodes, these member nodes send their data to CH using multi-hop communication. MhSA-LEACH has the ability to select the shortest path for multi-hop routing in inter-cluster communication. MhSA-LEACH is proposed to solve the energy dissipation problem by choosing the optimal CH and optimal path that considers multi-hop communication between clusters to use the same energy from all nodes.

6. CONCLUSION

In this paper, the method of multi-hop routing protocol involves intermediate node selection to forward a packet from one node to another with the aim to CH has been proposed. This method is implemented in the LEACH protocol. We use the Simulated Annealing algorithm for TSP in the intra-cluster multi-hop process in intermediate nodes selection called Multi-hop Simulated Annealing LEACH (MhSA-LEACH). In the MhSA-LEACH algorithm for optimal CH determination, BS ensures that the energy load is distributed to all nodes. Base Station also calculates the average energy of each node and the selection of CH is done by considering the remaining energy of each node to avoid nodes that have low energy into CH. Protocol analysis of the proposed method shows that MhSA-LEACH is more optimal at

the number of dead and alive nodes. Then the number of packets received by BS and CH shows that MhSA-LEACH is still more optimal than MAHEE and LEACH. For further research, MhSA-LEACH testing should also be done in LEACH protocol on inter-node cluster where the intermediate nodes are CH.

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