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Low Energy Adaptive Clustering Hierarchical Leach Lifetime Analysis in Two- and Three-Dimensional Wireless Sensor Networks

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Abstract:

Among the key LEACH protocol approaches are techniques for dividing clusters eventually forming, flexible cluster establishing, and cluster header location modifying. Most target nodes will self-organize thanks to the cluster formation distribution technique. By evenly distributing energy dissipation among all nodes, the dynamic cluster structure and cluster head place algorithms ensure that the overall device's entire life is renewed. The study examines The Low Energy Adaptive Clustering Hierarchical protocol (LEACH) was renewed from a 2-D and a 3-D environment in a wireless sensor network comprised of various sensor devices at fixed speeds and different speeds of nodes at a fixed number of nodes to collect data for applications. A comparison of the homogeneous LEACH implementation in a two-dimensional plane and three-dimensional space has been provided, with a Concentrate on a node viewed in three dimensions, as this is more relevant for real environments. Using MATLAB and a variety of performance metrics, including the Packet-Delivery-Ratio (PDR), Average energy consumption, Active Node Ratio, and Inactive Node Ratio, we explore the Leach routing protocols in 2D and 3D in this work. The routing techniques' performances are specifically evaluated over a range of UAV node densities and for several speed changes.

Keywords: LEACH, 2-D, 3-D, MATLAB, PDR, UAV.

1. Introduction

A sensor network that is wireless (WSN) is made up of several small pieces of types of equipment known as sensors that can detect environmental incidents to occur, procedure them, and transmit the data or information to a central location. The sensors are scattered across a geographic location area. Sensor devices are also known as nodes, and the sink, or Base Station (BS), is the main destination for the transmission of data. A sensor network node is composed of several components, including a radio signal generator, data transmission as well as reception, a data processing microcontroller, and a source of energy, which is usually a device. These nodes are essential in terms of energy conservation due to the power supply. Due to the limited life of batteries, the biggest problem in sensor networks is conserving energy. Furthermore, the applications establish the nodes in regions where conventional wired communication isn't entirely feasible. Although that two-dimensional (2D) clustering design is suggested and regarded across most implementations, it only achieves poor effectiveness and direct observation. In such cases, three-dimensional (3D) design is more precise and suitable [1]. Now, environmental sensing is limited to three dimensions. In the architecture of two-dimensional wireless sensor networks for ground networks, it is commonly assumed that all network nodes reside on a plane. This assumption is not always correct when deploying a network in a three-dimensional environment,

such as the ocean or forest. In such cases, the subject should be investigated as three-dimensional spaces because they are more conceivable, effective, and accurate.

Wireless sensor networks have a wide range of applications, including:

1) Monitoring the ocean column necessitates the placement of nodes at various levels of the water, resulting in a three-dimensional network.
2) 3-D design is required for environmental monitoring, such as wireless sensor networks applied on different heights of trees in a forest.
3) For monitoring railway tunnels, mine tunnels, and forest caves, a 3-D wireless sensor network is an observable option.
4) A 3-D WSN is more effective for sufficiently controlling the regions of interest when tracking the safety of the structure of non-linear and non-constructions.
5) Detectors in the volcanic region prefer 3-D design for gathering temperature and graphics.
6) 3-D sensor networks are useful for disaster relief management in the occurrence of massive crises such as Floods and seismic events, floods, and blasts, among others.
7) In addition, wireless chemical detectors are airlifted over a nearby damage gathering data about chemical vapours' exposure to harmful chemical harmful gases from a chemical plant.

The document is laid out as follows. Section 2 discusses related work based on Leach routing protocols and different Leach routing protocol enhancements. Section 3 describes the Leach protocol with its several stages and energy consumption equation, as well as a flow chart showing Leach functioning in 3D. Section 4 uses appropriate diagrams to illustrate LEACH execution in 2D plane and 3D space. Section 5 uses a figure to describe the simulation parameter. Section 6 contains an explanation of the Evaluation outcome. Section 7 compares the state of the art, and Section 8 concludes the work.

2. Related Work

Wireless sensor networks (WSNs) have become incredibly popular because of their extensive applications in a wide range of industries. A recently created tool called the Internet of Things (IoT) makes it possible to link different objects or gadgets to the Internet. According to Paper [2], under different parameters in terms of surface area, power, and node degree, the proposed technique surpasses previous energy- protocols in phrases of network lifespan and consistency period. In Article [3], the Leach protocol is used to select CHs, which has historically been a crucial factor in clustered networks. This paper provides an overview of changes made to the network's threshold value for CH selection. The paper [4] throws light on the potential uses of IoT clustering in contemporary technologies that are integrated with IoT and enable greater knowledge of its design issues for IoT networks. The paper [5] The survey also covers each LEACH-variant protocol's advantages and disadvantages. In the context of HSVN, paper [6] presented a distributed mechanism for ensuring WSN connectivity and coverage. Regardless of the occasion of a sensor node failure, the proposed protocol can detect all road events and uphold integration between sensor nodes. Paper [7] focus on the power consumption problem of the Leach Routing Protocol in WSN. Paper [8] gives a comparative study of different variants of Leach routing protocols in WSN author of this paper is working on Leach node energy in WSN networks, and MG Leach is a revised form of the LEACH-based protocol. LEACH exchanges data using a medium cluster header, which spreads network life and means

allowing for more transmission of data than that of the study protocol. The author of [9] proposed a multi-hop simulated annealing (MhSA-LEACH) protocol based on interpersonal cluster and inter multi-hop connectivity and a LEACH protocol-derived method to pick several nodes in a multi-hop protocol, the Simulated Annealing (SA) algorithm on the Traveling Salesman Problem (TSP) is used. The author of Paper [10] used K-Means prior to CH selection to conserve energy and communication costs and examined the effects of K-Means on several effectiveness standards. As a result, before choosing the CH, K-Means divides the entire network into K clusters, with in all endpoints at every cluster becoming very similar to the cluster center's position, going to bring nodes close to the CH. The paper's author [11] gives a summary of routing protocols as well as some complexities in creating an entirely new routing protocol used in UAVs and flying ad-hoc networks. The paper's author [12] updated the Leach protocol as RED LEACH, which utilizes two metrics in cluster head selection: maintaining energy per each node and due to distance to the base station, and it outranks the existing LEACH in contexts of the amount of transmission power against round and number of dead nodes against the session. The author of the paper [13] created a way for energy reduction and rising Leach network lifetime in WSN. Everything is done in two dimensions. In paper [14], the author modified Leach as SILEACH and ELEACH to increase the network's lifetime. All work was done in 2 Dimensional as the author assumed the BS inside the network area. The authors of [15-16] use the Fuzzy C-Means (FCM), residual energy of nodes, Euclidean distance from the BS, and cluster centroid to increase the network lifespan of WSNs using the Energy-Aware Distance-based Cluster Head selection and Routing (EADCR). The FCM approach is used at the BS to build clusters in the EADCR. Then, each cluster selects its CH using a fitness function, and the initial and residual energy of all nodes impact the fitness function.

After analysis of some papers related to the Leach routing protocols, we can summarise as follows in Table 1.

Table 1: Summary of related works

References	Proposed work	Contributions	Limitations
[1]	I- Leach	The proposed algorithm works on minimizing energy consumption for increasing the network lifetime.	Proposed algorithm only considered 2D environment not for 3D.
[2]	Leach-Mac	Works for improving the lifetime for network.	This work is only done in 2D, not in 3D environment
[3]	Survey on 2D clustering algorithm	Survey on IoT clustering for design challenges in IoT networks.	Considered only 2D papers for survey.
[4]	Review Paper	Comparative analysis of clustering routing protocols	All comparative analysis done for 2D environment
[5]	Distributed protocols	Proposed new distributed protocol for road safety and connectivity in HSVN	No inter communication inside the VANET
[6]	Traditional Leach	Worked on how the nodes are arranged and how routing is done	Shows working of only Leach protocol in 2D
[7]	MG_Leach	Improving the lifetime of this network	Need to work for security as well as 3D

[8]	MSHA_ Leach	Based on intra cluster multi hop communication	This algorithm is applicable for 2D only
[9]	.+ Leach_K	Apply K mean algorithm for clustering that useful for energy conservation	This work focused on 2D scenario and not give proper routing information to all connected nodes.
[10]	Review paper	Describe the different issues for designing the routing protocols in FANET	There is no suggested algorithm for designing the routing protocols
[11]	Red_ Leach	Significantly reduce the number of dead nodes and save energy than traditional LEACH	Fuzzy logic and 3D environment are not considered
[12]	Modified LEACH	The author modified the Leach protocol for improving the lifetime of the network	This improved work is only for 2D and data security, and privacy not considered.
[13]	SI_ LEACH	Increase the network lifetime when the BS located inside the network	Need to improve the scalability of the proposed algorithm
[14]	EADCR	Improve network life by utilizing the Fuzzy C-Means (FCM)technique to create clusters and choose CHs based on a fitness function based on Euclidean distance and node remaining energy.	CH selection is a difficult procedure.
[15]	Improved-LEACH	The selection of CHs is based on two criteria: distance and residual energy.	Calculation difficulty
[16]	BN LEACH	The Bayesian Network is used in this model for selecting CHs.	High complexity

3. Leach Protocol

The process of selecting optimal paths in networks is referred to as routing. In wireless sensor networks, to transfer packets of data from one destination to another, various routing protocols are used. Clustering is one of the most important concepts in network routing. Clustering is an abbreviation for uniting or grouping. The basic concept besides clustering is to collect information from diverse sources and sent it to its desired location. The advantage of clustering is that it will save data from traveling long distances or huge networks and guarantees that only the data required is being sent forward, deciding to leave irrelevant data behind. As a result, other routes must be selected utilizing routing information. This link can be formed in numerous hops via intermediary nodes. In other words, communication cannot be limited to each device's range of action, but rather to the aggregate of each device's radius of action. The mobility of a UAV is also important in determining contact paths and their spatial organization. These pathways are typically reconstructed, allowing for continuous movement and connectivity of the UAVs. As a result, it is critical to carry out the routing process dynamically to make UAVs more autonomous and minimize the delay time between a source node and a target node [17, 18]. In wireless communications, the node that accumulates data from the

sensors is known as the cluster head (CH). The information is then sent to the base station (BS) by every cluster head (CH) using direct interaction. LEACH is focused on a formation or collecting procedure that converts raw data into lossless compression that only needs to carry important data to every active device. LEACH differentiates a network into groups or clusters of sensors via regionalized management and coordination [19]. The main attributes of LEACH are completely random rotation of the CH and relating clusters, local compression to massively reduce connectivity, and confined management and coordination for change in composition and operation. LEACH uses a truly random rotation of high-energy CH in a 3D network to offer all sensors a chance to serve as CHs and minimise different sensor battery exhaustion. As shown in figure 1, LEACH's procedure is separated into rounds, which consist of primarily two phases or levels.

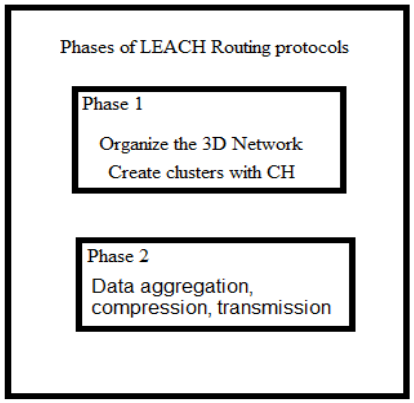

Figure 1: Phases or levels of LEACH Routing protocol

The energy used in data packets transmitting and receiving is an essential parameter for evaluating the performance of a routing system. However, the energy spent by the CH while employing fusion technology should be considered, but the energy consumed by the node during the computation and storage processes should be ignored. The energy model describes how much energy is spent by each kbit of data delivered by the wireless circuit. $E_{Tc}(k, D)$ represents the energy consumed by each k-bit data carried by the wireless circuit. According to the energy consumption model energy consumption at the transmitting circuit is calculated in different two cases. In case 1 when the threshold D_o is greater than the distance between the sender and receiver nodes, energy is consumed at the transmitting circuit is calculated by using the equation (1). In case 2, threshold D_o is smaller and equal to the distance D by using equation (2).

$$if\ .D < \mathrm{Th}\,(\mathrm{Sn})$$

$$E_{Tc}(k, D) = kE_{Ec} + kE_{fsm}D^2 \quad (1)$$

$$.else\cdot D \geq .\mathrm{Th}\,(\mathrm{Sn})$$

$$E_{Tc}(k, D) = kE_{Ec} + kE_{msa}D^4 \quad (2)$$

E_{Ec} represents the energy consumed for each bit of the data sent or received in equations (1)-(2). $E_{fsm}D^2$ is the amount of energy expended by the free space model for every k bit of data amplification in equation (1). $E_{msa}D^4$ is the amount of energy expended by the multipath attenuation model for every k bits of data amplification. As a result, in order to reduce data transmission energy consumption, the distance between nodes must be reduced.

All such CHs are randomly selected or rather transmitted their statuses to the various sensors throughout the network. Which are distributed in three dimensions. A device decides whether to be a CH centered on the Dp of CHs, the present round, and the setting of sensors that are not becoming CH during the last $\frac{1}{Dp}$ rounds. If indeed the number of CHs is N, a sensor Sn is converted into a CH for the existing session. Equation (3) may be used to compute the threshold.

$$Th(Sn) = \frac{Dp}{1- Dp} * \left(Cr \,.\mathrm{mod}\,.. \frac{1}{Dp} \right) \tag{3}$$

If Sn ε n

Else Sn→0

Where

Dp = Percentage of nodes desired to become the CH

Cr = Current Round or Ongoing sweep

n = Installed nodes that have been CH during the initial 1/n rounds

Sensor network which is CH in round 0 is not allowed to be CHs in the subsequent (1/ Dp-1) rounds. Within every cluster, Leach protocols always enable data combination by aggregating data so that the overall data portion is reduced before sending it to the hole. Sensor nodes in Clusters transmit data over small distances and see as CHs communicate with the sink immediately. Each node's transmitting portion sends data even further absorbing E_{Tx} as transmitting energy while also using some energy in modulation. The information is condensed by the cluster head and sends it to the intermediate nodes or ground station, which also uses clustering energy. Equally, E_{Rx} is used as receiving energy to accept data at the receiving end. Figure 2 depicts the energy consumption model of Leach routing protocol at transmission and receiver side.

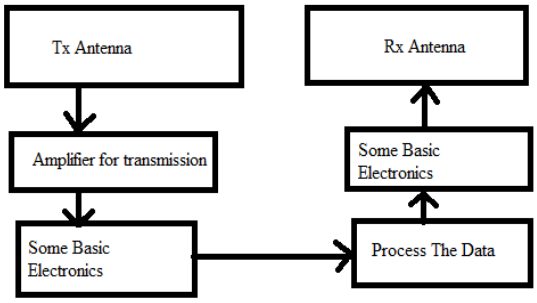

Figure 2: Energy consumption model at transmission and receiver side

The broadcasting model in LEACH calculates the power consumption during communication and reception. The distance parameter is required for the energy estimation. In 2D, the distance is calculated using the coordinates x and y. Distance in 3D can be calculated similarly by using the 3rd coordinate z. Figure 3 depicts the LEACH protocol's flowchart.

4. LEACH execution in 2D plane and 3D space

2D or bi-dimensional area is a dimensional model of the natural universe during which we live. The two dimensions are popularly referred to as both width and length. All these orientations exist on about the same plane. A 2D topological structure is a 2D depiction of an object, like the one depicted in figure 4.

The x and y locations are taken as the two components, each to have a 100-unit length (100,100), with a specific amount of n mobile nodes in the area of 100X100 and BS at every node, as shown in figure 5.

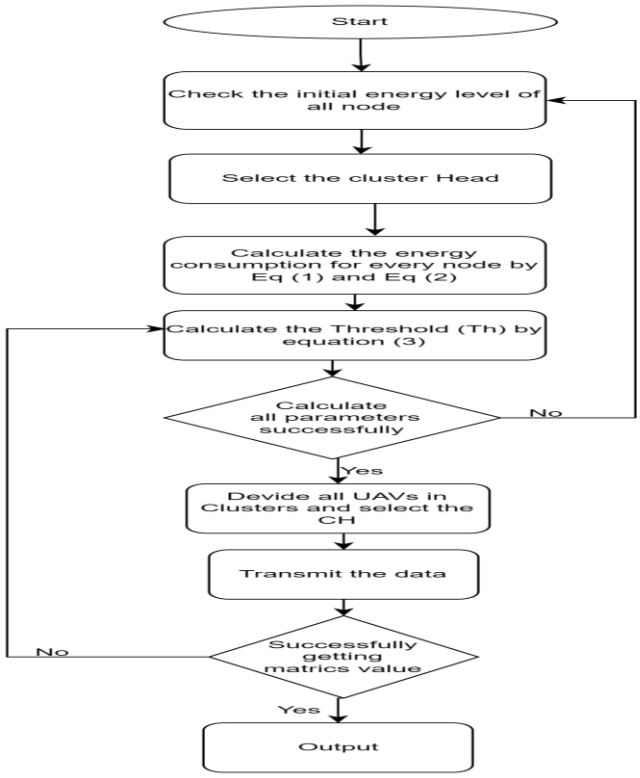

Figure 3: Flow chart of Leach protocol

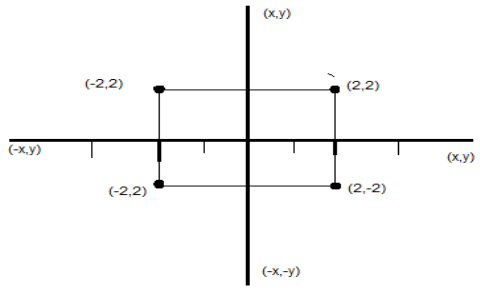

Figure 4: 2D Coordinate System for the position of nodes

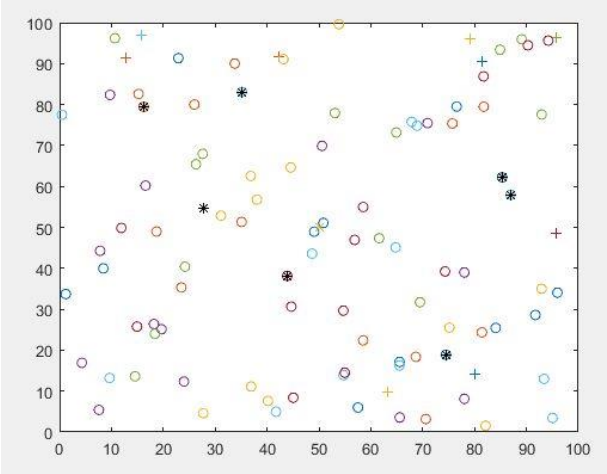

Figure 5: LEACH routing protocols analysis in 2D networks

Length, width, height, depth, and breadth are all acceptable labels for the three dimensions. The 2D visual gives a general idea about nodes in the special-purpose network area. Evaluation of the 3 directions of a sensor network and its nodes is more feasible and practical in some implementations, particularly some discussed in the previous section of the manuscript. Real-world Requirements and applications make use of three-dimensional views. So, to make the protocol more similar and realistic, we executed LEACH in 3D space. We had been using three precise locations (x, y, z) approaches to predict the position of each node in the cluster. Correspondingly, just before creating a 3D cluster, we followed a similar procedure, such as how the internet was expressed in 3-dimensional space and how data points were observed. A "3D space" is a three-dimensional symmetrical idea of the natural surroundings, as depicted in figure 6.

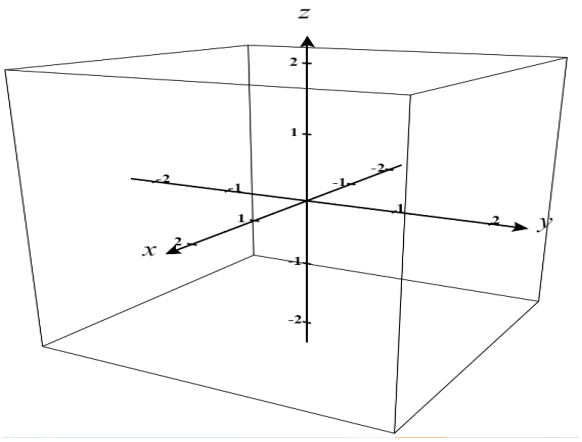

Figure 6: 3D Coordinate System for the position of nodes

If a cluster or group is thought to consist of nodes when the node closest to its cluster head is considered. The x, y, and z coordinates of each node in the network area determine its location. As shown in figure 8, the three dimensions are the x, y, and z coordinates, with 100x100x500 unit lengths to every side and a constant value of n nodes deployed around 100x100x500 with a fixed Base station as shown in figure 7.

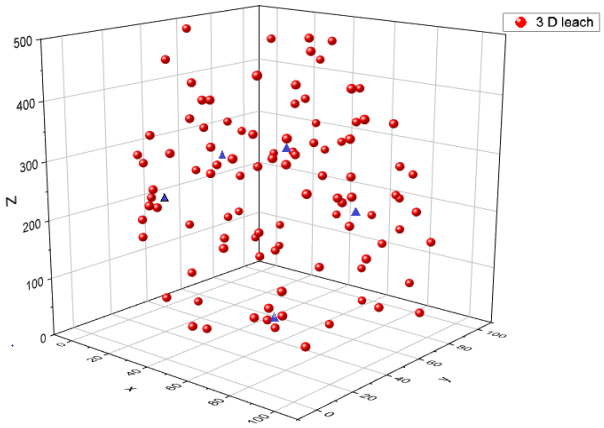

Figure 7: Leach routing protocols in 3D model

5. Simulation

MATLAB was used to implement all simulations. Table 1 lists the simulation parameters. Given its length and width, we first thought of the network as depicted in two dimensions (100x100). When considering a three-dimensional network, we used height or depth as the third dimension, resulting in 100x100x500. MATLAB is the simulation software used to implement the LEACH protocol. Table 2 lists the various parameters used in the simulation.

Table 2: Simulation parameters

Parameters	**Values**
Simulator	MATLAB
Simulation Areas	(100*100) m^2, (100*100*500) m^3
Simulation Time	200sec
UAVs number	50,100,150,200,250
No. of the base station	1
Starting Energy Level	90 W/H
Constant bit rate	100 KBPS
PHY model	IEEE 802.11
CBR rate	2mbps
UAV moving speed	40-90 m/sec
Mobility model	Reference point mobility model
Message size	250 kb
Node transmission range	150 m-300 m
Node sensing range	200 m
Traffic type	CBR
Traffic load	5 msg /sec
Transmission frequency	2.4 GHz

6. Evaluation result

Following the simulation, we obtained the following results, which reveal the diversity of the beginning-to-end concede PKT-delivery-ratio, active-node-ratio, Inactive- node-ratio, and average energy consumption in two cases, one case is belong to various node densities and second case is for limit of node speed.

6.1 Packet-delivery-ratio

After creating the cluster head and cluster members, the author calculates the energy consumption through transmission. This depicts the volume of data sent to the desired location. The higher the packet delivery ratio value, the better the protocol's performance. We compared the leach protocol to our protocol in 2D and the 3D environment concerning the number of nodes for case 1 as well as the speed of nodes for case 2 in figure 8 and figure 9 respectively. The performance of Leach in 3D in terms of increasing the speed of UAVs and the number of nodes is great as compared to Leach in a 2D environment.

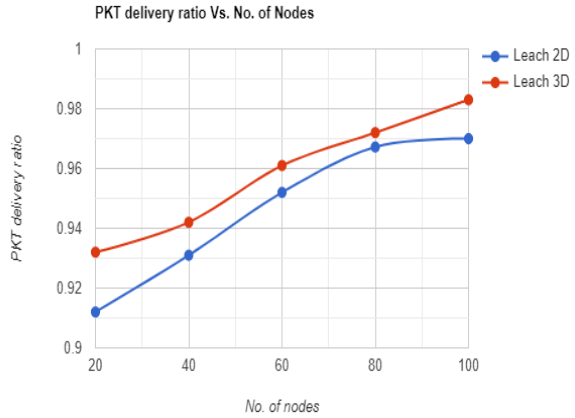

Figure 8: PKT-delivery-ratio vs. no. of nodes

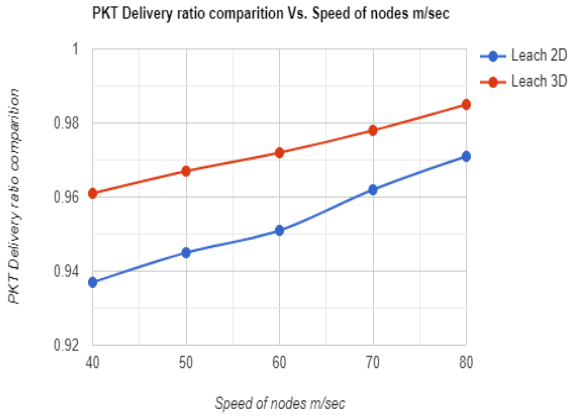

Figure 9: PKT-delivery-ratio vs. speed of nodes

Average energy consumption: Figure 10 shows that when the quantity of UAV nodes with speed at a constant rate of 40 m/sec is increased, LEACH 3D requires less energy than LEACH 2D. The reasons are as follows: In 3D, the leach selects cluster heads focused on remaining energy and node precise location, allowing so every node to require energy in a nearly equal manner, avoiding the untimely death of minimal nodes, saving system power diffusion, and significantly increasing network connectivity. In figure 11 we observed, when the speed of nodes at fixed node 40 is changed, Leach 3D utilizes more energy than Leach 2D.

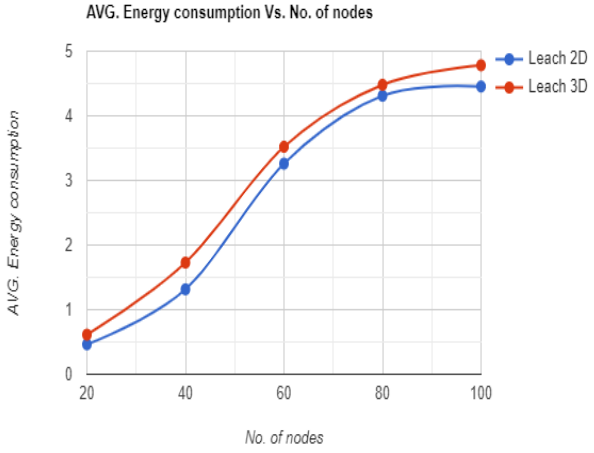

Figure 10: Avg-energy consumption vs. no. of nodes

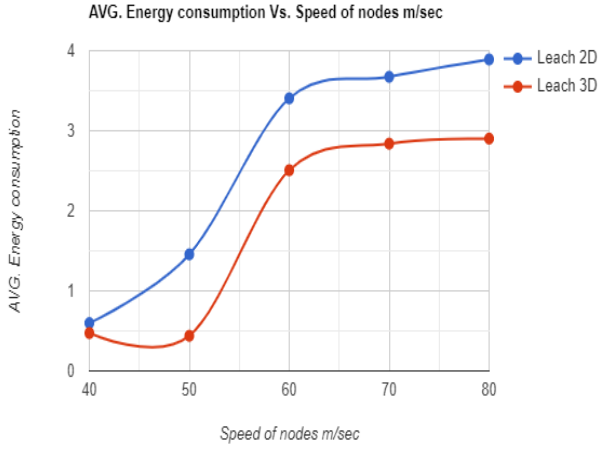

Figure 11: Avg-energy consumption vs speed of nodes

6.2 Active node ratio

The curve in figure 13 compares the number of active nodes when the protocol has 20 to 100 UAV nodes with a constant speed of 40m/sec, as well as the speed of nodes, which varies from 40 m/sec to 80 m/sec with a constant number of nodes of 40. The abscissa represents the number of UAV nodes and their speed in meters per second. In both figures, the ordinate represents the active node ratio. As shown in figures 12 and 13, the active node ratio of the LEACH protocol in 3D is significantly higher than that of the LEACH protocol in 2D. This happens because the nodes with minimum energy levels are secured even during the election phase by getting better the election feature. The network's energy consumption is balanced, and nodes with reduced emissions are designed to protect. In a broad sense, the LEACH protocol in 3D is focused on conserving node lifetime, so Leach in 3D performs well in terms of active node ratio.

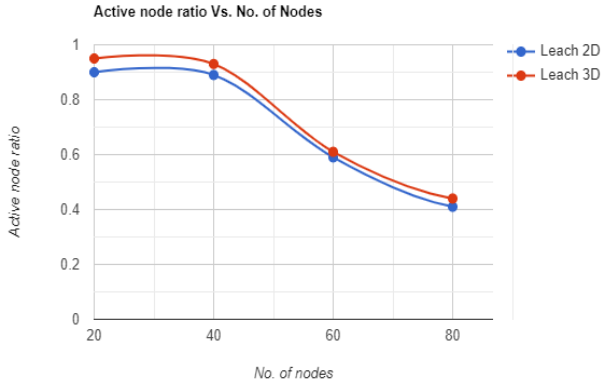

Figure 12: Active node ratio vs no. of nodes

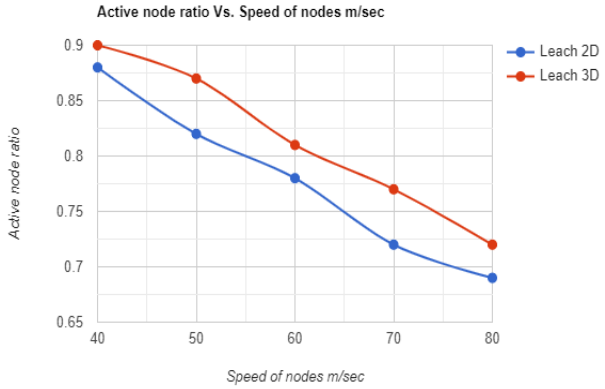

Figure 13: Active node ratio vs speed of nodes

6.3 Inactive node ratio

Figures 14 and 15 depict simulated network duration by displaying the number of dead nodes for various UAV node densities with a fixed speed of node at 40 m/sec and different speeds of nodes with a fixed number of nodes at 40. Leach 3D provides the longest network lifetime of either situation. As can be seen in both figures, Leach 3D has fewer dead nodes than Leach 2D. This is due to the limited number of transmissions, as well as the efficient cluster head replacement mechanism, which conserves energy globally and allows for multiple power levels for inter and intra-cluster communication.

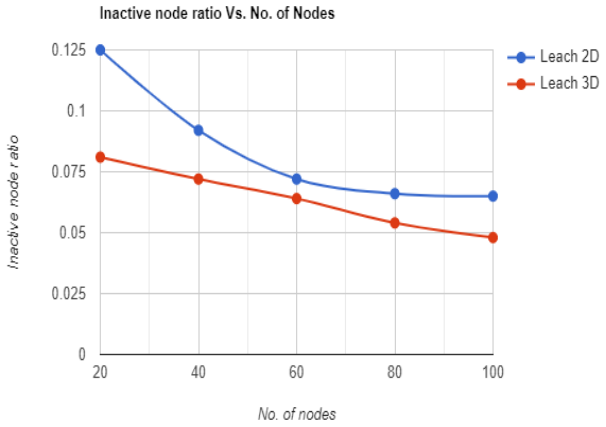

Figure 14: Inactive node ratio vs no. of nodes

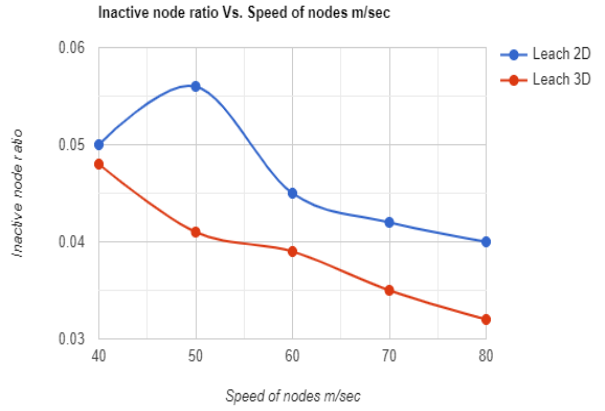

Figure 15: Inactive node ratio vs. speed of nodes

7. State of art comparison

Based on analysis, compared Leach routing protocols in 2D and 3D environment. Table 3 give the comparison study.

- PKT delivery ratio of Leach in 3D is high because Leach 3D identifies several pathways between source and destination in a single discovery procedure.
- Since CH is close to the centre of gravity, the energy consumption rate of Leach3D in scenario 2 is large. Presently, the centre of gravity node is merely a regular node with the only purpose of gathering data.
- In Leach 3D, the higher energy nodes are in charge of data fusion inside their own clusters as well as sending aggregated data packets from other cluster heads towards the sink in a multi-hop transmission by just cluster heads, because as active node ratio is larger than in Leach 2D.
- When the network size increases, more control packets are sent to find the routes. Leach 3D routing is designed to be spontaneously adaptable to traffic diversity. As a result, when traffic variety is high, Leach 3D routing is generally efficient in terms of controlling inactive nodes.

Table 3: Comparison of Leach in 2D and 3D for both cases

Protocols	**PKT Delivery ratio**		**Energy Consumption**		**Active node ratio**		**Inactive node ratio**	
	Case I	**Case II**	**Case I**	**Case II**	**Case I**	**Case II**	**Case I**	**Case II**
Leach 2D	Low	Low	Low	High	Low	Low	High	High
Leach 3D	High	High	High	Low	High	High	Low	Low

8. Conclusion

Real-world scenarios or applications, as stated in the paper, are better suited to three-dimensional. Correspondingly, LEACH, a standard protocol for two-dimensional wireless sensor networks, has been considered and implemented in three-dimensional wireless sensor networks. We have replaced the two dimensions, namely length and width, in the execution of LEACH with a height extension. Any 3D utilization can use the revised 3D protocol, including a rescue in hills, military operation, or underwater wireless sensor network. Because UAVs operate in a three-dimensional (height, length, and breadth) environment, we discovered that the LEACH protocol in a three-dimensional environment outperforms LEACH in a two-dimensional environment in terms of packet delivery ratio. As the number of UAVs rises, increases the network overhead, therefore the rate of energy consumption in Leach 3D is higher than in Leach 2D, but when we increase the speed of nodes, the energy consumption in Leach 3D is lower than in Leach 2D since the network traffic is the same. When the network speed and density are increased, the Leach protocol in 3D has more active nodes and fewer inactive nodes than LEACH 2 D since UAV nodes always move in a 3D (Height, Length, Width) environment. This manuscript examines the impact of various variations in densities and speed of nodes in the LEACH protocol used in 3D and 2D wireless sensor networks. 3D gives better performance in our analysis.

The following are the benefits of using the Leach in a 3D environment:

1) Consumption of less energy.
2) Lower Overheads
3) Shorter latency periods.
4) Increased Stability
5) Consistency
6) Areas must be balanced between groups.
7) Flexibility

Future work direction: In the future, we hope to develop a new version of the LEACH protocol that may be used to assign energy-efficient trajectory paths among a fleet of UAVs.

References

[1] Del-Valle-Soto, C., Rodríguez, A., & Ascencio-Piña, C. R. (2023). A survey of energy-efficient clustering routing protocols for wireless sensor networks based on metaheuristic approaches. Artificial Intelligence Review, 56(9), 9699-9770.

[2] Behera, T. M., Samal, U. C., & Mohapatra, S. K. (2018). Energy-efficient modified LEACH protocol for IoT application. IET Wireless Sensor Systems, 8(5), 223-228.

[3] Behera, T. M., Samal, U. C., Mohapatra, S. K., Khan, M. S., Appasani, B., Bizon, N., & Thounthong, P. (2022). Energy-efficient routing protocols for wireless sensor networks: Architectures, strategies, and performance. Electronics, 11(15), 2282.

[4] Shahraki, A., Taherkordi, A., Haugen, Ø., & Eliassen, F. (2020). A survey and future directions on clustering: From WSNs to IoT and modern networking paradigms. IEEE Transactions on Network and Service Management, 18(2), 2242-2274.

[5] Daanoune, I., Abdennaceur, B., & Ballouk, A. (2021). A comprehensive survey on LEACH-based clustering routing protocols in Wireless Sensor Networks. Ad Hoc Networks, 114, 102409.

[6] Souadih, R., & Semchedine, F. (2022). Energy-efficient coverage and connectivity of wireless sensor network in the framework of hybrid sensor and vehicular network. International Journal of Computers and Applications, 44(5), 444-454.

[7] Kumawat, S., Kaur, H., & Dahiya, O. (2022, April). A Modified leach protocol in wireless sensor networks for energy efficient routing protocol. In 2022 3rd International Conference on Intelligent Engineering and Management (ICIEM) (pp. 785-790). IEEE.

[8] Sennan, S., Alotaibi, Y., Pandey, D., & Alghamdi, S. (2022). EACR-LEACH: Energy-Aware Cluster-based Routing Protocol for WSN Based IoT. Computers, Materials & Continua, 72(2).

[9] Kirsan, A. S., Al Rasyid, U. H., Syarif, I., & Purnamasari, D. N. (2020). Energy efficiency optimization for intermediate node selection using MhSA-LEACH: multi-hop simulated annealing in wireless sensor network. EMITTER International Journal of Engineering Technology, 8(1), 1-18.

[10] Ashraf, N., Viratikul, R., Silawan, T., & Saivichit, C. (2024, June). Maximizing the Lifetime of Wireless Sensor Networks: Integrating K-Means Clustering with LEACH Protocol to Improve Energy Efficiency. In 2024 21st International Joint Conference on Computer Science and Software Engineering (JCSSE) (pp. 494-499). IEEE.

[11] Siddiqui, S. T., Ahmad, A., Ahmad, J., Haseebuddin, M., Siddiqui, A., & Salim, A. (2024, April). Analyzing energy efficiency of flying objects in Wireless Sensor and Mobile Ad Hoc Networks. In 2024 5th International Conference on Recent Trends in Computer Science and Technology (ICRTCST) (pp. 648-653). IEEE.

[12] Kandris, D., Evangelakos, E. A., Rountos, D., Tselikis, G., & Anastasiadis, E. (2023). LEACH-based hierarchical energy efficient routing in wireless sensor networks. AEU-International Journal of Electronics and Communications, 169, 154758.

[13] Chit, T. A., & Zar, K. T. (2018, September). Lifetime improvement of wireless sensor network using residual energy and distance parameters on LEACH protocol. In 2018 18th International Symposium on Communications and Information Technologies (ISCIT) (pp. 1-5). IEEE.

[14] Longla, T. T., Shah, A. S., Rabie, K. M., & Li, X. (2024). S-LEACH-CDMA: Sectoring and CDMA Integration with LEACH for Scalability and Energy Efficiency in Wireless Sensor Networks. Authorea Preprints.
[15] Behera, T. M., Samal, U. C., Mohapatra, S. K., Khan, M. S., Appasani, B., Bizon, N., & Thounthong, P. (2022). Energy-efficient routing protocols for wireless sensor networks: Architectures, strategies, and performance. Electronics, 11(15), 2282.
[16] Ahmad, W., Ahmed, S., Ahmad, A., Siddiqui, S. T., Khamruddin, M., & Khan, H. (2024, April). Renewable Energy Efficiency of Unmanned Aerial Vehicles Operating with Wireless Sensor Networks and Mobile Ad Hoc Networks. In 2024 Second International Conference on Smart Technologies for Power and Renewable Energy (SPECon) (pp. 1-6). IEEE.
[17] Latif, Z., Sharif, K., Li, F., Karim, M. M., Biswas, S., & Wang, Y. (2020). A comprehensive survey of interface protocols for software defined networks. Journal of Network and Computer Applications, 156, 102563.
[18] Dhipa, M., Rathore, N., Adivarekar, P. P., & Siddiqui, S. T. (2023). Enhancing energy efficiency in sensor/ad-hoc networks through dynamic sleep scheduling. ICTACT Journal on Communication Technology, 14(3).
[19] Vinodhini, R., & Gomathy, C. (2020). MOMHR: A dynamic multi-hop routing protocol for WSN using heuristic based multi-objective function. Wireless Personal Communications, 111, 883-907.