Non-cooperative Game Leach for Cluster Distribution Routing Method on Wireless Sensor Network (WSN)

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***Abstract*—A wireless sensor network (WSN) is a group of sensor nodes that take data with specific measurement parameters and then send the data wirelessly to a central node or server for data processing. WSN nodes are designed to be compact; therefore, the energy of sensor nodes usually depends on the integrated battery. The sensor node must work as efficiently as possible so that energy use can be more efficient and WSN life can be prolonged. The longer the lifespan of the WSN, the higher the throughput. One of the many ways to extend the life of the WSN is to use the concept of grouping nodes or the so-called cluster method. This study proposes the The Division Non-Cooperative Game LEACH (DivNCGL) routing method, a modified method based on Low Energy Adaptive Clustering Hierarchy (LEACH) by distributing cluster heads (CHs). The distribution process is performed by dividing the distribution area of the nodes into subregions. The subregion division process uses the probability value obtained by the non-cooperative game method based on the remaining active nodes, the total remaining energy, and the energy required for transmission. The simulation results, the lifespan of WSN using the DivNCGL method increases up to 30% with stable energy dissipation compared to the LEACH protocol. The increasing lifespan of the WSN also increases the amount of data transmitted, thereby increasing the received throughput. Received data increases up to 70% using the DivNCGL method compared to LEACH.**

***Keywords*—WSN, routing, LEACH, non-cooperative game, distributed cluster**

I. Introduction

A Wireless Sensor Network (WSN) is a collection of nodes with sensors on a communication network. The sensor nodes are spatially distributed in an area and serve various purposes, such as monitoring environmental conditions for humidity, pressure, movement, and temperature. In WSN, one of the most essential things is energy use. WSN uses energy to receive, transmit, and partly process the initial data. The more efficient the use of power in the WSN network, the longer the service life. The lifetime of the WSN depends on the battery capacity used in each sensor and certain conditions where there is a limit to the number of nodes that are still active while sending data. WSN is designed to minimize human intervention in its working process. Therefore, the sensor nodes in WSN are intended to have a small form that is easy to install and move with minimal or no maintenance [1].

Because the purpose of the WSN is to collect as much data as possible autonomously without much human intervention, to extend the network's life, apart from using low-power sensor nodes, a network routing protocol with a high energy efficiency level is also required [2]. The energy the sensor nodes use to transmit data is greater than the energy used to perform data processing. Therefore, a suitable routing method can reduce energy usage significantly. The routing process in WSN varies depending on the WSN application used for specific data processing tasks. In addition, the routing process also depends on the number of sensor nodes used and the coverage area.

Apart from the routing process, another effort to increase the lifespan of the WSN is to create a cluster on the network, which is a collection of adjacent sensor nodes. Grouping nodes into a cluster reduces the usage of transmission energy. Non-CH nodes not selected to be the Cluster Head (CH) will forward the data to the nearest CH, using only a tiny amount of power for data transmission. Meanwhile, CHs only used higher energy for sending the aggregation data collected in the cluster to be forwarded to the Base Station (BS).

One of the routing protocols on WSN that uses the cluster method is the low energy adaptive clustering hierarchy (LEACH) protocol [2, 3]. The LEACH protocol divides all sensor nodes into several clusters and selects one node to be a CH with more functionality. As mentioned in [4], the LEACH protocol sometimes creates orphan nodes that are not joined to any of the formed clusters, so they are not bound to any CH. This inadvertence occurs because of the groups' formation in each round changes. To resolve this, the author proposed adding a CH in the neighboring orphan nodes to collect potential data lost from the orphan nodes [4]. Hendrarini *et al.* [5] used game theory in the energy-balanced trace

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hold. The cluster method for distributed energy-efficient clustering was modified using game theory so that heterogeneous networks can flexibly distribute the average energy of sensor nodes on the web. Quy, Le, and Nguyen [6] proposed the hybrid multilevel multi-hop LEACH protocol (HM2LP), similar to the LEACH protocol, which employs two phases of work. This protocol is intended for wide-area and large-scale implementation of WSN. Another method uses distributed clusters to avoid orphaning nodes, as in [7], in which game theory was used to make tentative CH selections. Quy and Le [8] also carried out the cluster distribution method using a mixed strategy game based on game theory. This strategy works in the second phase, where the selected nodes will only send information that will go to sleep mode to reserve energy used in the next round.

Because the LEACH protocol determines the CHs based on the probability of each node, it is possible to select the adjacent CH. A CH that is not evenly distributed in the network will affect the wastage of energy. In addition, the accidental formation of orphan nodes will increase energy usage. An orphan node is formed because there is no CH representative in the area and which causes an inefficient energy usage [9].

This study proposes a routing method to prevent the selection of adjacent CH and avoid forming orphan nodes. The proposed routing method modifies the LEACH method in the setup phase by distributing CH. The CH distribution process is carried out by dividing the distribution area of nodes into subregions. The subregion division process uses the probability value obtained by the non-cooperative game method, which is calculated in each round so that the matter is adaptive to the remaining energy. Therefore, in this study, the LEACH method is used with subregion division based on the probability of non-cooperative games and circshift logic of the node’s location matrix.

The writing of this paper will be divided into several sections, namely: 1. Introduction, which explains the background, problem formulation, research objectives, scope, and research systematics; 2. related work, which contains previous research that has been done before; 3 Proposed model, this section describes the research steps carried out consisting of the research approach, research methods used, and simulation design; 4. Result and Analysis This section describes the results and discussion of the simulations that have been carried out, which were evaluated on specific parameters; 5. In conclusion, this section contains findings drawn from the results and discussion, considering the research objectives and suggestions for research development.

II. Related Work

A. Wireless Sensor Network

WSNs can be wireless networks that are self-configured to monitor physical or environmental conditions such as temperature, sound, vibration, pressure, motion, or pollutants. The collected data are forwarded across the network to a BS or sink to be observed and analyzed [10]. The sink or BS acts as an interface between the user and the network. A user can retrieve the required information from the network by entering a query and collecting the results from the sink.

Deploying WSNs involves various challenges. In addition, the sensor nodes communicate over a lossy wireless path without an infrastructure [11]. An additional challenge is related to the limited energy supply of the sensor nodes. A WSN must choose a suitable routing protocol to use energy resources to maximize network lifetime efficiently. Repeatedly game-based models were built to extend the life of WSN's sensor nodes under limited energy conditions, and the strategy adopted by the sensor nodes was determined by examining the length of the idle listening phase. If the idle listening time is longer than the sleep threshold, the sensor node goes to sleep to save power [12]. If the idle listening time is shorter than the sleep threshold, the sensor node remains idle listening. This reduces the power consumption caused by the transition between the sleep and active states of the sensor node [12]

B. LEACH Protocol

LEACH is a routing algorithm designed to collect and transmit data from each node to a data sink, usually a BS. The main objectives of LEACH are to extend the network life, reduce power consumption or energy usage by each node on the network, and use data aggregation to reduce the number of communication messages. The LEACH protocol adopts a hierarchical approach to organize the network into a set of clusters [13]. Each cluster chooses a CH for multi-tasking. The first task involves collecting periodic data from cluster members. After collecting data, CH aggregates the data and removes the redundancy between the correlated values. The second main task of the CH is to send aggregated data directly to the BS over a single hop. The third primary task of the CH is to create time-division multiple access (TDMA) based schedule in which each cluster node is assigned a time slot that can be used for transmission. The CH announces the schedule to its cluster members via broadcasting. The TDMA scheme will reduce the possibility of data transmission collisions between sensors inside and outside the cluster.

LEACH implements the concept of multi-hop communication, where the sensor is intended to communicate with the closest sensor node [6]. Sensor nodes require enormous power for long-term communication. The concept of multi-hop communication is advantageous if the wireless network used is extensive and has numerous nodes. This is because nodes will need more energy for long-distance communication than data collected in one representative node and send aggregation data. LEACH is a stochastic algorithm where nodes decide to be the CH without considering other CH localizations, which can lead to high concentrations of CH in a small area [14]. Variations of the LEACH protocol can be found in the survey [15].

C. Game Theory

Game theory is a mathematical construct that defines the conditions of cooperation, non-cooperation, and repetition among rationally independent decision-makers.

Numerous researchers have proved this theory as one of the best tools in wireless ad hoc networks for various purposes. *Game theory* can be used in WSN for multiple purposes, including security, clustering, routing, load balancing, quality of services, power control, intrusion detection, selfish node management, and efficient resource management. *Game theory* is a theoretical framework that studies strategic interactions by developing a model that determines the actions for interacting entities to achieve good benefits from the situation [15].

Hnini and Fihri *et al*. [16] compared the existing protocol with a new clustering algorithm based on localized game theory. For CH selection, each sensor node only communicates with neighbors within the communication radius, so the player playing can be limited. Several developments of the LEACH protocol, such as the weighted low energy adaptive clustering hierarchy (W-LEACH) method [17], have been reported. W-LEACH saves energy by allowing some normal nodes to 'rest' in one round by initiating sleep mode. The BS or server controls this sleep mode, so the sensor nodes do not work autonomously. This W-LEACH method is suitable for conditions in which data needs from the environment do not need to be sent continuously. This weighting method is developed on an improved W-LEACH [18], based on the weighting of each node using game theory. This weighting will be the basis for selecting nodes that rest in the current round. Another method is the "Cluster Head to Normal Ratio" (CTNR) which calculated cluster heads based on the distance and residual energy of a node, however, the CTNR protocol efficiency gets reduced to the existence of an energy hole problem. To solve the problem of an energy hole, an improved CTNR method is proposed in [19]. In this method, the gateway nodes are deployed optimally near the base station in our proposed model with a finite number of sensor nodes.

The development of game theory in WSN was carried out in [20] using the suitable game method. This method gives several other CH candidates a choice to become the CH and work together with other CH or withdraw from CH candidates. Comparative survey research on the game theory method was conducted in [21]. In this study, the types of game theory discussed were cooperative games, non-cooperative games, evolutionary games, and reputation-based games. The kind of game theory method describes how the technique is used and what factors are the most influential when using one of these methods.

One application of game theory in WSN was carried out in [22], who showed the residual energy obtained when using game theory in WSN with randomly generated values for the number and arrangement of nodes. This method uses a Nash equilibrium of both types of games: cooperative and non-cooperative. Energy efficiency in this study is viewed from the total energy savings, with better simulation results obtained when the network has a higher node density level.

III. Proposed Model

The basis for determining CH in the LEACH protocol is a predetermined probability value and a random value from the threshold; thus, it is possible to select the adjacent CH. A CH that is not evenly distributed in the network will impact energy wastage. In addition, the unequal distribution of CH will form inactive nodes or orphan nodes outside all CH ranges so that they do not transmit data and will impact the efficiency of energy usage. LEACH protocol aims to increase the lifetime of wireless sensor networks by lowering the energy consumption required to create and maintain Cluster Heads by maintaining a balance of weights among all nodes. This is important because each node has limited energy, so each node tries to use an energy load that is almost the same so that the life of the WSN gets longer.

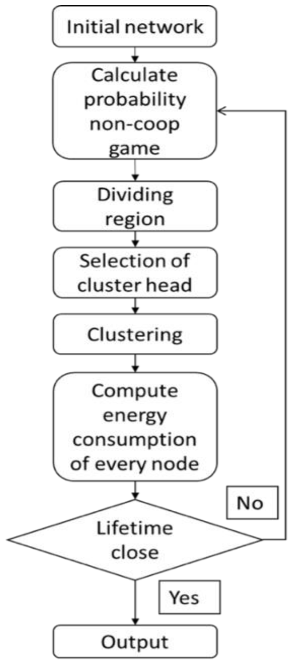

Figure 1. Simulation flowchart.

Fig. 1 describes a simulation flowchart; as previously mentioned, this study proposes a modified routing method based on the LEACH method, which distributes CHs to prevent the selection of adjacent CHs and avoid orphan nodes. The distribution process is carried out by dividing the distribution area of the nodes at the beginning of the setup process into subregions. Each subregion is then only allowed to choose a maximum of 1 CH representative. The subregion division process uses the probability value obtained by the non-cooperative game method based on the remaining active nodes, the total remaining energy value, and the energy required for transmission. Then, the CH is selected using a circshift logic on the node location matrix. After calculating the energy consumption of all nodes, the network will determine whether the data transmission cycle can still be carried out by looking at the remaining energy at each node. If the power in every node is below the threshold, then the process stops hence it is a "lifetime close".

The purpose of the routing model in this study is to provide better energy efficiency by considering the efficiency parameters from the perspective of network lifetime, energy dissipation, and total data (bit).

The simulations carried out in this study are WSN using the LEACH method, LEACH with the probability of non-cooperative game (NCGL), and the LEACH subregion with the likelihood of non-cooperative game (DivNCGL) shown in Fig. 2.

A. LEACH Step

The LEACH protocol divides the primary operating conditions into 2 phases—the setup phase and the *steady-state* phase—and is carried out in several rounds [23]. The first phase is the setup phase, which consists of two steps: selecting the CH and forming clusters. The second phase is the steady-state phase which focuses on data collection, aggregation, and delivery. The duration of the setup phase is assumed to be shorter than the steady-state phase to minimize the protocol overhead.

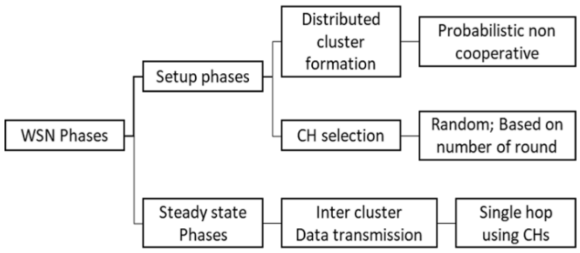

Figure 2. Proposed WSN phase.

CH selection begins at the start of the setup phase by calculating the threshold value (T) with the following equation:

$$CT = \begin{cases} \frac{p}{1-p\left(r \bmod \frac{1}{p}\right)}, & if\ N \in G \\ 0, & otherwise \end{cases} \quad (1)$$

where p is the probability with a predefined value, r represents the current round, and G is the group node in the last $1/p$ round that did not become CH. Before selecting a node to be a CH, each node is assigned a temporary random value between 0 and 1. If the random value exceeds the threshold value, the node will become a CH in the current round. The probability in the LEACH method determines the maximum number of CHs that can be formed in each round.

Then, the selected CHs will broadcast their information to all network nodes. Other nodes will receive all information from all selected CHs but only respond to the CH with the closest distance to transmit data. After receiving a join request from a regular node, the CH forms a group (cluster) with each node that has sent information to the CH. Thus, several clusters will be included in the WSN.

Next is the steady-state phase, also called the data transmission phase. The CH will define a different time division to send data to each node. This different timing aims to avoid signal clashes during communication. One round is considered complete at the start of the next round of initialization. Then, the process continues the same way as the previous rounds until the total energy at each node is depleted, or the remaining energy reaches a specific critical value [24].

B. Energy Model

The energy used during data transmission is more significant than that used during data processing. The LEACH protocol uses a first-order radio model to calculate the energy loss. The first-order radio model is a simple model that depends on the distance between nodes [25]. The energy dissipation of the nodes follows the energy model equation.

$$E_{RX}(n) = E_{elec}n \quad (2)$$

$$E_{TX}(n,d) = E_{elec}n + E_{fs}nd^{\gamma} \quad (3)$$

where E_{RX} is the energy consumed for receiving, and E_{TX} is the energy consumed for transmission. E_{elec} is the energy dissipated to activate the transceiver, n is the number of bits, and d is the node distance calculated from the Euclidean equation.

$$d_{(i,j)} = \sqrt{\sum_{k=1}^{N}\left(x_{ik} - x_{jk}\right)^2} \quad (4)$$

where $d(i, j)$ is the node distance, N is the number of nodes, x_{ik} is the value of node i on variable k, and x_{jk} is the value of node j on variable k.

In this study, the energy equation based on Eq. (2) and Eq. (3) becomes

$$E(sum) = E_{TX}(sum) \quad (5)$$

$$E(sum) = E_{TX} \times (CHbit) + (E_{fs} \times CHbit\ \times d^2) + (E_{RX} \times Nbit \times N_{ak}) \quad (6)$$

$$Eres = E - \sum_{i=1}^{r} E(sum)_i \quad (7)$$

where $E(sum)$ is the total energy used in the previous round, r - 1. *CHbit* and *Nbit* are the numbers of bits sent by the cluster head and normal nodes, respectively. N_{ak} is the comparison value between N_{alive} and the number of clusters formed. E is the initial energy of the network, which is the energy of each node times the number of nodes. *Eres* is the residual energy of the network.

C. Non-cooperative Game Probability

Determination of the probabilities based on non-cooperative games in this study aims to determine the variable's value for dividing the region in the network. In [26], the clustered routing for selfish sensors (CROSS) method was employed; i.e., the game theory was applied to each node by providing probabilities based on the Nash equilibrium

$$p = 1 - \omega^{1/(N-1)} \quad (8)$$

p in Eq. (8) is different from p in Eq. (1); p in Eq. (8) is the probability value sought. N is the number of nodes as a player. ω is a variable that has been defined in advance based on the payoff value, which is the value that must be paid if a decision is made, in this case, when the node becomes CH.

Meanwhile, in this research model, the equilibrium is a modified mixed Nash equilibrium. The value of the ω variable will change based on the total remaining energy in the network and the number of remaining active nodes. This change of value is because the determination of nodes to be the CH in this research model depends on the number of regions formed, so that the maximum number of CHs in a region *CHdivmax* = 1

For determining the CH declaration, a non-cooperative game scheme is applied to each node, which maximizes its efforts to save energy by considering the choices for other nodes. The game scheme is written as follows $G = \{N, S_i, U_i\}$ with $i \in N$ and N are nodes on the network. *Si* is a strategy that can be chosen by each node, namely $S_i = \{YCH, NCH\}$, *YCH* is a node that is selected to be CH, and *NCH* is a node that refuses to become CH. *Ui* is a utility function given as follows:

$$U_i = \begin{cases} g; if\ S_i = YCH\ \exists\ j \in N_{alive} \mid S_j = NCH \\ g - c; if\ \ S_i = YCH \\ 0; if\ \forall\ j\ \in N_{alive}, S_j = NCH \end{cases} \tag{9}$$

N_{alive} is the remaining active node, $\boldsymbol{N_{alive} = N - N_{dead}}$, g is the gain value that the node gets if it refuses to become CH, and *c* is the value issued if the node becomes CH. In this study, *g* assumed to be the value of the remaining energy, and *c* is assumed to be the total energy used by the network in that round.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Area	1000 m × 1000 m
Number of nodes	100
Eo (initial energy)	2 J
Eda (data aggregation energy)	10 nJ/bit
Etx (transmission energy)	100 nJ/bit
Erx (reception energy)	100 nJ/bit
Efs (free space energy)	0.34 nJ/bit/m^2
Tsu (average time used in setup phase)	4 s
Tss (average time used in steady-state phase)	10 s

In the LEACH protocol, the value of *p* indicates the probability of a node becoming CH, *p(YCH) = p*. In contrast, the probability of a node not becoming CH is *p(NCH) = 1 - p*, so that the probability of all nodes not being the CH and the probability of at least one CH being selected becomes

$$p(all\ NCH) = (1-p)^{N-1} \tag{10}$$

$$p(min\ 1\ YCH) = 1 - (1-p)^{N-1} \tag{11}$$

If we assume the probability that the mixed Nash equilibrium value is formed based on $U_{YCH} = U_{NCH}$ as in Eq. (9), then, in this study, *pg*, which is the probability of calculating the non-cooperative game, is given as

$$g - c = g(1 - (1-pg)^{N-1}) \tag{12}$$

$$pg = 1 - \left(\frac{cost}{gain}\right)^{1/_{N-1}} \tag{13}$$

By changing *c* and *g* based on the remaining energy, *Eres*, and the number of active nodes remaining, N_{alive}, the *pg* value becomes

$$pg = 1 - \left(\frac{E(sum)}{Eres}\right)^{1/_{N-1}} \tag{14}$$

Thus, the calculation of the threshold value of the NGCL method will adjust to changes in the probability value from the calculation of the non-cooperative game to

$$T = \begin{cases} \frac{pg}{1-p(r\ mod^1/_p)},\ if\ pg \geq 1 \mid N_{alive} \in G \\ \frac{p}{1-p(r\ mod^1/_p)},\ if\ pg < p \mid N_{alive} \in G \\ 0 \qquad\qquad ,\ other \end{cases} \tag{15}$$

The *T* value with this non-cooperative game calculation is a modification of Eq. (1) used in the LEACH method. This new *T* value is used in the NCGL method to determine the threshold value for CH selection. For the DivNGCL method, the probability value in Eq. (14) is used to determine the region's variable formation. The maximum number of CH formed in DivNCGL is only as much as the formed region.

$$Psub = \frac{Area\ Network}{round\ (\sqrt{pg \times N},\ <0)} \tag{16}$$

$$Xdiv = \frac{1}{W} \times Psub; \qquad Ydiv = \frac{1}{L} \times Psub \tag{17}$$

where *Psub* is the value of the variable to divide the field and *N* is the number of nodes. *pg* is the non-coop probability value. *Xdiv* and *Ydiv* are the numbers of areas divided on the x and y axes, respectively. *W* and *L* are the plane lengths in the x and y axes, respectively. In the DivNCGL method, the CH determination technique will release the *T* function in Eq. (15) and will use the *circshift* logic

$$CH = circshift(XY, r, dim) \tag{18}$$

by shifting the elements in the XY array, which is the position matrix of each node in a circular manner with a position according to the value of *r*, with dimensions (dim) = 2, which is the position of the x and y coordinates of a node. This is to ensure the formation of *CHdivmax = 1*

IV. RESULT AND ANALYSIS

This study compares three methods—the LEACH protocol, LEACH with probability NCGL, and DivNCGL. NCGL is a modification of the LEACH protocol in which a non-cooperative game method is added during the setup phase so that a probability value is found that will be used in that round. DivNCGL is a modification of the NCGL method in which the region is divided using probability values from non-cooperative game calculations. The performance evaluation parameters are network lifetime, total energy dissipation, and total data sent.

The network lifetime is the lifetime of the WSN until the network is declared dead when the network runs out of energy, or the number of nodes reaches a critical value. The total energy dissipation is the total energy used per round until the network is declared dead. The total data is the number of data (bits) sent to the BS during the network lifetime.

As shown in Table I, this simulation uses 100 sensor nodes allocated over an area of 1000 × 1000 on the x and y axes. The initial energy values of all nodes are assumed to have identical values. The setup phase time and steady-state phase time are assumptions that show the WSN lifetime results from a time perspective. WSN lifespan is the length of time for which the network is still considered to be functioning based on the remaining energy or active nodes according to a predetermined critical value. The critical value in this simulation is 5% of the total nodes, so if the number of active nodes are five or less, then the simulation will stop because the network is considered to be unable to work optimally only with the remaining active nodes.

The simulation is carried out using MATLAB and has the following conditions. Nodes are randomly distributed; sensor nodes are static. The dimensions of the area have not changed. The simulation does not include interference factors and SNR.

The sensor nodes are static and randomly distributed, the simulation results for each iteration will never be the same. Therefore, to compare the values for each method, for the simulation discussion, we take the simulation results from one iteration so that the arrangement of nodes tested in each method will be the same.

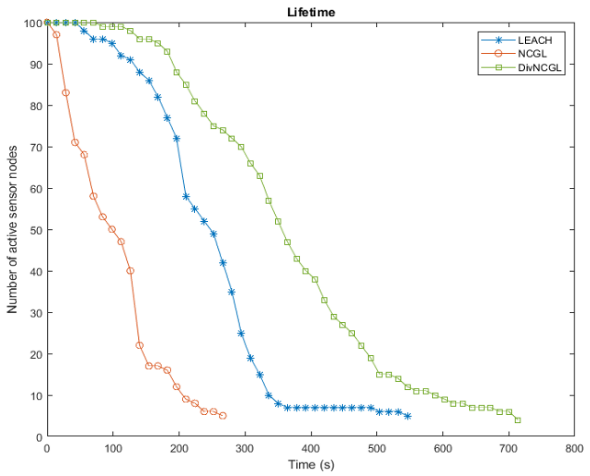

Figure 3. Network lifespan comparison among LEACH, NCGL, and DivNCGL.

A. *Lifetime*

Fig. 3 describes the network lifetime graph, the X-axis shows the network time, the Y-axis shows the number of active nodes, and each marker on the graph shows the ongoing round. Using the LEACH method, the network age reaches 546 seconds with the remaining five active nodes. The LEACH method begins to experience saturation when the remaining active nodes is seven. This saturation can occur because of two reasons: first, when the value of T at each node does not reach the specified value limit so that no node becomes CH, and second, when the remaining active nodes approach the specified critical value. Saturation occurs because all nodes do not reach the T value only if the remaining active nodes are gathered around the sink or BS.

In the LEACH simulation, the number of active nodes is close to the critical value of 5%, which causes graph saturation, its the remaining active nodes are close to the sink or BS. Because the T value of each node is not met, there is no selected CH representative, so no cluster is formed. Because no cluster is formed, each node will directly send data to the sink or BS. The lifetime of each of the remaining active nodes will be longer because the node is close to the sink or BS, so only a slight amount of the energy is expended to transmit data.

At the beginning rounds, the CH selected can meet the maximum probability of CH formation, p = 0.1 or 1/10 of the number of active nodes, because there are still many active nodes. In the middle of the round, the network is 210 s old, with 58 active nodes remaining. When the remaining 58 nodes are compared with 7 units, the time required by the network is 154 s, while from the remaining 7 to 5 nodes (critical value), the time required is more prolonged at 182 s. This value will affect the increase in throughput generated. Meanwhile, the most significant reduction in active nodes occurs at the 15th round, from 72 active nodes to 58 active nodes in the next round (16th round) (Table II).

TABLE II. LEACH: ACTIVE NODE VS TIME COMPARISON

Round	Active nodes	Time (s)
5	98	56
15	72	196
16	58	210
27	7	364
40 (end)	5	546

TABLE III. NCGL: ACTIVE NODE VS TIME COMPARISON

Round	Active nodes	Time (s)
2	97	14
3	83	28
10	40	126
11	22	140
20 (end)	5	266

TABLE IV. DIVNCGL: ACTIVE NODE VS TIME COMPARISON

Round	Active nodes	Time (s)
7	99	84
14	93	182
37	15	504
52 (end)	4	714

TABLE V. LIFETIME COMPARISON: LEACH, NCGL, DIVNCGL

Comparison	LEACH	NCGL	DivNCGL
First dead node	2 Nodes, 5^{th} round, 56^{th} s	3 nodes, 2^{nd} round, 14^{th} s	1 node, 7^{th} round, 84^{th} s
Lifetime	40 rounds, 546 s, 5 active nodes	20 rounds, 266 s, 5 ative nodes	52 rounds, 714 s, 4 active nodes

For the NCGL method, during the 10th round, there is a significant decrease of nodes, from 40 to 22 active nodes (11th round) (Table III). The number of CH formed in that round is only a little or none at all so that each node will send data directly to the sink or BS. Sending data without going through CH will require considerable energy from each node so that in the next round, most of the nodes will run out of energy and are considered dead nodes. It causes the network life to become shorter. From the comparison of the three methods, NCGL has the shortest time

Using the proposed DivNCGL method, by distributing CH evenly throughout the network through regional division, the WSN lifespan reaches 714 s with four active nodes remaining (Table IV). The decrease in the number of active nodes in DivNCGL tends to be stable because the maximum number of CH formed is only as many as the regions formed, and each region can only have a maximum of 1 CH. Thus, CH is forced not to form close together and can connect all normal nodes in the region to form clusters and avoid orphan nodes that are not connected to a cluster.

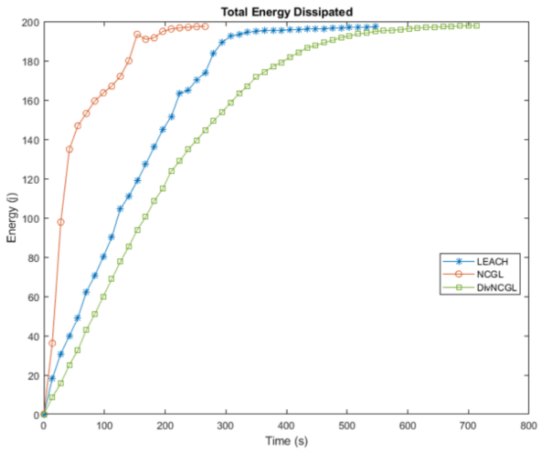

Figure 4. Energy dissipation comparison among LEACH, NCGL, and DivNCGL

B. Total Energy Dissipation

Fig. 4 describes the LEACH method. Energy use begins to reach saturation in the 23rd round until the end of the WSN period. In the 23rd round, the total energy use in the network reaches 192.4 J, and at the end of the WSN life, the total energy used reaches 197.2 J. The remaining energy of 2.8 J is the total remaining energy from the five actives nodes. The total energy used has a reasonably stable graph and reaches its saturation value at the 308th second. There are several points where there is a spike in energy use, namely at the 56th (5th round), 112th (9th round), and 210th second (16th round) (Table VI). In these rounds, adjacent CHs are formed. One or more parts of the network do not have a CH so that nodes that are not part of the cluster will send data directly to the sink or BS.

Like in network lifetime, the NCGL method also shows results under the LEACH method. The NCGL method shows results from the 1st until the 4th round; the energy dissipation reaches 134.9 J, which is ~67.5% of the total energy owned by all nodes on the network. This energy wastage occurs because the probability value of the non-cooperative game calculation at the beginning of the round is very small, which causes very few CHs to be selected so that many orphan nodes use large amounts of energy to send data directly to the sink or BS. There was an anomaly in energy use during the 168th second (13th round), where the total energy dissipation value decreased from the previous round. In the 12th round, the total energy dissipation was 193.5 J, and in the next 13th round, the value did not increase but decreased to 190.9 J (Table VII)

This is a common weakness of the LEACH method, and this weakness was adopted in the NCGL method. As described in [13, 23−26], the LEACH method can inadvertently cause a node which is not a member of any cluster to become an orphan. If this orphan node is located too far from the sink or BS and does not have enough energy, then the energy sent by this node will be wasted because the data will not reach the sink or BS. This wasted energy usage information will not be recorded. In the next round, where this node is no longer an orphan node, the difference in the total energy information will decrease. This false information due to the node should still be recorded as having energy, but because there is information on energy use that is not recorded, updating the information will cause a decrease in the total value of energy dissipation [28].

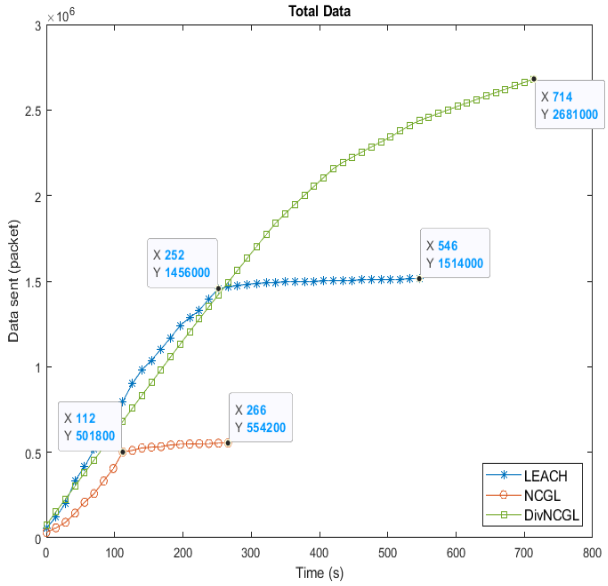

Figure 5. Comparison of total data among LEACH, NCGL and DivNCGL.

TABLE VI. LEACH: USED ENERGY VS TIME COMPARISON

Round	Used Energy	Time (s)
5	48.89	56
9	90.09	112
16	151.5	210
23	192.4	308
40 (end)	197.2	546

TABLE VII. NCGL: USED ENERGY VS TIME COMPARISON

Round	Used Energy	Time (s)
4	36.16	14
12	193.5	154
13	190.9	168
15	194.9	196
20(end)	197.4	266

TABLE VIII. DIVNCGL: USED ENERGY VS TIME COMPARISON

Round	Used Energy	Time (s)
5	32,58	56
15	114,8	196
39	194,1	532
52(end)	197,9	714

TABLE IX. TOTAL DATA COMPARISON: LEACH, NCGL, AND DIVNCGL

Comparison	LEACH	NCGL	DivNCGL
Total data	1,514,000 bits, 546 second	554,200 bits, 266 seconds	2,681,000 bits, 714 seconds
Saturation point	Start at 252nd s, with 1,456,000 bits	Start at 112nd s, with 501,800 bits	Steady increase

In the DivNCGL method, the energy consumption in the network looks more stable and approaches the saturation point starting at around the 532nd second until the end of the WSN operation (Table VIII). This stable energy dissipation is caused by the distribution of CHs in each region, which is divided based on the calculation of probability values using non-cooperative games. The increase in the average use of energy in each round only occurred in the 5th and 15th rounds. This DivNGCL method could overcome one or two weaknesses of the LEACH method, namely the formation of adjacent CHs and orphan nodes.

C. Total Data

Fig. 5 shows that the total data on the WSN can be seen from the total data bits sent in a certain period. With the same network deployment configuration, the method that results in a longer life is likely to give better results.

In the LEACH method, the amount of data sent is saturated starting at the 252nd second, and in the NCGL method, the saturation point starts at the 112th second. In contrast, in the DivNCGL method, the data are sent with a steady increase (Table IX); this is related to how the energy is dissipated and how the number of active nodes changes. This is because in the DivNCGL method, the total energy dissipation tends to be stable, causing the number of active nodes to steadily decrease. By reducing the number of stable nodes, more data are sent

V. CONCLUSION

The DivNCGL routing method was successfully performed. The DivNCGL method provides improved performance compared to the LEACH method. The lifetime of the DivNCGL method is increased by more than 30% compared to that of the LEACH protocol. The number of rounds of the NCGL, LEACH, and DivNCGL protocols are 20, 40, and 52, respectively, while the network lifetimes of the NCGL, LEACH, and DivNCGL protocols are 266, 546, and 714 s, respectively.

The DivNCGL method provides a more stable energy dissipation graph compared to the LEACH and NCGL protocols. This graph indicates that the DivNCGL method uses its energy better to increase the throughput value. The DivNCGL method increases throughput by up to 70% when compared to LEACH. DivNCGL sent a total of 2.7×106 bits in 714 s, and LEACH sent a total of 1.5×106 bits in 546 s. In contrast, NCGL, which has the shortest lifetime, only sends a total of 5.5×105 bits.

The longer lifespan occurs because the proposed DivNCGL method avoids the selection of multiple nodes within the same region to be CH. Thus, CH is evenly distributed throughout the network and can overcome orphan node problems of the LEACH method. Nonetheless, further research is needed to achieve more efficient energy dissipation in WSN. Several proposals can be submitted as further research, including detecting potentially orphaned nodes and how to optimize them; How will WSN perform if the node is mobile; What if the number of nodes is always changing or always moving with different energy values. This research proves that our new routing method the DivNCGLL routing can reduce energy usage significantly.

CONFLICT OF INTEREST

The authors declare no conflict of interest This article has not been published and is not under consideration for publication elsewhere. The authors have no conflict of interest in regard to this research or its funding.

AUTHOR CONTRIBUTIONS

The first author, Muhamad Asvial is contributed to the conceptualization, methodology, implementation of algorithms, the conduct of experiments, and the formation of the paper. The second author, Awangga Febian Surya Admaja is contributed to writing-original draft preparation, resource data, and software simulation. The third author, Muh. Asnoer Laagu is contributed to analyse data, supervision, checking and proofreading the paper.

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