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A Proposed Multi-hop Dynamic Multi-Zone LEACH Protocol to Extend Network Lifetime in Wireless Sensor Network

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***Abstract*—Wireless Sensor Network (WSN) applies in large areas for monitoring and control, such as in agricultural areas and areas prone to natural disasters. Single-hop routing protocol, such as the Low Energy Adaptive Clustering Hierarchy (LEACH), is ineffective for large areas. LEACH derivatives of the multi-hop category are very important to be developed in overcoming their routing problems. We propose a LEACH derivative routing protocol that is Multi-hop Dynamic Multi-Zone LEACH (MDMZ-LEACH). Matlab simulation is carried out on the distribution of 100 nodes in the WSN area of 100mx100m and the scenario of a 50m position increase on the y-axis at Base Station coordinates. The results showed that the proposed protocol better than comparison protocols in extending network lifetime. Average network lifetime round difference between the proposed protocol to LEACH (860 rounds), to Multiple-hop LEACH (587 rounds), to MR-LEACH (1076 rounds), to DL-LEACH (1731 rounds), and EDL-LEACH (489 rounds).**

Keywords—Wireless Sensor Networks (WSN), multi-hop dynamic multi-zone, LEACH (low energy adaptive clustering hierarchy) protocol, energy efficiency

I. INTRODUCTION

Energy efficiency is a crucial parameter in planning routing protocols for Wireless Sensor Networks (WSNs). Through WSNs, information from sensors located in the implementation area is transmitted and aggregated to a remote server. To effectively and efficiently transmit data from multiple sensors to the server and extend network life, appropriate routing techniques are needed; the routing protocols utilized in traditional wireless networks are not suitable. Thus, designing an efficient one may be an open challenge.

In large areas with difficult terrain or with ongoing disaster management operations, sensor nodes are distributed randomly, and power generally comes from limited battery power [1]. Because replacement is not an option for networks with hundreds to thousands of sensor nodes, batteries must endure for months or even years. Thus, energy consumption is the most critical factor in determining the life span of a sensor node. Available resources (size, energy, power, and computational complexity) limit storage and processing capabilities within sensor nodes; at the same time, however, energy is needed within the sensor node to transmit, receive, and process data [2].

WSN routing protocols that forefront the energy efficiency concept have been extensively researched and developed based on the classification of routing protocols in WSNs [3]. Low Energy Adaptive Clustering Hierarchy (LEACH) [4] is one distributed clustering algorithm for random sensors. It can extend network lifetime, and thus significant efforts have been made to develop and produce energy-efficient WSNs. Methods derived from LEACH have been proposed in single-hop and multi-hop scenarios [5]. However, single-hop routing methods are ill-suited for expansive sensor networks, as nodes can be located far from the Base Station (BS). Because more energy is necessary for signal transmission, and more than one jump (hop) through the nodes that act as routers or cluster heads (CH) is necessary [6]. The solution, thus, is to consider LEACH-derived algorithms in the multi-hop category. WSNs must adapt and resist errors by providing efficient mechanisms for distributing information, especially in multi-hop scenarios [7].

In hierarchical clustering [8,9], one sensor node from each cluster acts as the Cluster Head (CH), while the others act as Member Nodes (MN), thereby forming a cluster. During the data collection phase, the CH collects data from all of its MN, which is then aggregated to be transmitted to the Base Station (BS). Figure 1 shows a simple clustering model of a data-gathering wireless sensor network.

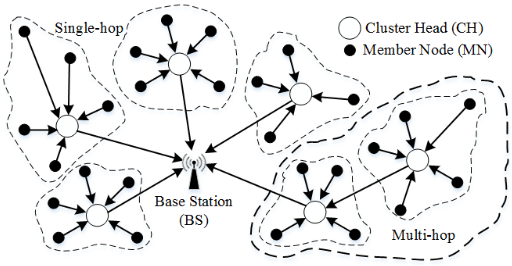


Fig. 1. Clustering models in WSN.

Due to the distance of their transmissions to the BS, CH nodes generally consume more energy than MN nodes [10]. As suggested by the LEACH protocol, randomly selecting the CH in distributed sensor nodes can solve the routing problem. The LEACH protocol has been a breakthrough in cluster-based data collection in the WSN field. However, shortcomings and limitations have become evident. It has been necessary to improve LEACH, producing the single-hop and multi-hop models.

In the LEACH [4] protocol, there are two phases. In the set-up phase is CHs selected randomly with a certain rule and form the clusters. All sensor nodes in the WSN area choose using a random value (between 0 and 1). The random value is then compared to a threshold value $T(n)$. The node being observed if the result of the value comparison is less than the value of T(n), then the node is selected as CH. The $T(n)$ value can be calculated using equation (1):

$$T(n) = \{\frac{p}{1 - p * \left(r \bmod \frac{1}{p}\right)} \; if\ n \in G\ 0\ otherwise \qquad (1)$$

The p parameter is the percentage of CHs that can be selected in the network. The r parameter is the round number, and the set of sensor nodes that have not been CHs in the last $1/p$ rounds specified in G. The probability of the sensor node being selected as CH with low and high energy will be the same on several rounds. As a result, LEACH's overall energy becomes unstable and reduces network lifetime. Therefore, it is necessary to consider LEACH's development in the multi-hop category. The LEACH derivatives in the multi-hop compared in this research are Multiple-hop LEACH [11], MR-LEACH [12], DL-LEACH [13], and EDL-LEACH [14]. However, the methods that use the single-hop and multi-hop mentioned usually do not calculate the tolerance distance effect of member nodes in the cluster. Thus when nodes are outside the tolerance distance, the node energy expended quickly.

This research uses a new approach for distributing CH more uniform to prolong network lifetime and performance metrics in WSN. In this approach, the data routing process becomes more organized and dependent on every sensor node's coordinates and energy status. Our routing approach consists of two routing mechanisms: static and dynamic. The static routing mechanism indicates that the routes with the shortest distance are preferable during the round process. The selection of the shortest route allows the transmission energy consumed to be minimized to support energy efficiency. The dynamic routing mechanism occurs in advanced hops indicating a multi-hop method with certain rules. Zone division is used in this method where the tolerance distance value is half of d_0. This method uses an approach that can dynamically switch routes in search of the shortest routes in defined zones. In this case, energy efficiency is done by reducing energy consumption due to dynamic routes and zone division for the shortest route search of each round.

This paper is organized as follows: Section 2 reviews the related work. Section 3 shows the proposed protocol methods and analysis. The simulation of the proposed protocol performance will be shown in Sections 4. Finally, section 5 presents this study's conclusions and recommendations.

II. Related Work

Wireless sensor networks are used in many applications, such as wide-area surveillance for border security, such as heat, sound, and pressure monitoring in a given area. Most routing protocols operate without considering energy. It is necessary to consider the transmitter and receiver power amplifiers' energy to improve its effectiveness. Due to the ease of developing LEACH algorithms, this protocol became well known and widely researched. Many studies modify LEACH protocols using some techniques or hybrid with other algorithms to continue with the advantages offered by protocol improvements in LEACH derivative categories. LEACH modification protocols can improve the performance of WSN metrics compared to conventional LEACH. Some have done so by modifying the LEACH protocol's set-up phase, while others have been interested in enhancing the steady-state phase.

The centralized LEACH (LEACH-C) [15] protocol modifies LEACH's set-up phase while maintaining the steady phase. It supposes that the BS is responsible for choosing the CHs with sufficient energy. The LEACH-G [16] routing protocol adopts a centralized and distributed approach for selecting CH and forming clusters. This protocol uses a combined centralized and distributed approach in CH selection to balance cluster numbers. The P-LEACH [17] protocol divides sensor nodes clusters into four independent regions and elaborates more on prediction techniques to save energy. EA-LEACH [18], a modified LEACH, which selects cluster heads using their residual energies. LEACH-K [19] use of K-Means before the election of CH.

Meanwhile, the multi-hop clustering routing method improves scalability and is suitable for WSN applications over a large area. Nonetheless, the multi-hop clustering routing protocols derived from LEACH have their advantages and disadvantages, and thus their performance must be developed and improved. One early multi-hop method that used inter-cluster communication in the LEACH derivative is Multiple-hop LEACH [11]. MR-LEACH [12] is a pure multi-hop concept, where BS will choose the CHs for lower layer CHs from its immediate upper layer CHs. DL-LEACH [13] uses dual-hop (single-hop + multi-hop) to increase transmission distance to solve LEACH's rapid energy consumption. EDL-

LEACH [14], enhanced DL-LEACH, select CH from the nodes that still have the greatest energy than the previously selected CH. BRE-LEACH [20] is based on the nodes' residual energy, the minimal distance to the base station, and the multi-hop between the CH and the BS.

III. METHODS

The multi-hop clustering routing method in the LEACH derived category aims to design routing in the delivery of selected CH data to communicate with other CH on a multi-hop path up to BS. Thus there is a demand for energy efficiency during transmitting data in the network every round as long as the network can still operate. In most cases, WSN sensor nodes are used randomly, regardless of distance from the BS, requiring large amounts of energy to transmit their data. In such a scenario, the sensor node energy will run out, and the sensor node will shut down early. This problem occurs in LEACH because the protocol assumes that each CH sends its data directly to the BS. Not only does this reduce network lifetime, but it also limits the coverage area, as sensor nodes located far from the BS will run out of energy quickly.

The radio model to count energy dissipation is the same as in LEACH. The d_0 parameter is used as a tolerance distance. From [21], it is known that LEACH uses the value d_0, which is 87m. The transmission of a *k*-bit message through distance *d* dissipates along with the following equation:

$$E_{Tx}(k,d) = \{k(E_{elec} + \varepsilon_{fs}d^2), d < d_0 \; k(E_{elec} + \varepsilon_{mp}d^4), d \geq d_0 \tag{2}$$

Where

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \tag{3}$$

The amount of energy spent to receive the message follows the formula:

$$E_{Rx}(k) = kE_{elec} \tag{4}$$

Where the E_{elec} parameter represents the dissipation energy for transmitting or receiving data in WSN. The ε_{fs} parameter indicates the effect of free space on the consumption energy. The ε_{mp} parameter indicates the multipath factor's effect, affecting energy consumption due to the communication distance between nodes more than tolerance distance.

Data is generally transferred between CH to reach BS and from the upper and lower levels in a multi-hop multi-hop-based LEACH protocol. Each level is divided based on the d_0. It is required to reduce the transmission distance from CH to CH closer to the BS and nodes closer to the BS to extend network lifetime.

Each CH located outside the d_0 can create a custom routing table to select the BS's shortest route. Our proposed protocol, Multi-hop Dynamic Multi-Zone LEACH (MDMZ-LEACH), creates zones dynamically by dividing each zone's tolerance distance into $d' = d_0/2$. MDMZ-LEACH can improve the performance of metrics in energy efficiency in certain WSN areas.

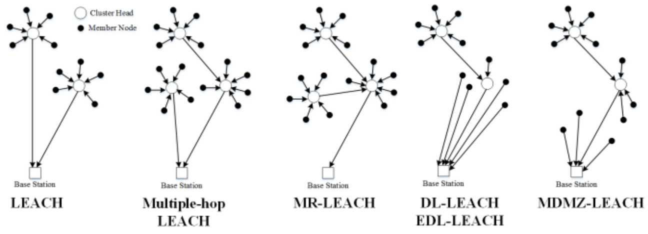


Fig. 2. Comparison of protocols in treating sensor nodes close to BS.

The differences in MDMZ-LEACH protocols compared to previous protocols are seen in figure 2. LEACH is single-hop; all selected CH directly transmit data to BS. The MDMZ-LEACH algorithm ensures that normal nodes, when they are closer to BS, can send the data directly to BS, but if the normal node distance is closer to CH, it joins the CH cluster. Our proposed MDMZ-LEACH divides zone *d*', resulting in more zones reducing the influence of distance for certain conditions.

A. Initial phase

This method assumes that all sensor nodes are deployed in the WSN area and that the LEACH protocol's set-up steps have been carried out. Assuming the use of positioning hardware such as GPS, each CH selected knows its position and can calculate its distance to the BS to determine its zone. The environment is divided into several levels around the BS. To model this initial phase, suppose that hundreds of nodes are randomly distributed over a large area and form a WSN. In each particular round, 12 CHs are selected, as shown in figure 3. We assume that the BS has coordinates (60, 20), and the length of each zone is *d*' = 43.5m. Each zone has a CH and is marked with a specific color.

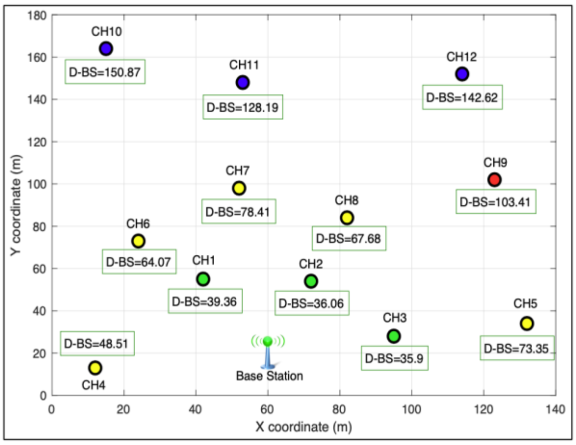


Fig. 3. The initial phase of MDMZ-LEACH.

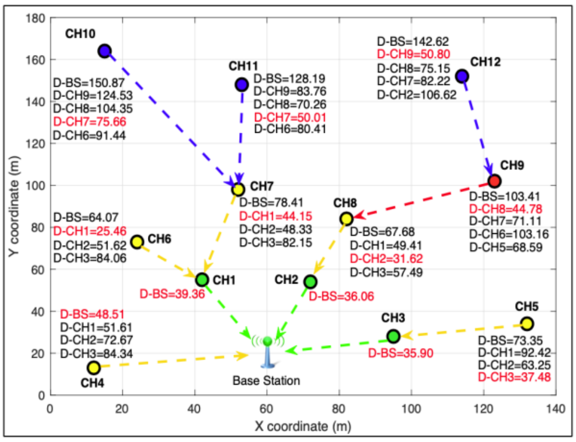


Fig. 4. Routing phase of MDMZ-LEACH.

B. Broadcasting phase

In this phase, the broadcast process of an announcement message from the selected CH occurs. This message contains the location of the CH and the distance to the BS. Usually, the number of messages received by a CH determines the size of the routing table.

As mentioned above, Zone 1 includes all CHs less than 43.5m away from the BS. The CH nodes belonging to Zone 1 include CH 1, CH 2, and CH 3, while the CH nodes belonging to Zone 2 include CH 4, CH 5, CH 6, CH 7, and CH8. Zone 2 is positioned at a distance of between 43.5m to 87m. Zone 3 includes the only CH 9, positioned at a distance of between 87m to 130.5m. CH 10, CH 11, and CH 12 are included in Zone 4, between 130.5m to 174m.

C. Routing phase

This phase is the main phase in which the routing table setting algorithm is performed. The routing table is created based on an announcement message to get the closest distance of CH that is in the furthest zone to the zone closer to BS. There are four cases defined for CH in choosing its route, where the amount of energy consumed will differ based on the CH route chosen as follows.

- Case 1: If CHs in Zone 1 or $CH_{d-BS} < d'$,

  Then the CH transmits its data directly to the BS. The equation calculates its transmission energy:

  $$E_{Tx}(k) = k\left(E_{elec} + \varepsilon_{fs} {CH_{d-BS}}^2\right) \quad (5)$$

- Case 2: If CHs in Zone 2 or CHs in $(CH_{d-BS} \geq d')$ and $(CH_{d-BS} < 2d')$, their data transmitted to a CH with a minimum distance value in Zone 1.

  $$E_{Tx}(k) = k\left(E_{elec} + \varepsilon_{fs} {CH_{d-Z1}}^2\right) \quad (6)$$

  where CH_{d-Z1} is the distance between CH, the CH located in Zone 2 transmits its data to all CH located in Zone 1.

- Case 3: If CHs in Zone 3 or CHs in $(CH_{d-BS} \geq 2d')$ and $(CH_{d-BS} < 3d')$, their data transmitted to a CH with a minimum distance value in Zone 2.

  $$E_{Tx}(k) = k\left(E_{elec} + \varepsilon_{fs} {CH_{d-Z2}}^2\right) \quad (7)$$

  where CH_{d-Z2} is the distance between CH, the CH located in Zone 3 transmits its data to all CH located in Zone 2.

- Case 4: If CHs in Zone 3 or CHs in $(CH_{d-BS} \geq 3d')$ and $(CH_{d-BS} < 4d')$

  - If $(CH_{d-BS} \leq CH_{d-Zn})$, then the CH transmits its data directly to the BS. Its transmission energy:

  $$E_{Tx}(k) = k\left(E_{elec} + \varepsilon_{mp} {CH_{d-BS}}^4\right) \quad (8)$$

  - If $(CH_{d-BS} > CH_{d-Zn})$
    - If $(CH_{d-Zn} < 2d')$, the CH transmits its data to a CH with a minimum CH distance in the n-th zone using the free-space model of energy transmission.

  $$E_{Tx}(k) = k\left(E_{elec} + \varepsilon_{fs} {CH_{d-Zn}}^2\right) \quad (5)$$

    - If $(CH_{d-Zn} \geq d_0)$, the CH transmits its data to a CH with a minimum CH distance in the n-th zone using the multipath model of energy transmission.

  $$E_{Tx}(k) = k\left(E_{elec} + \varepsilon_{mp} {CH_{d-Zn}}^2\right) \quad (5)$$

  where CH_{d-Zn} = the CH located in Zone n transmits its data to all CH located in zone n-1.

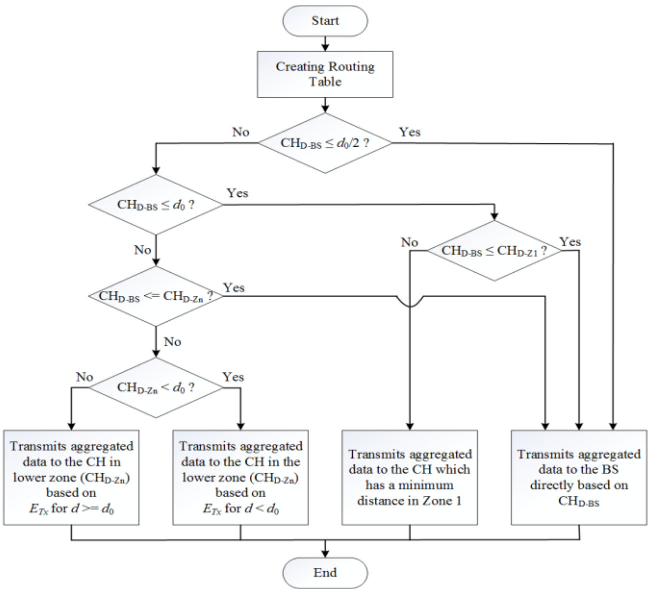


Fig. 5. Routing phase flow chart in MDMZ-LEACH.

For the Figure 5, examples may be provided as follows. Figure 4 shows that all CH selects the other CH for the next hop based on the zone obtained. The closest CH to BS, such as CH 4, can directly send its data to BS without sending the data through other CH. In contrast, other CH in the same zone can send data to the nearest CH in the other zone by sorting from zone 4 to zone 1. CH can also send their data to CH that is not in its nearest zone if the CH distance to that zone is closer to BS.

The process in the routing phase is seen in figure 5. The routing table is created based on the flow of the closest distance of data delivery from CH to CH in the upper zone to its lower zone. After creating a routing table, the aggregated data is sent to the BS based on the CH-to-BS distance, and the zone division is based on the d' distance. Nodes whose distance from BS is less than d' can send data directly to the BS. The selected CHs located further from d' will follow cases 1 through 4 as described above.

D. Node checking phase

The occurrence of nodes not included in existing clusters needs to resolve by calculating for isolated nodes (IN). IN nodes are possible due to distant nodes or nodes that are still operating in positions that allow only one or two nodes as the next hop. All CH and IN can broadcast announcement messages in the broadcasting phase to obtain data communication connections. The routing table (RT) records a node as CH and IN to prioritize the selected route. If the IN node only gets one CH or one normal node as the next-hop node, then the routing table records that the IN node route is static. Source nodes (SN) acting as CH or IN can forward their data based on predetermined static RT. MDMZ-LEACH protocol presupposes that all CHs and INs are distributed in zones around the BS, where each zone's length is d'.

All CHs and INs are allowed to send their data to the BS via other CHs and INs in the lower zone. Therefore, it is recommended to select the route dynamically during the data transmission process. There are two factors to consider during this phase—next-hop distance (NH) from the CH/IN to BS and the remaining next-hop energy. To set the available route, each IN uses σ as a cost function (residual energy divided by initial energy).

$$CH_N(i) = \frac{d(SN)_i^2}{d(IN)_{BS} - d(CH_N(i))_{BS}} + \sigma * CH_{NE}(i) \qquad (9)$$

Distance $d(SN)^2_i$ shows the square of the distance between the SN and the next-hop node. The value i refers to the member in the set of NHs selected by the SN with the minimum value in the current round. During the rotation, the CH and IN energies begin to decrease. All IN can broadcast messages continuously to get connection updates to the nearest CH.

IV. Results

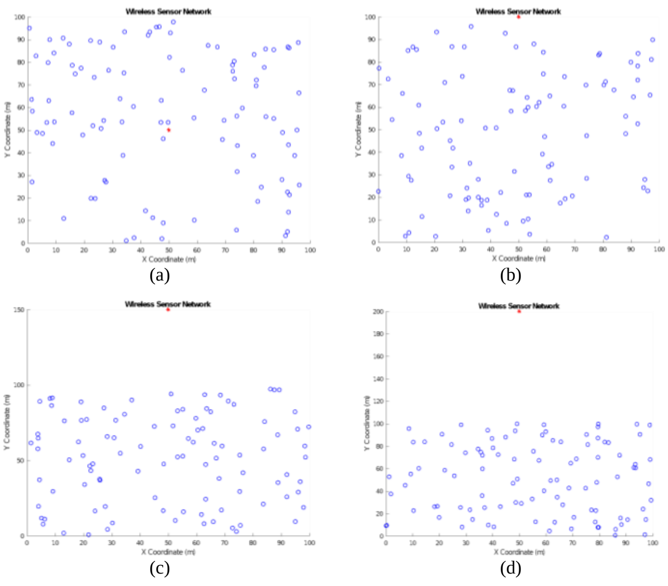
The MDMZ-LEACH protocol was simulated and evaluated using MATLAB. The simulation parameters are specified in table 1. Five performance metrics are used to evaluate and compare the performance of the proposed protocol and other protocols:

- Network Lifetime: Number of live nodes in each round
- Stability: Time interval between the started working-time of the network until the first node dead.
- Throughput: Data packets delivered to the CH and BS in each round
- CH Selection: Number of CHs selected in each round
- Processing Time: The total time for each protocol to complete the task until the round ends.

TABLE I. Simulation parameters.

Parameter	Value
WSN Area	100m x 100m
Number of Nodes, n	100
E_O (initial energy)	1 Joule
E_{elec} (initial energy)	50 nJ/bit
ε_{fs}	10 pJ/bit/m^2
ε_{mp}	0.0013 pJ/bit/m^4
E_{tx} (initial energy)	50 nJ/bit
E_{rx} (initial energy)	50 nJ/bit
E_{agg} (aggregation energy)	5 nJ/bit
Desired % of CHs, p	10%
Data Packet Size, k	4000 bits

The WSN areas are seen in figure 6. In the first scenario, the BS (red dot) is in the middle of the WSN area (50,50). Then the BS location moves up (y-axis direction) by 50 meters to (50,100). The next scenario is that the BS location is moved until BS is in (50,300). These scenarios are simulated to determine the protocol performances if the BS position is in the middle, edge, and outside the WSN area.



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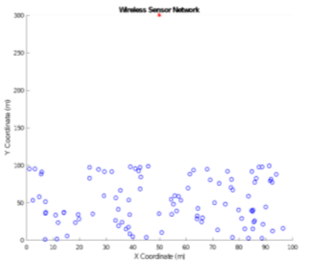
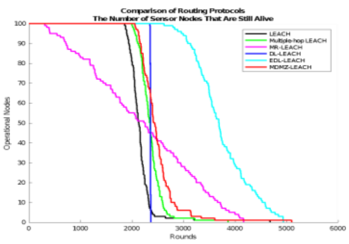


(f)

Fig. 6. WSN over area of 100x100. (a) BS location (50,50); (b) BS location (50,100); (c) BS location (50,150); (d) BS location (50,200); (e) BS location (50,250); (f) BS location (50,300).



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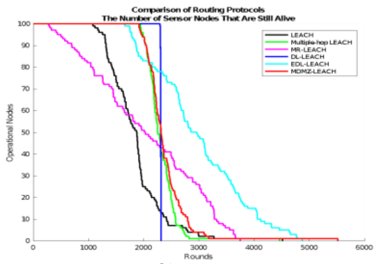

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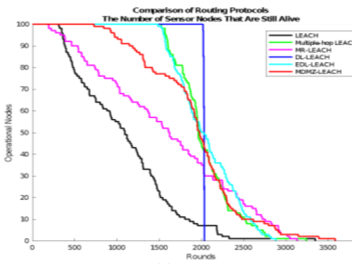

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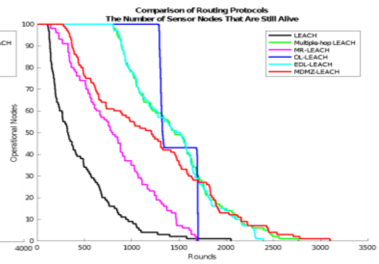

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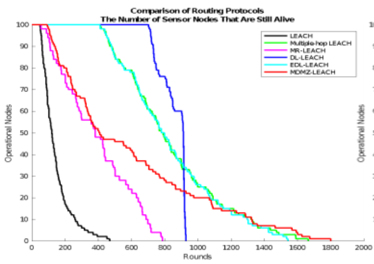

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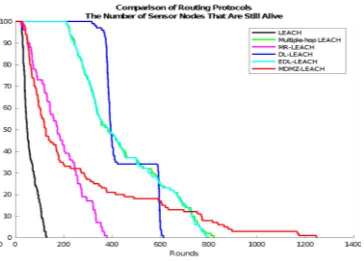
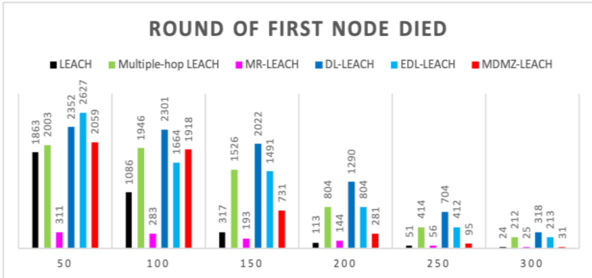


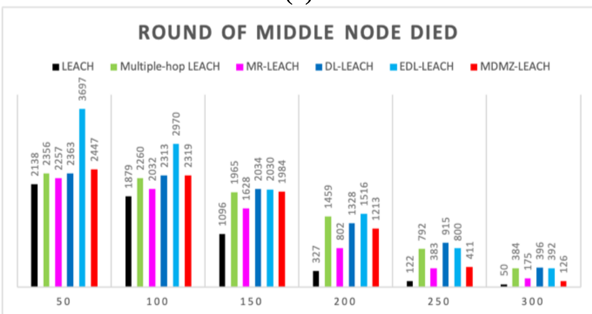
(f)

Fig. 7. Number of operating nodes. (a) BS location (50,50); (b) BS location (50,100); (c) BS location (50,150); (d) BS location (50,200); (e) BS location (50,250); (f) BS location (50,300).

The simulation results of the proposed protocol, as compared to several LEACH derivative protocols, can be seen in figure 7. The EDL-LEACH protocol and the proposed protocol seem to be the protocol capable of having the longest network lifetime in the BS location (50,50). In other BS location, the proposed protocol is capable of better than other protocols. The stability of protocol performance indicates from the round position when the first node is dead, as seen in figure 8(a). Figure 8(b) shows protocol performance when the middle node (the 50th node) is dead. Figure 8(c) shows the network lifetime or when the end node is dead. Although sensor nodes' distribution varies by scenario, the proposed protocol performance in extending network lifetime remains better than other protocols.



(a)



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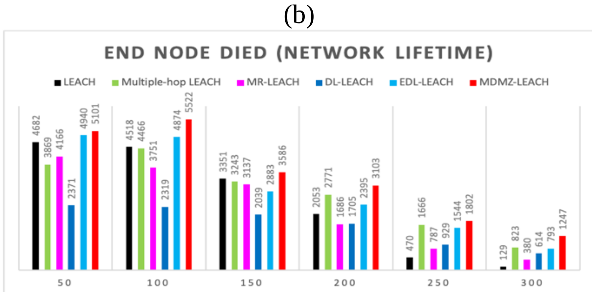

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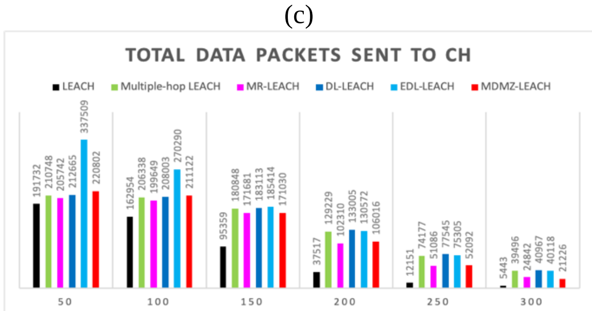

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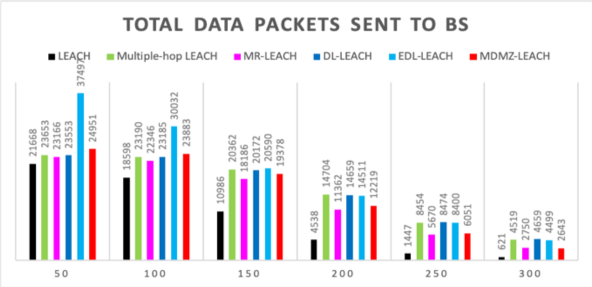

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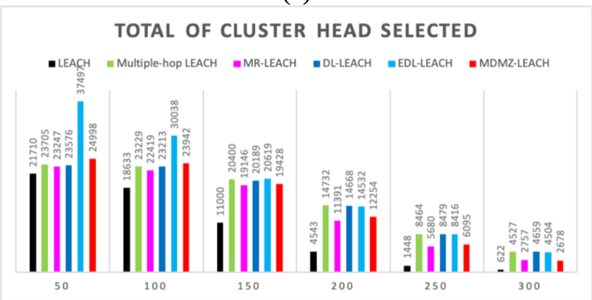

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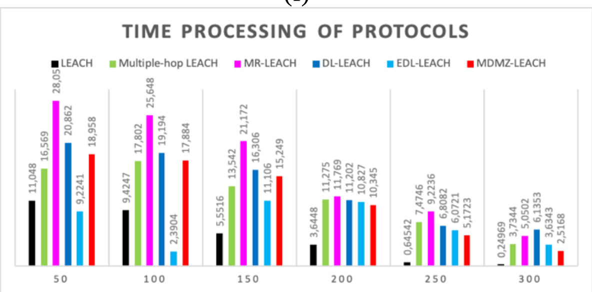

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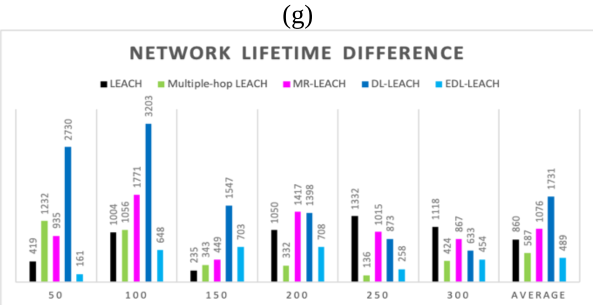

(h)

Fig. 8. Performance metrics of protocols. (a) Round of the first node died; (b) Round of middle node died; (c) Network lifetime; (d) Total data packets sent to CH; (e) Total data packets sent to BS; (f) Total of CH selected; (g) Time processing of protocols; and (h) Network lifetime difference.

The proposed protocol's performances are also excellent on packet delivery data metrics, CH selection, and processing time. Packet delivery data or throughput performance can be seen in figure 8(d) and figure 8(e) for the total of data packets sent to CH and sent to BS packets, respectively. The total of data packets sent to BS has an almost equal graph to CH selected in figure 8(f). The total data packets sent to CH and BS vary for each protocol due to random CH selection depending on the algorithm used. The processing time will be longer, comparable to the protocol's ability to extend network lifetime. As seen in figure 8(g), the proposed protocol takes longer in processing time than other protocols in all BS positions. Figure 8(h) shows the average network lifetime round differences from the comparison of network lifetime differences of the proposed protocol against the compared protocols.

V. Conclusion

The main goal of routing protocols for energy efficiency is to increase network lifetime as much as possible. This research seeks to improve energy efficiency performance metrics in LEACH derivative protocols in the multi-hop category. For this purpose, the MDMZ-LEACH protocol is proposed and analyzed to meet energy efficiency needs in WSN. Average network lifetime round difference between the proposed protocol to LEACH (860 rounds), to Multiple-hop LEACH (587 rounds), to MR-LEACH (1076 rounds), to DL-LEACH (1731 rounds), and EDL-LEACH (489 rounds). Our simulation results indicate that, compared to other protocols, the proposed protocol prolongs network lifetime in all of the sink position.

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