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PERFORMANCE OF MULTI-HOP DYNAMIC MULTI-ZONE FOR LEACH IN WIRELESS SENSOR NETWORK MAPPING ON THE AGRICULTURE AREA

Made Santo Gitakarma[1,2,3], Tri Kuntoro Priyambodo[1,2,*]
Yohanes Suyanto[1,2] and Raden Sumiharto[1,2]

[1]Department of Computer Science and Electronics
[2]Center for Environmental Studies (PSLH)
Universitas Gadjah Mada
Bulaksumur, Caturtunggal, Depok, Sleman, DIY 55281, Indonesia
made.santo.g@mail.ugm.ac.id; { yanto; r_sumiharto }@ugm.ac.id
*Corresponding author: mastri@ugm.ac.id

[3]Department of Electronics Systems Engineering Technology
Universitas Pendidikan Ganesha
Jalan Udayana No. 11, Singaraja, Bali 81116, Indonesia

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Abstract. *Recent technology of communication advances resulted in the developing and improving Wireless Sensor Networks (WSN) consisting of low-cost, low power and smaller multi-functional sensor units. In large-scale deployments like agricultural areas, scalable and energy-efficient routing and data aggregation protocols are essential. Usually, the sensor nodes deployed in large WSN areas depend on limited battery resources. Cluster-based routing techniques are primary methods to extend the lifetime of WSNs. For this reason, we propose a Multi-hop Dynamic Multi-Zone Low-Energy Adaptive Clustering Hierarchy (MDMZ-LEACH), a multi-hop clustering-based protocol architecture for improving the performance of LEACH. We use mapping for fixed node distribution planning based on research needs in large agricultural areas. Matlab simulation results show good performance of network lifetime and energy consumption with the optimal CH selection based on the proposed protocol and also compared the results with existing LEACH-derived routing protocols with various number of sensor nodes and initial energy.*

Keywords: Wireless sensor network, LEACH, Multi-hop, Multi-zone, Energy efficiency

1. **Introduction.** Wireless Sensor Network (WSN) [1,2] is an advanced technology supporting the Internet of Things (IoT). It is composed of a large number of small, low-cost and low-power nodes that are distributed in a specific area to collect data and remote it either to another node in a group or directly to a sink node. WSN has been widely applied for monitoring and data collection in several domain areas, such as military, health care, agriculture, plantation, industrial [3]. WSN is a network formed by a group of multi-functional microsensor nodes randomly placed in a remote area to monitor and analyze environmental data collected in real time [4]. One of the significant challenges in WSN is energy efficiency, as sensor nodes generally have a limited resource (battery) and cannot be recharged [5]. This problem can be overcome by using appropriate network routing techniques to maximize network lifetime by reducing energy consumption until all sensor nodes run out of energy [6]. The Low Energy Adaptive Clustering Hierarchy (LEACH) protocol [7] is one of the leading routing protocols that can solve sensor network efficiency problems. This protocol uses two phases: the set-up phase and the steady-state phase. In the set-up phase, percentage p, as seen in Formula (1) used to select sensor nodes as cluster heads (CH) with consideration of threshold value $T(n)$ using random value, r,

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between 0 and 1. Consider all nodes are listed as set S, and G is the collection of nodes that have not been selected as the CH nodes in that last $[1/p]$ round, i.e.,

$$p = 1 - \frac{|G|}{|S|} \tag{1}$$

If $r \leq T(n)$, the sensor node is selected as CH, where the threshold $T(n)$ is as follows:

$$T(n) = \begin{cases} \dfrac{p}{1 - p\left(r \bmod \frac{1}{p}\right)} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

After CHs have been chosen, each CH node will broadcast advertisement signals to the other nodes via Code Division Multiple Access (CDMA), and the normal nodes will connect the closest CH to be member nodes of one cluster. Then the CH nodes use Time Division Multiple Access (TDMA) to provide time for data transmission to the Base Station (BS). In the steady state phase, nodes will receive the TDMA schedule first, and then, in that scheduled time, all the member nodes communicate data to their respective CH. CHs collect and aggregate data from the member nodes and then forward data to BS. Sending data from the member nodes to the CH, then the CH transmits the data directly to the BS, called the single hop technique. After a specific time interval, the loop ends, and the network returns to the Set-up phase where a new cluster is formed and a new CH is selected.

In LEACH, if the selected CHs are far from the BS, transferring information to the BS requires more energy; therefore, CHs will die soon. The single-hop LEACH method is effective for small areas, so some researchers [8-10] are improving this technique to extend the network lifetime. Meanwhile, in large areas with rugged terrain or ongoing disaster management operations, a multi-hop LEACH method is required for transmitting data from one CH to another in several hop scenarios until the BS receives the data.

We propose to improve LEACH on multi-hop technique by dynamically selecting CH and routing technique that considers the shortest path from CH to another CH if CHs are in multiple zones, and considers best path to outermost nodes as isolated nodes. The method we propose is Multi-hop Dynamic Multi-Zone LEACH (MDMZ-LEACH). The proposed method is applied to sensor nodes spread over a 12-hectare agricultural area in Bulian village, North Bali, Indonesia. Our protocol is compared with several other protocols to show the performance of the proposed method, which will be recommended in the actual implementation of the WSN. The main difference between our test scenarios from other researchers is the deployment of sensor nodes that are fixed in a map of the agricultural area. We have carried out LEACH simulations on agricultural areas in [11] and have tested the MDMZ-LEACH method on rectangular regions as described in [12]. This paper will enhance our work by recommending the best routing method for agricultural maps as our test object.

This paper is organized as follows. Section 2 presents related works on LEACH-derivatives protocols in single-hop and multi-hop methods. In Section 3, we discuss our proposed method in detail. We discuss the performance of our proposed method's test results compared to other methods in Section 4 before concluding in Section 5.

2. **Related Works.** Research for routing problem-solving strategies in WSNs is generally divided into three categories: flat-based, hierarchical-based, and location-based [13]. However, researchers do more on hierarchical-based types [14]. Forming clusters and transmitting and receiving data are challenging tasks to solve the problem of optimal and effective routing techniques in hierarchical-based routing protocols in WSNs. Many researchers improve the performance of the LEACH protocol, some of which can be categorized into single-hop and multi-hop methods.

Threshold LEACH or T-LEACH [8] modifies LEACH by minimizing the selection of CH groups based on the threshold energy scheme of the sensor nodes. Energy Aware LEACH or EA-LEACH [9] considers the sensor node's residual energy against the network's residual energy to select the CH in each cycle. Advanced Efficient LEACH or AE-LEACH [10] uses a particle filter algorithm to predict the data transmission path, and sets a CH based on the remaining energy, the distance between the sensor node and the BS, and the threshold value to improve energy efficiency. LEACH and its derivatives in the single-hop method [7-10] have the disadvantage of their limited range which results in low efficiency over a large WSN area, unequal energy distribution, and high latency. Multi-hop Routing LEACH or MR-LEACH [15] generates the same cluster size in each layer, which means every normal sensor node sends data to the BS in the same number of hops. In MR-LEACH there is no CH role to transmit data to other CHs based on the distance between adjacent CHs. Energy Efficient LEACH or EE-LEACH [16] offers an energy-efficient routing in WSN based on the effective data ensemble and optimal clustering, which involves a Gaussian distribution model for adequate sensing network area coverage and the conditional probability theorem for node aggregation. However, sorting cluster routing based on residual energy can result in accelerating sensor nodes running out of energy because the distance between CHs becomes uncertain. Enhanced Dual Layer LEACH (EDL-LEACH) [17] enhances the performance of Dual Layer LEACH [18] by using the mobility factor in the selection of CH level two. A random mobility process is carried out if the CH energy is low in the level-two clusters. However, by limiting it to two layers, the method still has the possibility of being inefficient in the distribution of energy consumption. EESRA (Energy Efficient Scalable Routing Algorithm) [19] protocol randomly selects CH, adopts three-layer hierarchical routing to minimise CH load, and uses multi-hop transmission for intra-cluster transmission. EESRA relies on the utilization of unoccupied radio frequency spectrum regardless of the distance between CHs based on the distance of the CH to the BS for energy efficiency when transmitting data.

3. **Methods.** In this study, the threshold function in Equation (2) is affected by the ratio of the residual energy of the nodes to the total residual energy of all nodes in the network, as shown in Algorithm 1. For sensor nodes that are spread randomly, the residual energy of each member node is calculated in the cluster and embedded in the information sent by the member nodes to the CH until it reaches the BS. It is not easy to estimate the residual energy to be sent along with the environmental information sensed by the sensor nodes. With the fixed position of the sensor nodes, the BS can calculate the distance of the sensor nodes from the BS based on the position of the Global Positioning System (GPS). The BS is responsible for calculating the residual energy of the sensor node data packets it receives, which is accumulated to get the total residual energy of all nodes in the network at the end of each round. Dissipation energy for transmitting a k-bit message through distance d is calculated using the following equation:

$$E_{Tx}(k,d) = \begin{cases} k\left(E_{elec} + \varepsilon_{fs} d^2\right), & d < d_0 \\ k\left(E_{elec} + \varepsilon_{mp} d^4\right), & d \geq d_0 \end{cases} \tag{3}$$

where

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \tag{4}$$

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

$$E_{Rx}(k) = kE_{elec} \tag{5}$$

where E_{elec} is the dissipation energy for transmitting or receiving data in WSN. ε_{fs} is the effect of free space on energy consumption. ε_{mp} is the multipath factor's effect, affecting energy consumption because the communication distance between nodes is more than the

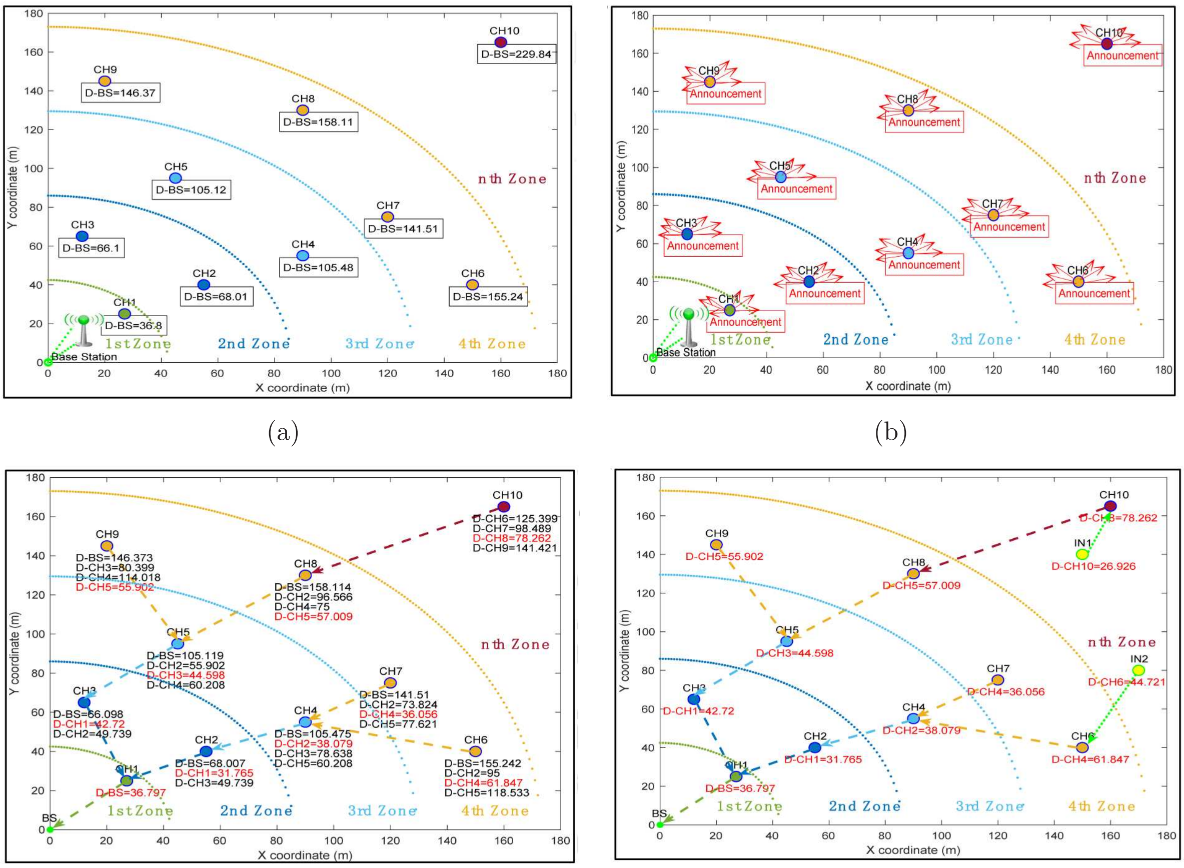
Algorithm 1: MDMZ-LEACH

Initialize all the parameters //- - - - 1. Initial phase - - - -
while operating nodes > 0 **do**
  Calculate Threshold value $T(n) = t_{val}\left(\frac{E(SN_i)}{E_{\max}}\right)$
  forall SN_i, $1 \leq i \leq n$ **do** // Cluster Heads election
    Calculate the Sensor Node (SN_i) distance to the Sink node
    if SN_i Energy > 0 **then**
      Generate the random value of r_{val}
      if $r_{val} < T(n)$ **then**
        Assigns SN_i as Cluster Head (CH_i)
        Calculates the distance of sensor node (dtS_i) between the sink and the CH
        Assigns the node ID of the newly elected CH to an array
      end
    end
  end
  Fix the size of the CH array to n_{CH} //- - - - 2. Broadcasting phase - - - -
  Set CH_Id based on SN_Id of elected CH
  forall CH_m, $1 \leq i \leq n_{CH}$ **do** //For the number of m CHs formed
    if $CH_m(dtS_i) < d_0/2$ **then**
      Set CH_m route direct to Sink //- - - 1st zone
    else if $CH_m(dtS_i) >= d_0/2$ and $CH_m(dtS_i) < d_0$ **then**
      Set CH_m route to nearest CH in area $< d_0/2$ //- - - 2nd zone
    else if $CH_m(dtS_i) >= d_0$ and $CH_m(dtS_i) < (3/2)d_0$ **then**
      Set CH_m route to nearest CH in area $d_0/2$ to d_0 //- - - 3rd zone
    else if $CH_m(dtS_i) >= (3/2)d_0$ and $CH_m(dtS_i) < 2d_0$ **then**
      Route CH_m to nearest CH in area d_0 to $(3/2)d_0$ //- - - 4th zone
    else //CH_m as Route-Free Node (RFN)
      Route CH_m to nearest CH in area $< 2d_0$ //- - - n-th zone - - -
    end
  end
  for $1 \leq i \leq n$ **do** //- - - - 3. Routing phase - - - -
    if (SN_i not CH) and (SN_i Energy > 0) and ($n_{CH} > 0$) **then**
      forall CH_m, $1 \leq i \leq n_{CH}$ **do**
        Calculates the distance d_i between SN_i and the CH_m
      end
      Fix the size of "d" and find the minimum distance of node to CH
      Finds the minimum distance of node to CH
      Set the Cluster Number in which this node belongs to
      Assigns node to the cluster and the distance of node to CH_m
    end
  end
  Check C_{NN} and connect IN to the nearest CH or IN //- - - - 4. IN Routing phase
  Calculate Energy Dissipation for all types of nodes
  Check dead nodes if SN_i Energy $<= 0$
end
Calculate and print parameters for analysis

tolerance distance. As used in LEACH, here we use the same radio model and parameters for several protocols compared to the proposed protocol. $E_{elec} = E_{Tx0} = E_{Rx0} = 50$ nJ/bit; ε_{fs} 10 pJ/bit/m^2; ε_{mp} 0.0013 pJ/bit/m^4; E_{agg} 5 nJ/bit; (aggregation energy); $p = 0.1$; and data packet size k 4000 bits. Based on Formula (4), we get $d_0 = 87.7$ m.

Data is transmitted between CHs to reach BS from the upper to the lower level in a multi-hop manner. Levelling using distance can be divided into zones based on d_0. It is essential to reduce the transmission distance to reduce energy consumption by paying attention to the shortest distance from CH to CH, which is closer to the BS. By reducing the transmission distance, network life can be extended. Our proposed protocol creates algorithms for dynamically multi-hop routing and zone division based on reliable signal transmission tolerance distances ($d' = d_0/2$).

There are 4 phases to generate routing and clustering in our proposed protocol, as shown in Figure 1.



(a) (b) (c) (d)

FIGURE 1. The phases in the MDMZ-LEACH protocol: (a) Phase 1, to determine the selected CH and calculate the distance of all nodes to the BS; (b) Phase 2, where each selected CH node gives an announcement signal for clustering; (c) Phase 3 for determining to route based on zone division; (d) Phase 4 for path determination for isolated nodes

3.1. **Initial phase.** Our proposed protocol follows several assumptions adjusted in the LEACH protocol test to initialize the parameters used in the Set-up phase. Assuming the sensor nodes are equipped with GPS features, all nodes deployed in the WSN area can be identified, and their distance from the BS can be calculated. Suppose there are hundreds of nodes distributed randomly in a particular area designed to be connected to form a WSN. In one round in our algorithm, several Cluster Heads are selected based on the threshold value in Formula (2). Suppose there are ten CHs chosen as shown in Figure 1(a), then the distance is calculated from the BS in coordinates $(0, 0)$. In this phase, CHs are determined in zones whose range is known. Each CH group in different zones has a different colour to make recognizing it easier.

3.2. **Broadcasting phase.** In this phase, see Figure 1(b), each selected CH node sends announcement signals to its surroundings to connect with normal nodes not selected as a CH. These normal nodes respond to their nearest CH to join as member nodes. One CH and member nodes joined together to form a cluster. Normal nodes closer to the BS than the CH can directly transmit their data to the BS. The CH node is responsible for aggregating data from its member nodes and sending it to the CH closer to the BS according to the zone order.

3.3. **Routing phase.** The routing phase is the main phase in which the routing table setting algorithm is performed. The routing table is created after the Broadcasting phase. The result is a transmission path based on the shortest distance of CH, which is in the farthest zone to the zone closer to the BS. From Figure 1(c), it can be seen that the BS gets its distance information from the CH (D-BS) to be compared with the distance of the CHs in the farthest zone to the CHs in the nearest zone. This shortest-distance information is sent to the CHs as the data transmission line. The CH1 node in Zone 1 directly transmits its data to the BS. CHs in Zone 2 (CH2 and CH3) get information on their closest path to CH1. The CHs in Zone 3 (CH4 and CH5) know their distance to the CHs in Zone 2, with the chosen route: CH5 to CH3 and CH4 to CH2. The CHs in Zone 4 know their shortest distance to the CHs in Zone 3, with the path chosen: CH6 and CH7 to CH4, while CH8 and CH9 to CH5. CH10, which is in the n-th Zone, obtains information on its closest path to CH8. This RT setting algorithm is shown in Algorithm 1.

3.4. **Isolated nodes routing phase.** At the end of each round, several sensor nodes in the n-th Zone are categorized as isolated nodes. In this case, isolated nodes (INs) behave similarly to CHs; IN nodes can choose the nearest other INs or nearby CHs. Unlike CH, IN has no clusters and independently connects with other normal nodes to find a path for sending data. There are two factors considered during this routing phase: first, the distance of the next node (NN) to BS; second, the remaining energy from IN. Figure 1(d) shows that IN1 has the closest path to CH10, while IN2 has the closest path to CH6. The routing table for IN is defined by calculating the value of the cost function, which is affected by the residual energy of the nearest node as follows:

$$C_{NN}(i) = \frac{D_i^2}{SN_{D-BS} - NH_{iD-BS}} + \eta \cdot C_{IN}(i) \tag{6}$$

where

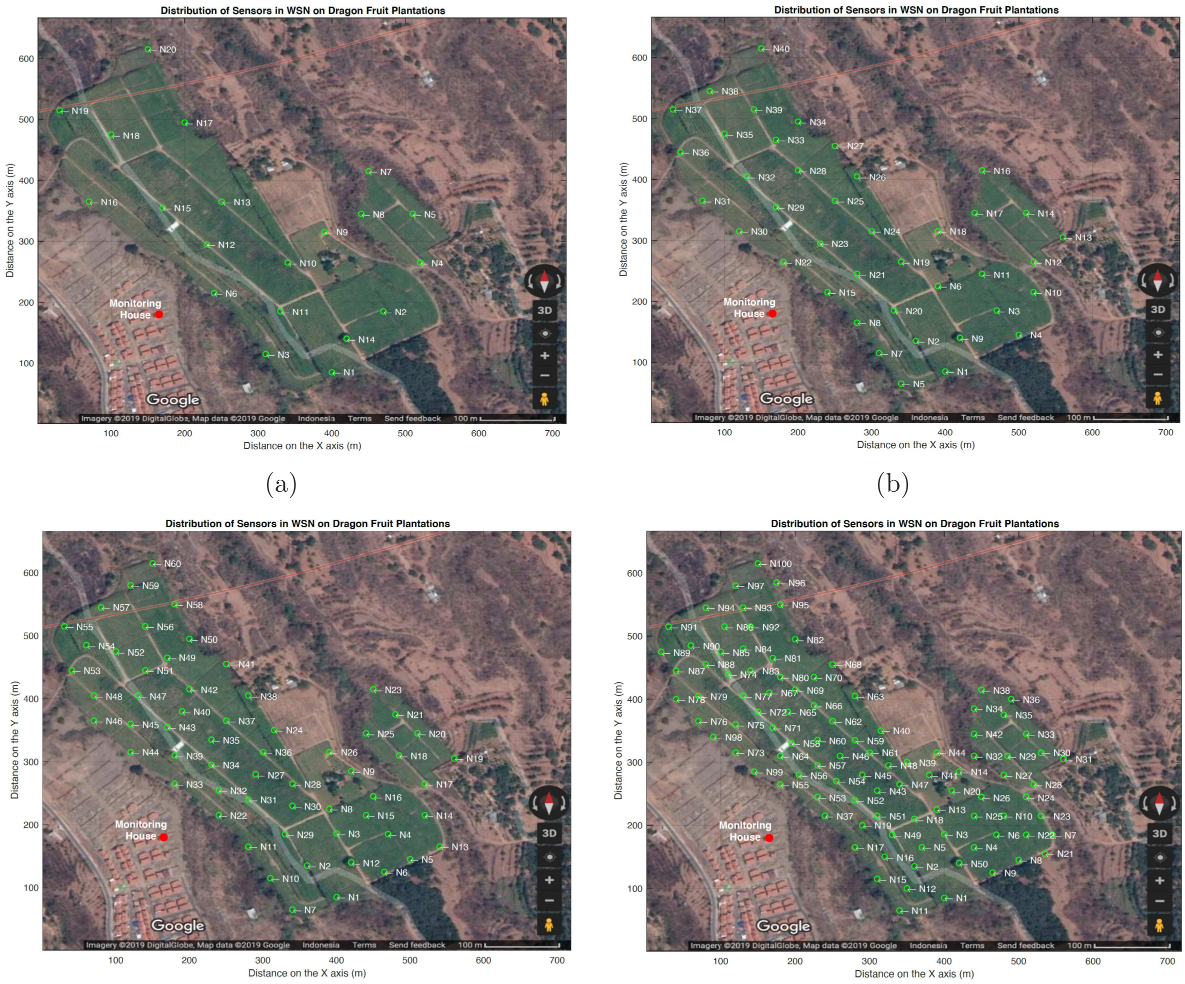
$$\eta = \frac{Residual\ energy}{Initial\ energy} \tag{7}$$

The distance D_i shows the distance between SN and NH. The parameters SN_{D-BS} and NH_{iD-BS} are respectively referred to as the distances of SN to BS and NH to BS. The parameters C_{NN} and C_{IN} are referred to as cost function of next and isolated nodes. Meanwhile, the variable i refers to the member in the NH group selected by SN in the current round. In each round, independent nodes can update by choosing the route with the lowest η cost.

4. **Result and Analysis.** The proposed new MDMZ-LEACH algorithm was analyzed by MATLAB tool by plotting a sizeable agricultural area as a network area. We use two

scenarios, different numbers of sensor nodes and the initial energy of sensor nodes. The difference in the number of sensor nodes to see the effectiveness of the proposed protocol in extending network lifetime. Initial energy difference scenarios to look at the point of the proposed protocol in reducing energy consumption in the network.

The distribution of sensor nodes for Scenario 1 can be seen in Figure 2. We put alternative 20, 40, 60, and 100 sensor nodes to see the ability of the proposed protocol compared to some of its predecessor protocols in extending the network lifetime if all nodes are uniform. Simulation of the performance of our proposed protocol is compared to LEACH [7], MR-LEACH [15], EDL-LEACH [17], and EE-LEACH [16].



(a) (b) (c) (d)

Figure 2. Distribution of sensor nodes within the agricultural area for Scenario 1: (a) 20 nodes; (b) 40 nodes; (c) 60 nodes; (d) 100 nodes

Table 1 shows a more detailed comparative analysis of the two scenarios, with the parameters of the number of rounds at First Node Dies (FND), Half Node Dies (HND), and Last Node Dies (LND). The FND value indicates the ability of the protocol to survive until the first node runs out of energy. For the average initial energy (E_0) scenario, it is known that the MR-LEACH FND is better in the E_0 0.25 J and 0.75 J cases, while the EDL-LEACH FND is better in the E_0 0.5 J and 1 J cases. For the average performance of HND and LND, MDMZ-LEACH has the best average results compared to other protocols. The average throughput or packets received by the BS for the MDMZ-LEACH protocol is better than others. It is known that the average packet received by CH is that MDMZ-LEACH is better in the E_0 0.75 J case, while for the other E_0 cases EDL-LEACH is

Table 1. Comparative analysis based on the average of Scenarios 1 and 2

Initial energy (Joule)	**Total nodes**	**Protocol**	**FND** (rounds)	**HND** (rounds)	**LND** (rounds)	**Packets** Received by BS	**Packets** Received by CH	**Simulation time** (second)
0.25	20	LEACH	**4**	21	1593	276	496	0.3481
		MR-LEACH	1	24	86	43	417	0.3615
		EDL-LEACH	2	15	507	114	1007	0.2628
		EE-LEACH	2	11	530	37	935	0.3788
		MDMZ-LEACH	3	**100**	**3191**	**522**	**1580**	**1.4568**
	40	LEACH	**4**	16	1576	508	1531	0.7429
		MR-LEACH	9	16	119	148	968	0.2741
		EDL-LEACH	2	22	488	259	2344	0.3533
		EE-LEACH	2	12	530	88	2085	0.6213
		MDMZ-LEACH	5	**99**	**1856**	**643**	**3459**	**1.3914**
	60	LEACH	2	16	1413	562	2217	0.8067
		MR-LEACH	**17**	**44**	92	317	2996	0.4389
		EDL-LEACH	9	37	460	439	3897	0.5538
		EE-LEACH	2	12	530	119	2842	0.9159
		MDMZ-LEACH	1	41	**1691**	**739**	**5026**	**1.3884**
	100	LEACH	3	17	1100	709	3840	0.9693
		MR-LEACH	**12**	45	115	615	7036	0.9924
		EDL-LEACH	11	**73**	496	**1098**	**9755**	1.3908
		EE-LEACH	2	12	526	171	4594	1.6975
		MDMZ-LEACH	2	29	**1635**	787	6501	**2.9336**
0.50	20	LEACH	9	38	3254	555	916	0.6982
		MR-LEACH	10	28	265	72	1004	0.3327
		EDL-LEACH	2	27	1013	221	1961	0.2893
		EE-LEACH	3	22	1089	96	1832	0.5109
		MDMZ-LEACH	**32**	**178**	**6820**	**1003**	**2694**	**2.1482**
	40	LEACH	4	29	3121	986	2865	1.0169
		MR-LEACH	2	32	356	263	2715	0.5309
		EDL-LEACH	**11**	59	965	574	5092	0.5573
		EE-LEACH	3	24	1059	167	4159	0.9744
		MDMZ-LEACH	1	**92**	**3783**	**1265**	**6553**	**1.8059**
	60	LEACH	4	29	2717	1084	4249	1.2454
		MR-LEACH	**24**	52	337	661	6077	0.8958
		EDL-LEACH	22	85	916	993	8873	0.7822
		EE-LEACH	3	24	1053	265	5624	1.6898
		MDMZ-LEACH	1	**110**	**3354**	**1404**	**9934**	**3.3486**
	100	LEACH	5	28	2135	1342	7273	1.9777
		MR-LEACH	19	78	195	1013	11536	1.8625
		EDL-LEACH	**23**	**140**	975	**2123**	**18900**	2.0885
		EE-LEACH	3	24	1061	370	9100	3.0873
		MDMZ-LEACH	3	85	**3068**	1626	14724	**4.9213**

Continued

Initial energy (Joule)	**Total nodes**	**Protocol**	**FND** (rounds)	**HND** (rounds)	**LND** (rounds)	**Packets** Received by BS	**Packets** Received by CH	**Simulation time** (second)
0.75	20	LEACH	10	44	4858	816	1359	0.8284
		MR-LEACH	7	49	193	144	1043	0.2931
		EDL-LEACH	13	25	1513	319	2882	0.4720
		EE-LEACH	5	33	1588	137	2752	0.7247
		MDMZ-LEACH	**17**	**451**	**9844**	**1574**	**4743**	**2.8483**
	40	LEACH	7	42	4730	1473	4212	1.6217
		MR-LEACH	**24**	54	149	316	2811	0.3542
		EDL-LEACH	8	69	1433	789	7079	0.6700
		EE-LEACH	5	35	1593	282	6187	1.2783
		MDMZ-LEACH	17	**160**	**5899**	**1831**	**9107**	3.1149
	60	LEACH	7	38	4153	1600	6249	1.9884
		MR-LEACH	**39**	76	399	813	7763	1.0083
		EDL-LEACH	16	109	1388	1412	12606	1.5608
		EE-LEACH	5	35	1590	365	8447	2.6480
		MDMZ-LEACH	17	**280**	**4856**	**2090**	**16339**	**5.0062**
	100	LEACH	7	41	3182	1967	10693	3.3481
		MR-LEACH	23	127	317	1819	19192	2.3665
		EDL-LEACH	**30**	188	1492	**2934**	**26275**	2.7552
		EE-LEACH	5	35	1569	578	13590	4.9000
		MDMZ-LEACH	3	**126**	**4513**	2276	19785	**7.0747**
1.00	20	LEACH	13	59	6432	1074	1780	1.2160
		MR-LEACH	15	35	161	157	990	0.1628
		EDL-LEACH	15	38	2007	474	4270	0.5111
		EE-LEACH	6	43	2122	159	3705	0.8682
		MDMZ-LEACH	**26**	**400**	**13116**	**2035**	**5601**	**3.6066**
	40	LEACH	10	50	6247	1939	5554	1.9211
		MR-LEACH	16	59	494	440	4600	0.5941
		EDL-LEACH	**26**	96	1928	1067	9588	0.9128
		EE-LEACH	6	47	2130	386	8224	1.6508
		MDMZ-LEACH	17	**408**	**7240**	**2474**	**13889**	**3.5938**
	60	LEACH	9	48	5376	2118	8235	2.9155
		MR-LEACH	**58**	132	400	1137	10933	1.3541
		EDL-LEACH	35	152	1871	1889	16915	1.8864
		EE-LEACH	6	47	2123	465	11274	3.0576
		MDMZ-LEACH	15	**286**	**6628**	**2767**	**20276**	**6.1141**
	100	LEACH	9	53	4235	2603	14102	3.7347
		MR-LEACH	29	168	340	2003	22347	2.8757
		EDL-LEACH	**43**	**280**	2021	**4288**	**38419**	3.6776
		EE-LEACH	6	47	2104	781	18089	5.8941
		MDMZ-LEACH	6	195	**5882**	3189	28633	**9.7114**

better. For the average simulation time, it is known that MDMZ-LEACH is the longest among other protocols.

Regarding FND, the proposed protocol works well when the number of nodes is small (20) for almost all of Scenario 2. The more nodes used by MDMZ-LEACH, the faster the first node that runs out of energy appears compared to other protocols. The HND value for MDMZ-LEACH is quite suitable for several Scenarios 1 and 2 combinations. The performance of the proposed protocol is superior to other protocols in all scenarios in terms of LND. By placing fixed sensor nodes and fixed BS positions based on the location of the monitoring house (165, 180) on the map (see a red dot in Figure 2), the protocol performance will also adjust. In several cases, we find that the possibility of implementing single-hop protocols such as LEACH gives the best results, especially if the BS is positioned in the middle of an agricultural area. The performance based on the number of packets received by the BS is the same for the packets received by the CH in each protocol. MDMZ-LEACH performs better on the number of packets received by BS and CH for nodes below 100. The simulation time shows that MDMZ-LEACH is longer than other protocols, so the algorithm's complexity is high.

5. **Conclusions.** LEACH protocol derivatives in the single-hop and multi-hop categories have been widely studied in hierarchical-based clustering routing techniques. The proposed Multi-hop Dynamic Multi-Zone LEACH (MDMZ-LEACH) protocol is applied to a large agricultural area map in North Bali. Based on the simulation results of implementing the proposed protocol with two scenarios and a comparative analysis of several parameters, placing more sensor nodes does not result in better routing performance. Our proposed protocol provides excellent results in extending network life compared to some protocols. However, the simulation time required is longer than other protocols. The more clusters that are formed, the greater the data to the CH will result in, and the faster the network energy will run out. The placement of 20 sensor nodes on the agricultural area map can be a recommendation for implementing WSN in real time.

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REFERENCES

[1] K. Gulati, R. S. K. Boddu, D. Kapila, S. L. Bangare, N. Chandnani and G. Saravanan, A review paper on wireless sensor network techniques in Internet of Things (IoT), *Materials Today: Proceedings*, vol.51, pp.161-165, 2022.

[2] N. Temene, C. Sergiou, C. Georgiou and V. Vassiliou, A survey on mobility in wireless sensor networks, *Ad Hoc Networks*, vol.125, pp.1-17, 2022.

[3] R. E. Mohamed, A. I. Saleh, M. Abdelrazzak and A. S. Samra, Survey on wireless sensor network applications and energy efficient routing protocols, *Wireless Personal Communications*, vol.101, no.2, pp.1019-1055, 2018.

[4] H. Chen and Z. Chen, Energy-efficient power scheduling and allocation scheme for wireless sensor networks, *Energy Reports*, vol.8, pp.283-290, 2022.

[5] O. Kanoun et al., Energy-aware system design for autonomous wireless sensor nodes: A comprehensive review, *Sensors (Switzerland)*, vol.21, no.2, pp.1-25, 2021.

[6] Y. Ge, Y. Nan and Y. Chen, Maximizing information transmission for energy harvesting sensor networks by an uneven clustering protocol and energy management, *KSII Transactions on Internet and Information Systems*, vol.14, no.4, pp.1419-1436, 2020.

[7] W. R. Heinzelman, A. Chandrakasan and H. Balakrishnan, Energy-efficient communication protocol for wireless microsensor networks, *Proc. of the Hawaii International Conference on System Sciences*, pp.1-10, 2000.

[8] J. Hong, J. Kook, S. Lee, D. Kwon and S. Yi, T-LEACH: The method of threshold-based cluster head replacement for wireless sensor networks, *Information Systems Frontiers*, vol.11, no.5, pp.513-521, 2009.

[9] N. E. Majd, P. Chhabria and A. Tomar, Energy aware LEACH protocol for WSNs, *Future of Information and Communication Conference (FICC)*, pp.1200-1209, 2019.

[10] V. Babu M, C. N. S. V. Kumar, S. Parthiban, U. Padmavathi and M. Z. Ur Rahman, AE-LEACH: An incremental clustering approach for reducing the energy consumption in WSN, *Microprocessors and Microsystems*, vol.93, 104602, 2022.

[11] M. S. Gitakarma, T. K. Priyambodo, Y. Suyanto, R. Sumiharto and D. Wijayanto, Designing wireless sensor network routing on agriculture area using the LEACH protocol, *The 3rd International Seminar on Research of Information Technology and Intelligent Systems (ISRITI)*, pp.221-226, 2020.

[12] M. S. Gitakarma, T. K. Priyambodo, Y. Suyanto and R. Sumiharto, A proposed multi-hop dynamic multi-zone LEACH protocol to extend network lifetime in wireless sensor network, *International Conference on Innovation in Science and Technology (ICIST)*, pp.54-61, 2020.

[13] H. Aetesam and I. Snigdh, A comparative analysis of flat, hierarchical and location-based routing in wireless sensor networks, *Wireless Personal Communications*, vol.97, no.4, pp.5201-5211, 2017.

[14] N. Qubbaj, A. A. Taleb and W. Salameh, Review on LEACH protocol, *The 11th International Conference on Information and Communication Systems (ICICS)*, pp.414-419, 2020.

[15] M. O. Farooq, A. B. Dogar and G. A. Shah, MR-LEACH: Multi-hop routing with low energy adaptive clustering hierarchy, *Proc. of the 4th International Conference on Sensor Technologies and Applications*, pp.262-268, 2010.

[16] A. G. Saminathan and T. Ponnuchamy, EE-LEACH: Development of energy-efficient LEACH protocol for data gathering in WSN, *EURASIP Journal on Wireless Communications and Networking*, vol.2015, no.1, pp.1-9, 2015.

[17] S. Dhivya, N. Jayanthi and K. R. Valluvan, Enhancement of dual-hop layered LEACH routing protocol with mobility in wireless sensor networks, *International Journal of Engineering Science*, vol.2, no.3, pp.46-50, 2018.

[18] J. Y. Lee, K. D. Jung, S. J. Moon and H. Y. Jeong, Improvement on LEACH protocol of a wide-area wireless sensor network, *Multimedia Tools and Applications*, vol.76, no.19, pp.19843-19860, 2016.

[19] M. Kalra, A. Vohra and N. Marriwala, LEACH based hybrid energy efficient routing algorithm for dynamic cognitive radio networks, *Measurement: Sensors*, vol.24, pp.1-6, 2022.