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LEACH algorithm analysis and simulation using MATLAB

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ABSTRACT

Research on Wireless Sensor Network (WSN) began to be carried out to meet various industrial needs including defense, health, environmental surveillance, and others. However, there are several obstacles in WSN, namely the problem of energy consumption which is the object of research by many researchers. The solution offered in this paper is to use the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol which is a hierarchical protocol where this protocol focuses on saving energy use on WSN. This study used Matlab 2023 simulation software which used several measurement parameters to determine tissue life time, average residual energy, and throughput. The research scenario uses a homogeneous topology with three network sizes, namely 500 x 500, 750 x 750, and 1000 x 1000. Then also used three conditions for the number of sensor nodes, namely 100 nodes, 150 nodes, and 200 nodes. The results showed that the smaller the tissue size, the longer the life time and if the network size is wider, the network life time is shorter. The number of data packets transmitted depends on the number of active sensor nodes and sufficient energy to transmit.

1. Introduction

Wireless Sensor Network (WSN) is a collection of a large number of nodes that function as sensors, communication devices and computing facilities [1], [2]. Sensors are used by sensor nodes to measure changes in the environment [3]. These changes are logged and sent to the sink. Sensor nodes not only collect data but also filter data using their limited computing capacity. By communicating with the transceiver, the base station analyzes and takes decisions from the data it receives [4]–[6]. To enable high-quality and fault-tolerant sensing networks, an evolution of sensor nodes has been developed that are small, power-efficient, and can be deployed in hundreds or thousands of numbers [7]–[9]. The network can be used in a variety of industries, including defense, healthcare, environmental surveillance, disaster management, and industrial process control [1], [10]–[13].

Some aspects that affect the design of WSN and its functions are energy consumption, cost, connection management, fault tolerance, storage and dynamic network topology [4], [7], [14]–[16]. Of these factors, the main challenge is related to energy consumption [17]–[22]. Each sensor node used in a WSN is battery-operated so this determines the life of the network because generally nodes are placed in environments that are difficult to access by humans so replacing or recharging batteries is difficult or even impossible [23]–[25]. Because of these problems, the researchers conducted research to overcome problems with routing protocols such as Low Energy Adaptive Clustering Hierarchy (LEACH) [1], [17], [26], Adaptive Threshold-sensitive Energy-Efficient sensor network (APTEEN) [6], [21], Hierarchical Ad hoc and Demand Distance Vector (AODV), Coordinate/Routing for Nanonetworks (CORONA), Power Efficient Gathering in Sensor Information System (PEGASIS) [21], [27], and so on.

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In WSN, there are two primary kinds of routing protocols: hierarchical or cluster-based routing and flat routing [5], [6]. Flat routing works with all nodes and sends data to the Sink Node (SN). Flat routing methods encounter data overload as node density rise, which leads to unequal energy allocation and constrained scalability. In contrast, hierarchical routing groups nodes and chooses a Cluster Head (CH) who is in charge of communicating data to the SN [21]. As a result, in recent years, hierarchical routing has received greater attention worldwide [28]. For wireless sensor networks, the LEACH protocol is widely used as a routing protocol due to its implementation of a fully decentralized hierarchical network design [29]. By using CH to create a top hierarchy and LEACH to split the network into layers, cluster administration can be made simpler, resulting in fewer routing packets and reduced network energy usage [30]. However, due to the dynamic but random CH selection approach, LEACH suffers from an unsymmetrical CH distribution resulting in an unbalanced energy load, and a reverse data transmission [14]. Rounds are the foundation of the LEACH protocol as a whole. Each round consists of two stages: a "steady state" stage and a "set up state" stage. The "steady state" stage transmits the data gathered by CH to the sink, whereas the "set up state" step involves cluster building and CH selection for the relevant cluster [5], [9].

According to research authored by Anas Ali Hussein et al. (2020) [17], The study's focus is on how the initial energy of sensor nodes and the size of WSN affect how many nodes are operational. The lifespan and number of active nodes grow when the sensor node's starting energy is increased. The number of sensor nodes operating when utilizing the LEACH protocol is inversely connected with the size of the WSN. The study also mentioned that, due to the larger network size, the number of running nodes decreases because the distance between nodes and sinks is larger [17]. According to the research of Tarunpreet Kaur et al. (2019), The Quality of Service (QoS) mechanism in Wireless Sensor Networks (WSN) for multiple applications, including smart cities and healthcare, is the research topic. The survey discusses the computing intelligence-based routing protocol and its power in addressing QoS requirements in WSN. High computational complexity, erratic data delivery, network disturbances, late convergence, and other drawbacks of the current QoS-aware routing algorithms were noted [11].

Based on the results of the study above, the purpose of this study is to examine in terms of energy use from LEACH and use one of the QOS parameters, namely throughput by applying the initial energy that will be determined and network size to the number of sensor nodes running. This study uses one of the QoS parameters, namely throughput, with the aim of assessing network performance by measuring how many data packets can be transmitted in a certain time and can be used to evaluate how effective the LEACH protocol is. The data generated from the throughput results can later be used for further network development.

2. Method

This research was conducted using modeling and simulation as a framework. This stage of work includes problem definition, research design, implementation and simulation, data analysis and evaluation, conclusions. Fig. 1 shows the stages of the research methodology used.

Fig. 1. Research Framework

The simulation was carried out using MATrix LABoratory (MATLAB) software. This software is a tool used for modeling and numerical computing. MATLAB has the ability to perform mathematical calculations, write scripts and functions, create graphs, and run simulation models that have been created. The simulation process carried out can be seen in Fig. 2 below.

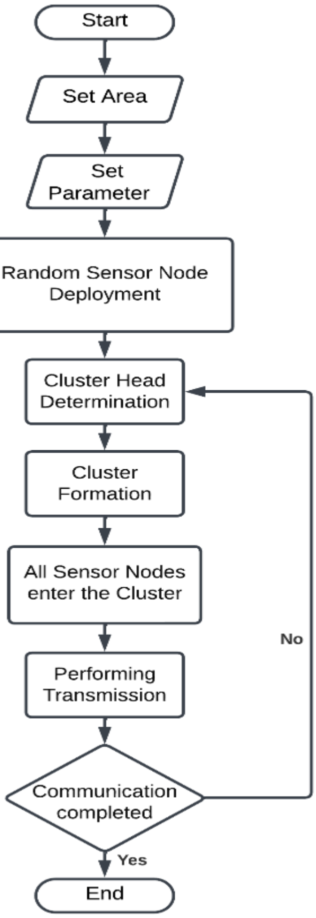

Fig. 2. Simulation Flow

The process starts by scaling the area to be used for simulation. Next, selecting parameters to use as conditions to see the effective node deployment conditions, here also sets the number of nodes to be used. Using the LEACH algorithm method will determine the cluster head (CH) as well as the formation of the cluster. The CH sends its status information to other nodes in the network where the existing nodes send the information to the nearest CH. The data received by CHs in their clusters is aggregated into one larger data packet. After that CH will transmit data packets to sink nodes then each node calculates the energy used for transmission and other activities, then the process will repeat to determine CH and so on until the simulation is complete. The LEACH parameters can be seen in Table.1 below.

Table.1 LEACH Parameters

P	**Probability of a node becoming a CH**	**0.01**
r	Number of rounds	1000
N	Number of sensor node	100, 150, & 200
E_{LEACH}	Initial energy of each sensor node (Joule/J)	0.5
E_{tx}	Energy of each node to transmit data (Joule/J)	50 x 10^{-9}
E_{rx}	Energy of each node to receive data (Joule/J)	50 x 10^{-9}
E_{amp}	Energy of each node to use the amplifier (Joule/J)	0.0013 x 10^{-12}
E_{fs}	Energy used by the radio frequency amplifier for short distance (Joule/J)	10e – 12

3. Results and Discussion

System simulations performed using MATLAB 2023 to evaluate the LEACH protocol with comparative analysis among various scenarios are introduced in this section. The scenario in the simulation uses a homogeneous topology in which the characteristics of each node used have the same energy. The sink will have X=250 and Y=250 in a 500 x 500 m network; X=375 and Y=375 in a 750 x 750 m network; and X=500 and Y=500 in a 1000 x 1000 m network. This study is to study WSN behavior with several scenarios such as reviewing the initial energy of sensor nodes against the number of nodes running rotation and transmission, average residual energy, and using one of the QOS parameters, namely throughput to check the amount of data successfully transmitted in a certain period of time.

It can be seen in Fig. 3. Node Deployment example above is a node deployment on a network size of 500 x 500 m where the node positions are scattered randomly.

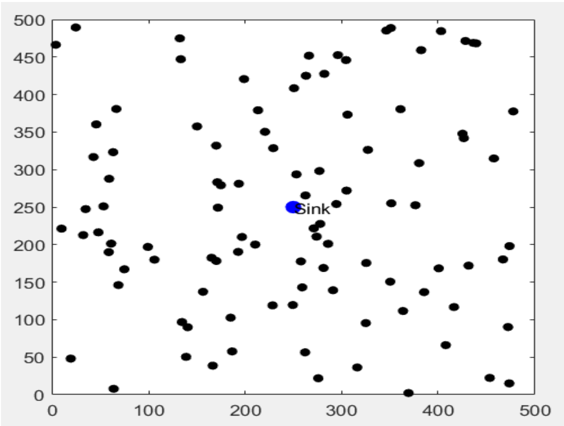

Fig. 3. Node Deployment Example

In Fig. 4. Network Life Time above shows the network life time whose tests were carried out with three network sizes, namely 500 x 500, 750 x 750, and 1000 x 1000. In the test above using the same initial energy which is 0.5j. Based on the results of the simulations carried out, data for a network size of 500 x 500 can be seen that its life time tends to be longer than other network sizes. It can also be seen in the diagram above, each network size is getting wider, the network life time decreases. With the same network size, the network life time also changes if the number of nodes changes. According to the simulation results, if the number of nodes is added, the network life time will decrease, for example in a network size of 500 x 500 the number of nodes 100 has a longer life time than the number of 150 nodes, and the number of nodes 150 has a longer life time than the number of 200 nodes. Likewise, the network size of 750 x 750 is similar to the network size of 500 x 500 but the difference in network life time has a difference that is not so far as the network size of 500 x 500. As for the network size of 1000 x 1000, it displays network life time results that are not much different or more or less almost the same even though the number of nodes is different

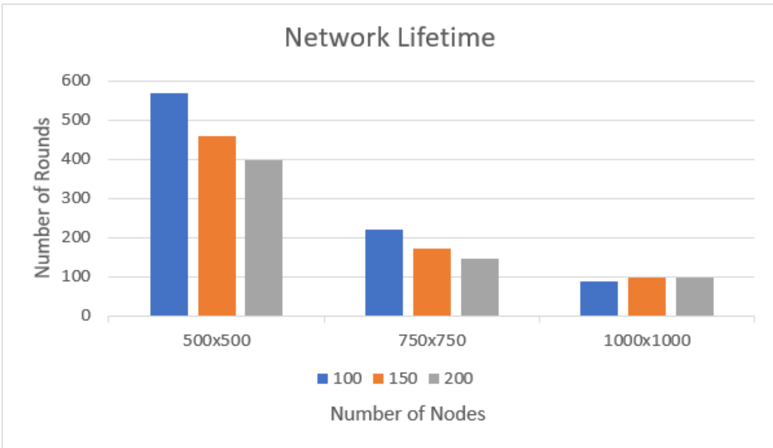

Fig. 4. Network Life Time

3.1. Test results for 500 x 500 network size

In Fig. 5. Average Residual Energy of 100 Nodes, displaying a graph for a network size of 500 x 500, which can be seen energy usage in the initial round or round experiencing a significant decrease in energy. In round 200 onwards the energy decreases very little.

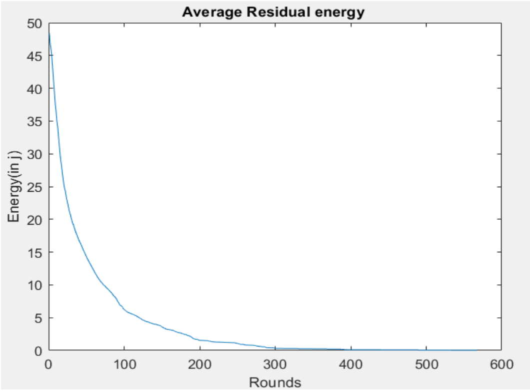

Fig. 5. Average Residual Energy 100 Nodes

Fig. 6. Throughput of 100 nodes, showing the amount of data that can be transmitted and received at a network size of 500 x 500, which in the graph shows the amount of data transmitted according to the number of active nodes, there is a slight instability but not significant.

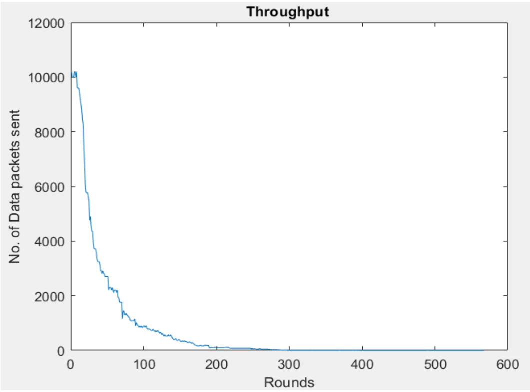

Fig. 6. Throughput 100 Node

In Fig. 7. Average Residual Energy of 150 Nodes, displays a graph for a network size of 500 x 500, which can be seen energy usage in the initial round or round has decreased energy significantly. In round 200 onwards the energy decreases very little.

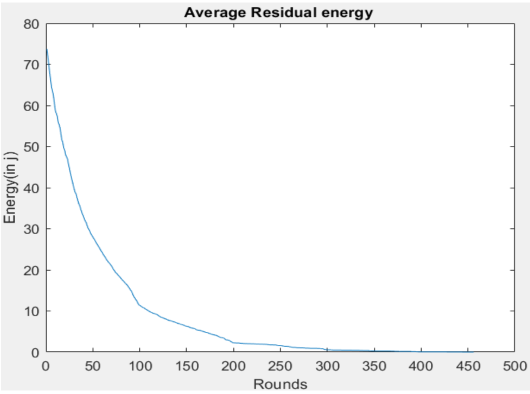

Fig. 7. Average Residual Energy 150 Nodes

Fig. 8. Throughput of 150 Nodes, displays the amount of data that can be transmitted and received at a network size of 500 x 500, which in the graph shows the amount of data transmitted according to the number of active nodes, there is a considerable decrease in data transfer but in a short time occurs

between rounds 1 to 50, then there is also a decrease in data transfer but not too significant between rounds 50 to 150.

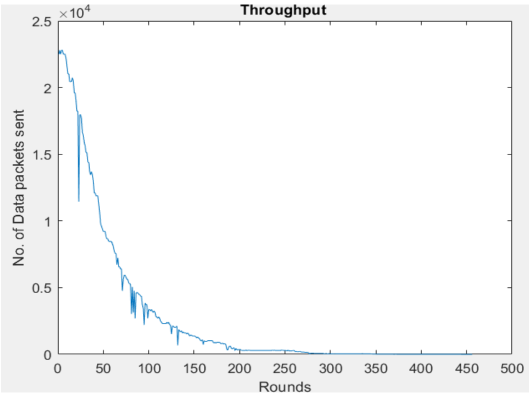

Fig. 8. Throughput 150 Node

In Fig. 9. Average Residual Energy of 200 Nodes, displays a graph for a network size of 500 x 500, which can be seen energy usage in the initial round or round has decreased energy significantly. In round 200 onwards the energy decreases very little.

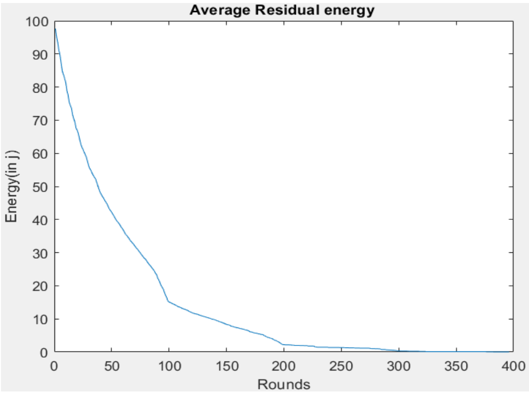

Fig. 9. Average Residual Energy 200 Nodes

Fig. 10. Throughput of 200 nodes, displays the amount of data that can be transmitted and received at a network size of 500 x 500, where in the graph you can see the amount of data transmitted according to the number of active nodes, there is a decrease in data transfer between rounds 50 to 100 which is quite a lot but in the round after the decrease in data transfer is not significant.

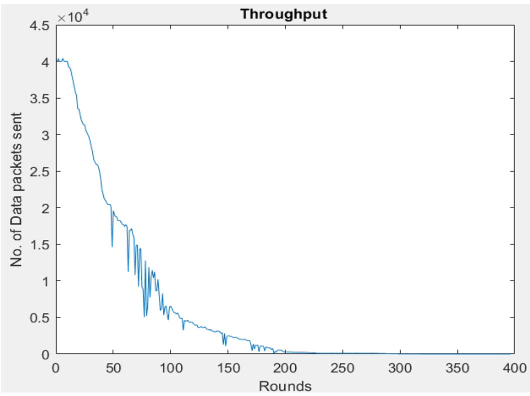

Fig. 10. Throughput 200 Node

3.2. Test results for 750 x 750 network size

In Fig. 11. Average Residual Energy of 100 Nodes, displaying a graph for a network size of 750 x 750, which can be seen at the beginning of the simulation it appears that the initial energy is only 45h which means that there are about 10 sensor nodes that die when the simulation starts due to lack of energy in the sensor nodes, energy usage in the initial round or round has decreased energy significantly. In round 100 onwards the energy decreases very little.

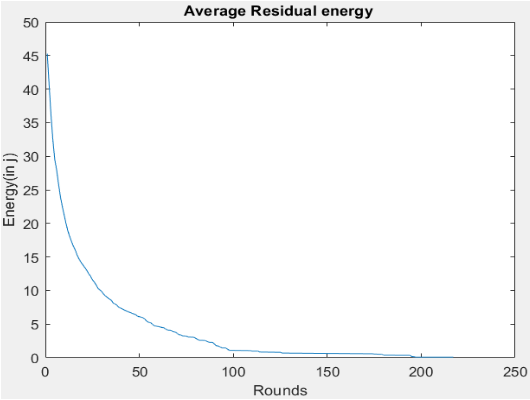

Fig. 11. Average Residual Energy 100 Nodes

Fig. 12. Throughput of 100 Nodes, displays the amount of data that can be transmitted and received at a network size of 750 x 750, which in the graph shows the amount of data transmitted according to the number of active nodes, there is a significant decrease in data transfer at the beginning of the round but it follows the number of active nodes, the rest of the decrease that occurs afterwards is not too significant.

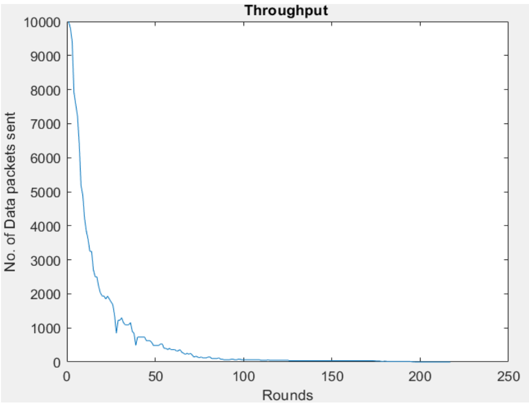

Fig. 12. Throughput 100 Node

In Fig. 13. Average Residual Energy 150 Nodes, displaying a graph for a network size of 750 x 750, which can be seen at the beginning of the simulation it appears that the initial energy is only 70h which means that there are about 10 sensor nodes that die when the simulation starts which is due to lack of energy in the sensor node, energy usage in the initial round or round has decreased energy significantly. In round 100 onwards the energy decreases very little.

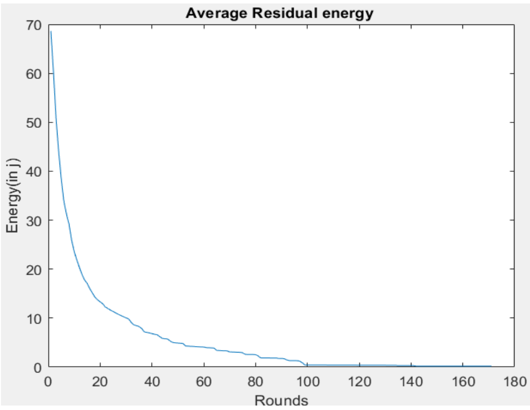

Fig. 13. Average Residual Energy 150 Nodes

Fig. 14. Throughput of 150 nodes, displays the amount of data that can be transmitted and received at a network size of 750 x 750, which in the graph shows the amount of data transmitted according to the number of active nodes, there is a significant decrease in data transfer from round 0 to 20 but the decrease in data transfer in the next round is not significant.

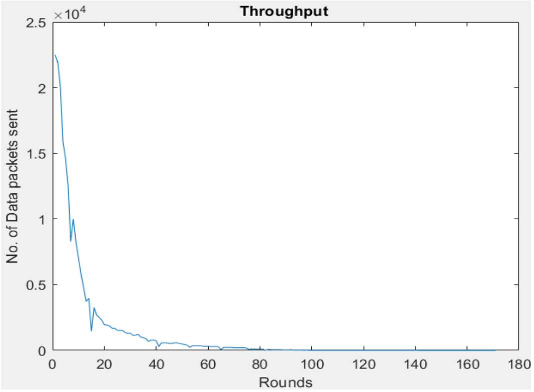

Fig. 14. Throughput 150 Node

In Fig. 15. Average Residual Energy 200 Nodes, displaying a graph for a network size of 750 x 750, which can be seen at the beginning of the simulation it appears that the initial energy is less than 100h which means that there are about 10 sensor nodes that die when the simulation starts which is due to lack of energy in the sensor node, energy usage in the initial round or round has a significant decrease in energy. In round 100 onwards the energy decreases very little.

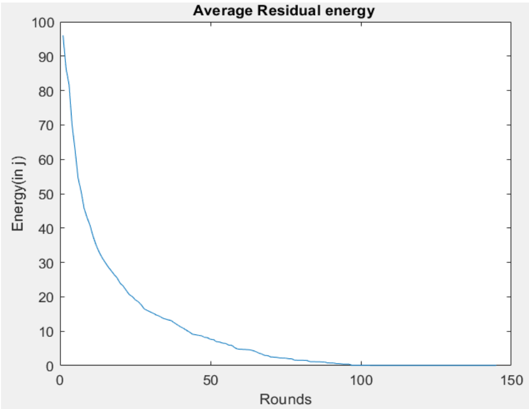

Fig. 15. Average Residual Energy 200 Nodes

Fig. 16. Throughput of 200 nodes, displays the amount of data that can be transmitted and received at a network size of 750 x 750, which in the graph shows the amount of data transmitted according to the number of active nodes, there is a very significant decrease in data transfer from round 0 to 50 but the decrease in data transfer in the next round looks insignificant.

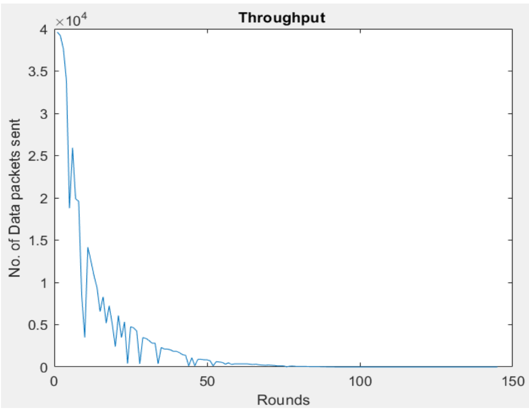

Fig. 16. Throughput 200 Node

3.3. Test results for network size 1000 x 1000

In Fig. 17. Average Residual Energy of 100 Nodes, displays a graph for a network size of 1000 x 1000, which can be seen at the beginning of the simulation it appears that the initial energy is only 40h which means that there are about 10 sensor nodes that die when the simulation starts which is due to lack of energy in the sensor nodes, energy usage in the initial round or round has decreased energy significantly. In round 20 onwards the energy decreases very little.

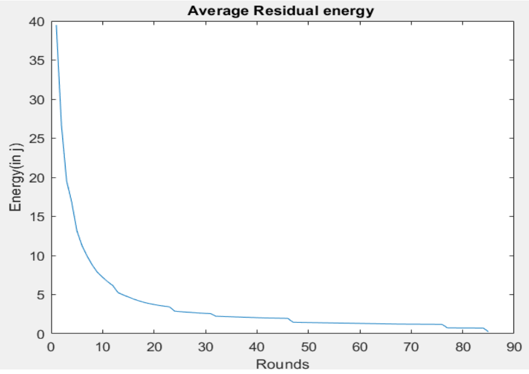

Fig. 17. Average Residual Energy 100 Nodes

Fig. 18. Throughput of 100 Nodes, displays the amount of data that can be transmitted and received at a network size of 1000 x 1000, which in the graph shows the amount of data transmitted according to the number of active nodes, seen at the beginning of data transfer, the transmitted data is too small then begins to increase and then drops significantly again between rounds 0 to 10, Then in the next round there was an insignificant decrease in data transfer.

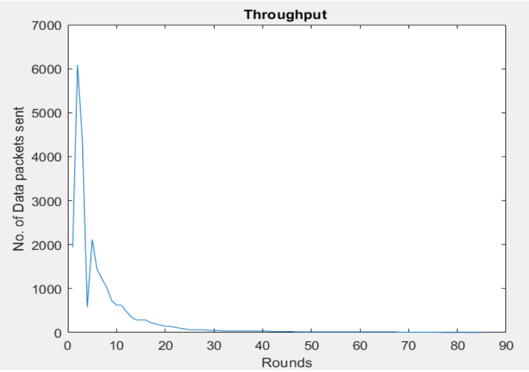

Fig. 18. Throughput 100 Node

In Fig. 19. Average Residual Energy 150 Nodes, displaying a graph for a network size of 1000 x 1000, which can be seen at the beginning of the simulation it looks like the initial energy is less than 50h which means that there are about 50 sensor nodes that die when the simulation starts which is due to lack of energy in the sensor nodes, energy usage in the initial round or round has a significant decrease in energy. In round 20 onwards the energy decreases very little.

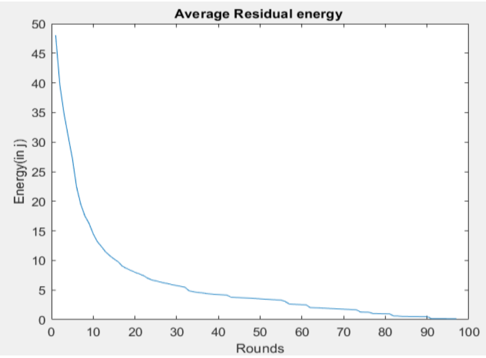

Fig. 19. Average Residual Energy 150 Nodes

Fig. 20. Throughput of 150 nodes, displays the amount of data that can be transmitted and received at a network size of 1000 x 1000, where in the graph you can see the amount of data transmitted according to the number of active nodes, there is a very significant decrease in data transfer and there is instability in rounds 0 to 20, but after that there is an insignificant decrease in data transfer.

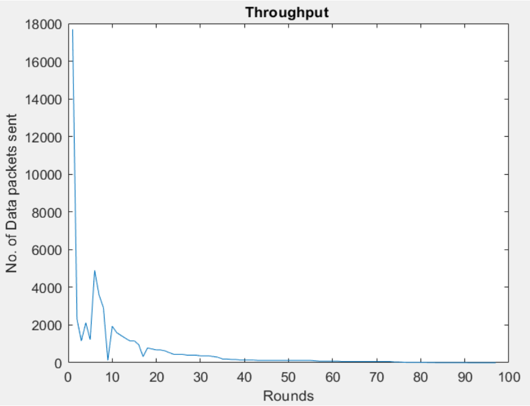

Fig. 20. Throughput 150 Node

In Fig. 21. Average Residual Energy of 200 Nodes, displays a graph for a network size of 1000 x 1000, which can be seen at the beginning of the simulation it appears that the initial energy is only 80h which means that there are about 20 sensor nodes that die when the simulation starts which is due to lack of energy in the sensor nodes, energy usage in the initial round or round has decreased energy significantly. In round 20 onwards the energy decreases very little.

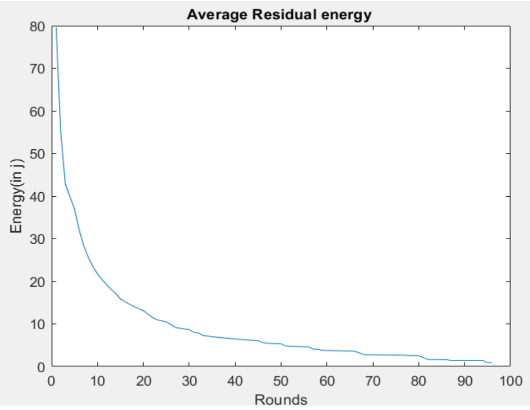

Fig. 21. Average Residual Energy 200 Nodes

Fig. 22. Throughput of 200 Nodes, displays the amount of data that can be transmitted and received at a network size of 1000 x 1000, which in the graph shows the amount of data transmitted according to the number of active nodes, seen at the beginning of data transfer, the transmitted data is quite small but has increased and after that there is a very large decrease and there is instability in data transfer from round 0 to 20, But the subsequent rounds experienced an insignificant decline.

Based on the number of nodes and network size, it has a significant effect on network lifetime. The more nodes there are, the less lifetime it has. Similar to network size, if the network size gets larger or increases, the lifetime will also decrease. However, for the average residual energy, it can show the reason for the reduced lifetime which can be seen as a result of the simulation above, each number of nodes increases, the initial energy at the beginning of the simulation is large, but if the network size is larger, the energy at the beginning of the simulation seems to be reduced because there are several nodes that have been dead since the beginning when the simulation starts.

The throughput value is affected by energy, number of nodes and network size. In 500 x 500 and 750 x 750 network sizes, the throughput values look the same but for 500 x 500 network sizes, the amount of data transmitted can be stable in the initial round but there is a decrease afterwards. As for the network size of 750 x 750, the amount of data transmitted decreased directly in the initial round. For a network size of 1000 x 1000, there is a very significant instability and many data packets are lost. The reason for this is that, if the node dies, the amount of data that can be transmitted decreases. So the more nodes that die, the less data is transmitted

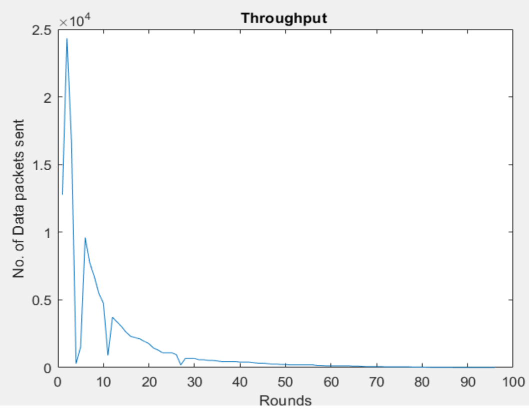

Fig. 22. Throughput 200 Node

4. Conclusion

Based on the results of this study, it is seen from the initial purpose of the study, which is to study or study the LEACH protocol in terms of energy and throughput. From the results of the research that has been carried out, it can be seen that network lifetime is influenced by the application of initial energy, network size and the number of nodes. In this case, the initial energy of each node set in this study is 0.5J and is set for all scenarios. If the network size is small and the nodes are few, it can extend the network lifetime, on the other hand, if the network size is large and the nodes are many, it can shorten the network lifetime. This can happen because the network life time is not fixed due to the uneven or random distribution of sensor nodes so that the energy consumption of each scenario is different. In the average residual energy graph, the results displayed from various scenarios can be seen that in the initial round there is a significant decrease in energy due to the sensor node running out of energy which is affected by the distance of each sensor node to the sink, so the farther the distance between the sensor node and the sink, the farther the sensor node will run out of energy first compared to the sensor node close to the sink, On the other hand, it can be seen that when the average residual energy is a little left, the network can last quite long because the sensor nodes that are still alive are close to the sink so that the network can last longer. As for the throughput results are influenced by energy, number of nodes and network size, the more active nodes the more data packets can be transmitted, but the wider the network size the number of data packets that can be transmitted decreases in line with the number of dead nodes and the remaining energy. There are several possibilities that affect throughput, one of which is that the selected CH has a bad signal or has a long distance from the sink and also the energy from the sensor node is insufficient due to the influence of the distance between the sensor nodes. Based on the findings above to get a long network lifetime, the initial energy settings for each node need to be increased according to the size of the network. So the larger the network size, the initial energy of each node needs to be added to extend the network lifetime. To achieve better throughput, the network size and number of nodes must be appropriate so that the data packets that can be transmitted are optimal to reduce data loss. The suggestions from this study that are considered for further research development are: 1) A study is needed related to determining the distance between sensor nodes to avoid random deployment of nodes and increase the chance of increasing network lifetime; 2) Can perform simulations to monitor the original state such as at sea, land, and air.

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