Developing Multi-Tier Network Design for Effective Energy Consumption of Cluster Head Selection in WSN

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ABSTRACT

Clustering in Wireless Sensor Network (WSN) is one of the methods to minimize the energy usage of sensor network. The design of sensor network itself can prolong the lifetime of network. Cluster head in each cluster is an important part in clustering to ensure the lifetime of each sensor node can be preserved as it acts as an intermediary node between the other sensors. Sensor nodes have the limitation of its battery where the battery is impossible to be replaced once it has been deployed. Thus, this paper presents an improvement of clustering algorithm for two-tier network as we named it as Multi-Tier Algorithm (MAP). For the cluster head selection, fuzzy logic approach has been used which it can minimize the energy usage of sensor nodes hence maximize the network lifetime. MAP clustering approach used in this paper covers the average of 100Mx100M network and involves three parameters that worked together in order to select the cluster head which are residual energy, communication cost and centrality. It is concluded that, MAP dominant the lifetime of WSN compared to LEACH and SEP protocols. For the future work, the stability of this algorithm can be verified in detailed via different data and energy.

Keywords: *wireless sensor network, energy, clustering, cluster head, multi-tier, fuzzy logic*

INTRODUCTION

Wireless Sensor Network (WSN) is defined as a network of devices indicated by nodes that can sense and communicate the gathered data from the monitored field through wireless link [1]. Sensor node has the limitation of its battery where the battery is impossible to be replaced once it has been deployed [2]. Thus, energy control is needed in order to sustain and minimize the power usage of the sensor energy. The sensor network lifetime can be prolonged by efficient use of its energy.

In WSN, clustering is one of the popular methods for grouping the sensor nodes and it has numerous advantages [3]. Clustering can support network scalability, reduce the size of routing tables which are sorted at each of the sensor nodes and can prolong the network lifetime [4, 5]. In each of the cluster, it should have at least one cluster head (CH) that acts as an intermediary between the sensor nodes and the base station. Two types of clustering can be formed namely the static and dynamic clustering [2]. In the static clustering, the cluster cannot be changed for the whole network lifetime as opposed to the dynamic clustering, where the cluster can be changed depending on the network characteristics. Routing protocol design is important in clustering. Efficient routing protocol can minimize the sensor nodes energy usage.

Hierarchical clustering is popular among the researchers [6]. To date, there is no benchmark in hierarchical clustering method especially the number of tiers involved in the clustering. The distribution of sensor nodes in multi-tiers clustering is important when implementing multi-tiers network where data transmissions from sensor node to the base station require minimum energy dissipation. Therefore, multi-tiers network design with accurate node distribution and better routing protocol can reduce the energy usage of sensor nodes hence prolonging the network lifetime.

The two-tiers clustering approach is used in this study cover the average network of 100Mx100M. Each of the tiers has its own cluster head to control the data transmission from sensor node to the base station. Normally, the selection of cluster head depends on one parameter which is the remaining energy [7, 8]. In this study, there are three parameters worked together in order to select the cluster head; residual energy, communication cost and centrality. These parameters have proven that, the selection of cluster head can minimize the energy usage for the whole network lifetime [8].

APPROACH

In this study, was introduced new algorithm for multi-tier network design which covers the cluster head selection via Fuzzy Logic and primary nodes location at each tiers for data transmitting.

Figure 1 shows the algorithm for initialization phase. In this phase, the areas of sensor network are set to the coverage of 100 meter for x-axis and 100 meter for y-axis. The network width has been decided based on LEACH. Network field were divided into 2-tiers which are tier one and tier two. Location of the base station has been used as a benchmark to design the tiers. It is divided according to 50 meters each. The base station was allocated at the center of network field. The coordinate for the base station is (50, 50). Minimizing the distance between the nodes and the base station tends to reduce the usage of the energy [9–11].

```
START
        set the network coverage to 100mx100m
        place BS location at center of network
        define tier 1 and tier 2 radius
        distribute x nodes randomly inside tier 1
        distribute y nodes randomly inside tier 2
END
```

Figure 1: Algorithm 1-Initialization Phase

Second phase is sensor node distribution. This is based on formula of circle (1[12, 13].

$$A = \pi r^2 \qquad (1)$$

Based on Equation (1), the distribution of sensor nodes is well explained as follows;

A = Area for 1st layer
Area of big circle, B = π (2r)2
= 4πr2
Area of second layer = B – A
= 3πr2

The proportion of sensor nodes at tier one are 25 nodes and 75 sensor nodes at tier two. The third phase of MAP algorithm is to select the primary nodes. This is based on K-optimal formula [14].

$$K_{optP} = \frac{\sqrt{N_s}}{\sqrt{2\pi}} \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \frac{M}{d_{toBS}^2} \quad \backslash s \qquad (2)$$

The description as follows;

K_{optP}	=	Optimal number of primary node
Ns	=	Number of nodes distributed randomly in a AxA region
Ɛ_fsd2	=	amplifier energy (10* 0.00000000001)
Ɛ_mpd4	=	amplifier energy (multi-path) (0.0013*0.00000000001)
d	=	distance between transmitting node and base station
d to BS	=	average distance between nodes and base station (50m)

The value for both amplifier energies have been taken from [14–16]. For MAP algorithm, the total number of sensor nodes at tier one are 25 nodes and for tier two are 75 nodes. From the original formula, the number of sensor nodes, N are equal to 100 nodes but after the modification, the numbers of nodes Ns, follow the numbers that are assigned earlier for each of the tiers as Equations (3) and (4).

$$K_{optP\,1} = \frac{(round)\sqrt{(noTier1)}}{\sqrt{2 * \pi}} * \sqrt{\frac{Efs}{Emp} * \left(\frac{M}{d2bs^2}\right)} \quad \backslash s \qquad (3)$$

$$K_{optP\,2} = \frac{(round)\sqrt{(noTier2)}}{\sqrt{2 * \pi}} * \sqrt{\frac{Efs}{Emp} * \left(\frac{M}{d2bs^2}\right)} \quad \backslash s \qquad (4)$$

K_optP2 represents the total number of primary node in the tier two. Based on the results, each tier identifies the total of primary nodes. For tier one, there are seven primary nodes and for tier two, there are twelve primary nodes. So each tier has its optimal primary nodes. The above equations have been applied in Algorithm 2 as shown in Figure 2.

```
START
        FOR each tier 1 and tier 2
        calculate fitness of all primary nodes using Equation 2
        select top alive nodes to become primary nodes based on Equation 3 and 4
        END
END
```

Figure 2: Algorithm 2- Primary Node Selection

The fourth phase of developing MAP algorithm is cluster head selection. The cluster head selection will be based on Fuzzy Rules as shown in Table 1. For the three parameters involved, each input variable has three linguistic states. So, it indicates the total possible number of fuzzy inference rules is 3x3x3 = 27 rules. Table 1 shows the 27 rules for the three parameters. The output variables are the chances of the sensor nodes to become a cluster head. The higher the value of the output, the greater the sensor nodes to become a cluster heads. Figure 3 shows the algorithm for selecting the cluster head.

```
START
    FOR each tier
        FOR each node
            IF node is alive
                calculate CH fitness / suitability of node based on FL rules
                select x best CH based on best fitness
    END
        END
            END
END
```

Figure 3: Algorithm 3 - Cluster Head Selection

Table 1: Parameter Fuzzy Rules [12]

Rules	Residual Energy	Communication Cost	Centrality	Chances
1	High	High	Far	Medium
2	High	High	Near	Medium
3	High	High	Satisfactory	Medium
4	High	Medium	Far	Medium
5	High	Medium	Near	Medium
6	High	Medium	Satisfactory	Strong
7	High	Low	Far	Medium
8	High	Low	Near	Strong
9	High	Low	Satisfactory	Strong
10	Medium	High	Far	Weak
11	Medium	High	Near	Medium
12	Medium	High	Satisfactory	Medium
13	Medium	Medium	Far	Medium
14	Medium	Medium	Near	Medium
15	Medium	Medium	Satisfactory	Medium
16	Medium	Low	Far	Medium
17	Medium	Low	Near	Medium
18	Medium	Low	Satisfactory	Strong

19	Low	High	Far	Weak
20	Low	High	Near	Weak
21	Low	High	Satisfactory	Medium
22	Low	Medium	Far	Weak
23	Low	Medium	Near	Medium
24	Low	Medium	Satisfactory	Medium
25	Low	Low	Far	Medium
26	Low	Low	Near	Medium
27	Low	Low	Satisfactory	Medium

Next phase is cluster formation. To prolong the energy for each of the sensor nodes, it should be placed in the cluster. Each cluster should have a cluster head which is responsible to control all the activities in the cluster. So, the clusters need to be formed. For the cluster formation, sensor nodes with the nearest coordinate to the cluster head, it will join the respective cluster. For all nodes at each tier, the clusters are formed by placing the adjacent nodes under the CH that have been defined previously in Algorithm 3. The algorithm for the cluster formation is shown in Figure 4.

```
START
    FOR all nodes in tiers
    IF nodes is CH and alive
      form cluster by placing adjacent nodes under that CH
  END
      END
END
```

Figure 4: Algorithm 4 - Cluster Formation

The last phase of MAP is data transmission. For tier one, any node from each cluster will send the data to its cluster head. The cluster head then will collect, aggregate and compressed the data from of all its member nodes. Then the data will be sent to the nearest primary node. The primary node only sends the data that are received from the cluster head to the base station. This process is shown in Algorithm 5 and 6 as in Figure 5 and Figure 6 respectively.

```
tier 1/ tier 2 CH to Primary node
START
    FOR each CH
        IF CH alive
            send data to the nearest primary node
    END
        END
END
```

Figure 5: Algorithm 5 – Data Transmission from Tier 1/ Tier 2 CH to Primary Node

```
primary node tier 1 to BS
START
    FOR each primary node tier 1
        IF primary tier 1 alive
            send data to BS
    END
        END
END
```

Figure 6: Algorithm 6 - Data Transmission from Primary Node Tier 1 to BS

At tier two, member nodes at the particular cluster will send the data to its cluster head and the cluster head will receive, compress and gather the data. This is the same process as cluster head in tier one. After that, the cluster head will send the data to its primary node. Primary node at tier two will find the nearest primary node at tier one to pass the data. Then, the data will be forwarded by primary node at tier one to the base station. The base station will have all the data that are requested by the users. These processes are described in Algorithms 7 and 8 as shown in Figure 7 and Figure 8 respectively.

```
    tier 1/ tier2 to CH
    START
          FOR each node
               IF node alive
                  send data to CH
           END
              END
END
```

Figure 7: Algorithm 7 – Data Transmission from Tier 1 / Tier 2 to CH

```
    primary node tier 2 to primary node tier 1
    START
            FOR each primary node tier 2
                 IF primary node tier 2 alive
                    send data to the nearest primary node tier 1
             END
                END
END
```

Figure 8: Algorithm 8 – Data Transmission from Primary Node Tier 2 to Primary Node Tier 1

RESULTS AND DISCUSSION

These algorithms have been simulated using MATLAB tools. The multi-tier network designs have been developed and the final design of the algorithm is shown in Figure 9. The purposed algorithm is then compared with LEACH and SEP for validation. Figure 9 shows the new design for two-tier network. The sensor area for tier one radius located from the base station is 25 meters and the area covers from 50 meters of the network design. For the tier two, it also covers 50 meters of the network with the radius of 50 meters from the base station. The design suits for the scalability if the network expands. The location of the base station also contributes to energy dissipation. This happens, when the base station is located far away from the sensor network, it will increase the distance between the sensor node and base station. This situation causes energy dissipation which will be highest while sending data to the base station [13].

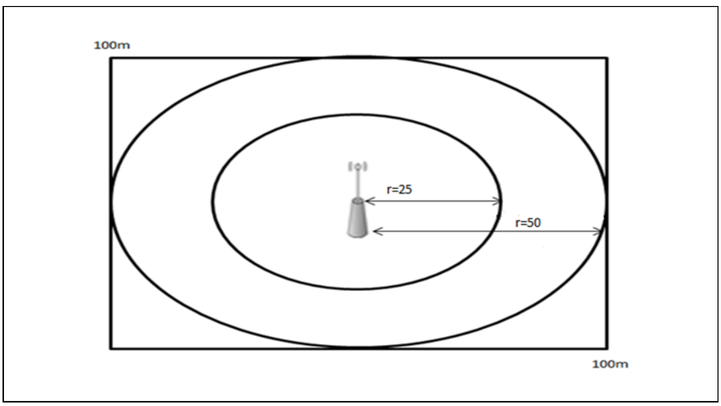

Figure 9: 2-tier Design

Figure 10 shows the sensor nodes distribution for each of tier based on Algorithm 1 as mentioned in Figure 1. There are 25 sensor nodes randomly distributed for tier one as dotted with blue colours and 75 sensor nodes dotted in red colours which located at tier two. Each of the sensor nodes has information about their details such as node ID, initial energy, location of the nodes, location of its tier, centrality and also the value of the communication cost.

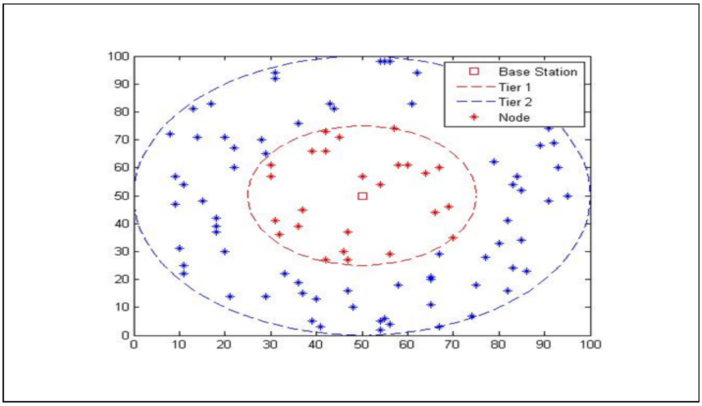

Figure 10: Sensor Nodes Distribution

Figure 11 is a design that refers to the algorithm in Figures 2 and 3. It is returned the number for the primary node which is 7 and 12 for Tier 1 and Tier 2, respectively. The sensor nodes located in these tiers are starred with red colours. They are known as primary node. These nodes in each tier are responsible to receive the data from the cluster head and send to the base station. The selection of the cluster head was based on the Fuzzy Logic approaches according to the Fuzzy Rules that have been designed previously in Table 1. The cluster head are starred with pink colours for both tiers 1 and 2. Cluster head received data from the sensor node in their clusters, gathered, compressed and sent it to the base station.

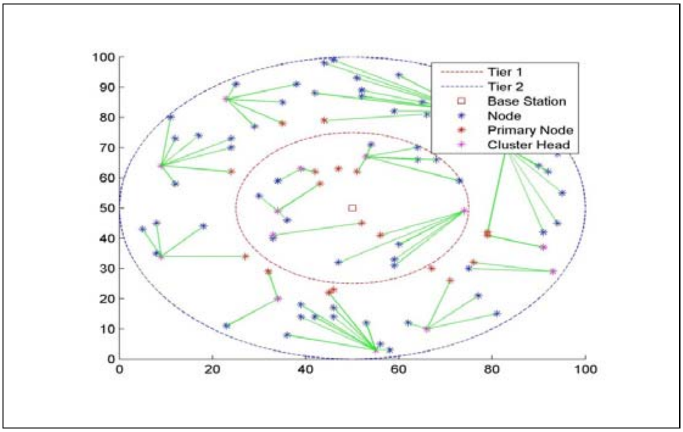

Figure 11: Primary Node and Cluster Head Location

The cluster was formed when all the sensor nodes received the message from the cluster head. The nearest node to the cluster head will join the cluster head and form a new cluster. This new cluster area is shown by either blue line circle for Tier 1 or blue dash circle for Tier 2. Sensor nodes in the respective clusters sent the data to their cluster heads that were starred with pink colour. The connection between the sensor nodes with the cluster head has been presented by the green line. This cluster formation is resulted from the Algorithm 4 in Figure 4.

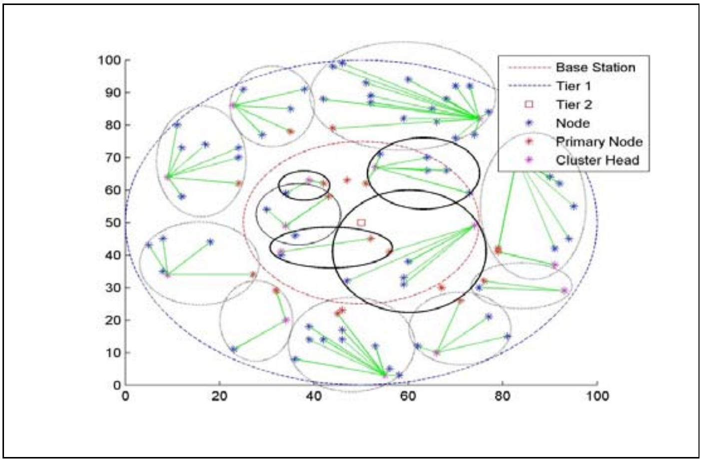

Figure 12: Cluster Formation

The data transmission occurred in two parts. First part is from Tier 1 to the base station. Sensor node in Tier 1 sent the data to its cluster head and after gathering all the data, the cluster head sent the data to its primary node. Lastly, primary node in Tier 1 sent the data to the base station. For the second part, the data transmission occurred at Tier 2. Sensor nodes at Tier 2 sent the data to its cluster head. The connection is shown by the green line. The cluster head at Tier 2 sent the compressed data to its primary node and then the primary node at Tier 2 sent the data to the nearest primary node in Tier 1. This has been shown by the red dotted line. Later, the primary node in Tier 1 sent the data to the base station.

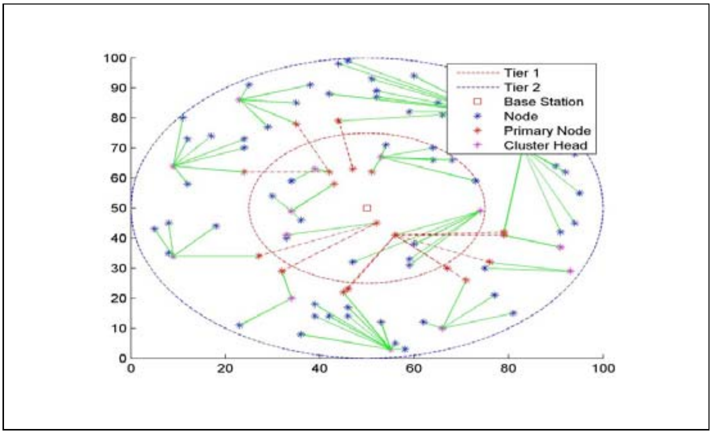

Figure 13: Data Transmission

Figure 14 shows the last node dead for LEACH protocol was at around 4999 and for SEP it was at around 5000. For the purposed algorithm which is MAP protocol, the last node dead at around 9824. This is slightly 48.25% improved from LEACH and SEP protocols. It is concluded that, with the improved method of selecting the cluster head and the data routing, the sensor lifetime can survive until around 9824.

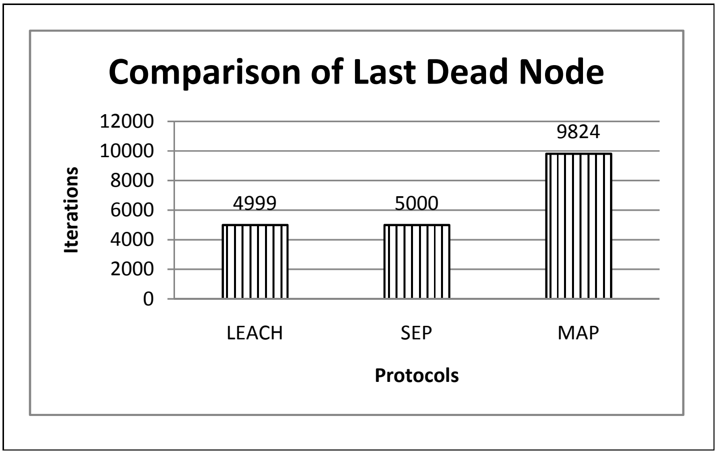

Figure 14: Network Lifetime

CONCLUSION

In summary, the new multi-tier network design for cluster head selection using three parameters namely; residual energy, communication cost and centrality have been successfully implemented. The combinations of parameters responsible in the analysis are useful as benchmark and can be used to standardize the cluster head selection. The energy consumption of sensor node can be preserved because the responsibility of primary node at each tier decreases the energy usage. It produces balanced energy among each other for the activities of data transition.

The intelligent technique developed in this study has been presented based on the reliability of blended three parameters to select the cluster head. The fuzzy method successfully identifies the output value for assigning the sensor node to become a cluster head. These significant values have been used for selecting the cluster head where the highest value of output given the greatest chances of sensor node to become a cluster head. This technique overcomes the uncertainty and irrationality where it limits the amount of the cluster number and uses the multi-hop communication to communicate with the base station. This approach can balance the network energy consumption effectively.

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