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Throughput and Energy Efficiency Evaluation of WSN Using Efficient Routing Protocols

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Abstract

Wireless Sensor Networks (WSNs) are sensors capable of wireless networking, environmental monitoring, and signal processing. In WSN, there are several challenges and design problems, such as node deployment, routing, coverage, connection, and quality of service. Due to the massive number of sensor nodes in the WSN, routing can be viewed as a significant challenge. Energy, storage capacity, and power consumption are the most effective WSNs' limitations. It is crucial to consider these restrictions while selecting routing protocols for wireless sensor nodes. The characteristics and network typology of the routing protocols can be used to classify them. Several performance approaches and algorithms are used to assess routing protocols' performance. This manuscript studies and compares the energy efficiency and throughput of Low Energy Adaptive Clustering Hierarchy (LEACH) and Hybrid Energy Efficient Distributed (HEED); the most effective power-aware routing protocols by changing the packet size and node density. This study was performed through simulation by utilizing the MATLAB tool. The simulation results showed that LEACH outperformed HEED in terms of throughput by an average of 28.85%, whereas HEED saved energy by an average of 3.41% compared to the LEACH protocol.
Keywords: Routing, Wireless Sensor Network, Clustering protocols, Performance metrics, Energy efficiency.

1. Introduction

A WSN is made up of geographically separated sensor nodes that may gather data at a low cost while recording and monitoring a range of physical and environmental parameters[**1**]. Most of the time, the sensor nodes don't have enough energy to do their jobs. This makes it necessary to come up with new methods or approaches to avoid energy loss that would shorten the life of the network**[1]**,**[2]**. Frequently, Energy-efficient wireless sensor networks are employed for medical and health care surveillance, environmental sensing, building control, the smart grid, transportation facilities, national defense, and military surveillance**[3]**.

Data transmission from sensors to base stations and conversely is done through routing. Due to the following properties, routing in wireless sensor networks is a challenging task. The first is that, due to the high sensor node density in sensor networks, the global addressing scheme is not suitable. Second, there is the issue of data redundancy carried on by sensor nodes that are close to each other in producing data. Third, great resource management is required due to the numerous energy, storage, and processing limits faced by sensor nodes. Fourth, different applications require different sensor networks. For wireless sensor networks, numerous routing techniques have been developed **[4]**.

Depending on whether the network organization is flat or hierarchical, routing protocols are classified. In flat routing, all sensor nodes are equally powered and capable of sensing; in hierarchical routing, nodes are split according to energy levels and each node is given a distinct role. The upper-level nodes are responsible for gathering and relaying the data to the base station(BS), whereas the lower-level nodes are responsible for sensing. **Figure 1** shows the WSN-routing protocol taxonomy**[5]**.

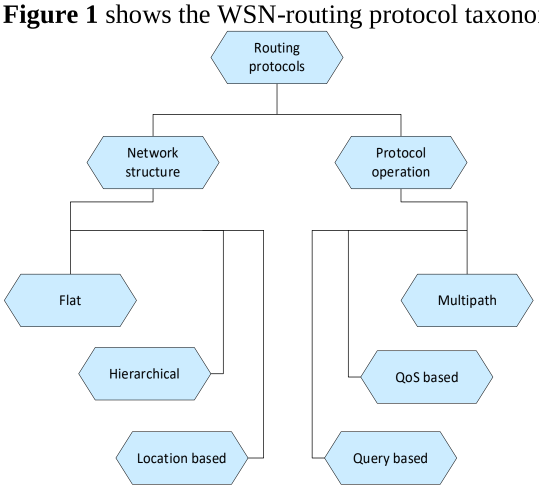


Fig.1 WSN-routing protocol taxonomy

When the network is divided into several sets of nodes or clusters, the hierarchical cluster architecture makes it easier for effective data aggregation and collection to occur independently of the expansion of wireless sensor networks and, in general, uses less energy and communications overall. Every cluster has a cluster head (CH) that manages the operations of the cluster's other nodes (cluster nodes) **[6]**,**[7]**. The three main types of clustering operations are grid-based, chain-based, or block-based. **Figure 2** displays the clustered structure of a basic wireless sensor network **[8]**.

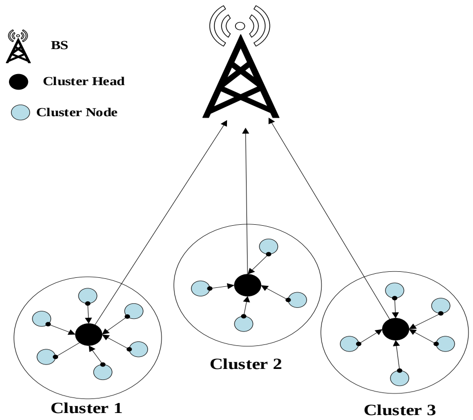


Fig.2 The basic model of clustered WSN

The majority of the clustering techniques used nowadays, including Low Energy Adaptive Clustering Hierarchy (LEACH), Power-Efficient Gathering in Sensor Information Systems (PEGASIS), and Hybrid Energy Efficient Distributed (HEED)are homogeneous techniques. Hierarchical clustering protocol LEACH offers an advanced approach to such algorithms. Since the method of CH rotation is used, each node has an equal chance of being chosen as a CH. Thus, the LEACH algorithm maintains the network's overall energy use and extends the network's overall life. According to the outcomes of the simulation, LEACH can extend the longevity of the network by about 15% versus the conventional flat multi-hop routing protocol and static slicing method **[9]**.

Minimizing energy utilization at each node to improve network energy efficiency and maximum throughput is one of the most crucial factors to take into account when designing a WSN**[10]**. Numerous protocols were therefore designed to lower the nodes' energy usage and keep the network running for a long time**[11]**. M. Shafiq et al. **[12]**, in 2020, have presented a survey on low-energy adaptive mechanisms, adaptive periodic threshold-sensitive methods, power-efficient distribution, and hybrid energy-efficient schemes. The results of the systematic review showed that despite the fact that energy usage is the most crucial problem in WSN, neither researchers nor practitioners are aware of it, even though it can help to increase energy efficiency. Additionally, it describes the flaws in the current methods that prevent them from being suitable for WSN routing that is energy efficient. To maximize WSN energy efficiency, J.-Y. Lee, and D. Lee **[11]**, in 2021, have planned to solve the K-means clustering issue more effectively. When choosing the CH, their proposed procedure considers the node's remaining energy as well as its distance from the BS.

A proposed improvement strategy to reduce energy use while extending the network lifetime was carried out by M. Elshrkawey et al. **[13]**, in 2018. This reduces energy wastage during network connections and has been achieved by enhancing the energy equilibrium in clusters between all sensor nodes. A CH selection method formed the basis for the improved method. Additionally, a modified TDMA schedule has been established as well.

An appropriate routing algorithm has been developed by R. J. Ismail et al. **[6],** in 2019, to increase WSN lifetime by utilizing fewer sensor nodes to transmit information with greater energy. Since the number of alive nodes in the WSN will remain constant for as long as possible, choosing sensor nodes with high energy instead of low energy will maintain the stability of the WSN topology. The suggested energy routing technique takes scalability into account. The cluster region's energy level will increase as its scalability causes the number of nodes to increase. Based on the K-means clustering technique to choose the clustering head, A. Amaithi et al. **[14]**, in 2018**,** have published a comparison study of LEACH and HEED. The comparative study of the aforementioned two procedures is shown at the end to demonstrate how the cluster formation enhances the network's lifetime in the NS2 network simulator. The average end-to-end delay(E2E), average throughput, packet delivery rate(PDR), and control routing cost are used to measure performance

An innovative routing strategy has been presented by Y. Liu et al. **[15]**, in 2019, to increase the energy efficiency of WSN. According to the following workflow shown in **Figure 3**, IEE-LEACH, a recently suggested improved energy-efficient LEACH approach, takes into account the average network energy as well as the remaining node energy when calculating the number of finest CHs and forbids the nodes that are physically closer to the BS from joining in the clustering process. To further increase the networks' energy efficiency, the suggested IEE-LEACH adopts a new criterion for choosing CHs in between the sensor nodes.

The LEACH protocol cycles through a random selection of CH nodes. T. Chang et al. **[16]**, in 2018, suggested a better solution to deal with this problem. To optimize the CH selection and clustering, the method first takes into account the average and standard deviation of residual energy of the nodes as well as their distance from the BS. It next took into account their distance from the CH as well as their energy. The outcomes of the performance evaluation demonstrated that this plan might reduce excessive energy consumption by some clusters and early deaths of the CHs. A. Gandhi et al. **[4]**, in 2018, have explord the advantages of clustering, WSN research aspects, and challenges and through **Table 1** compared and contrasted two significant clustering routing techniques, specifically LEACH and HEED.

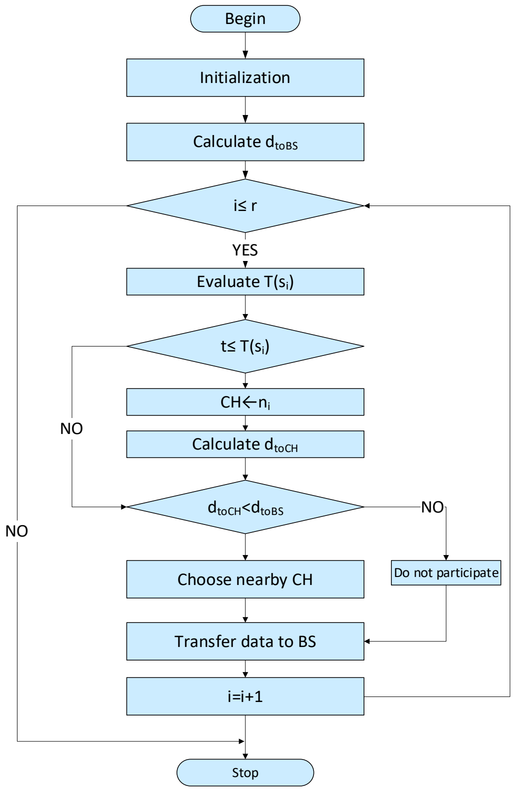


Fig.3 (IEE-LEACH) protocol workflow

Table 1 LEACH and HEED parametric comparison.

Parameters	LEACH	HEED
Routing within a cluster	Just one hop	Just one hop
Routing between clusters	Just one hop	Just one hop and many hops
Cluster overlapping	No	No
Executing a clustering method	Probabilistic	Iterative
Mobility	Stationary	Stationary
CH capability	Data aggregation, homogeneous	Data aggregation, homogeneous
Energy efficiency	Low	Moderate
Delay	V. small	Moderate

M. Omari and S. Laroui **[17]**, in 2015, have used MATLAB software to develop and analyze many clustering techniques, including LEACH, HEED, LEACH-1R, and LEACH-C. The number of live nodes, the maximum number of rounds, residual energy, data transfer to the BS, and other factors are compared between these clustering techniques. According to experimental findings, the LEACH methods outperformed the various HEED variants.

In this manuscript, selective saving-energy hierarchical clustering-based routing algorithms, which are LEACH and HEED are studied and compared across the two most crucial performance approaches (energy efficiency(how much energy is used) and throughput).

The methodology followed in this article, and unlike recent techniques used in WSNs is in compares the most recent and efficient techniques that are applied for high-performance WSNs. this study developed novel key characteristics in real-time WSN operations consisting of any kind of task. It is validated through the formal proof of the mathematical model and theoretical principles and a series of comparisons with recent achievements of LEACH and HEED protocols.

The other sections of this manuscript follow the following format: Section 2 through the state of the art will describe Efficient WSN routing techniques, The Energy Consumption Model, and Significant WSN Performance Challenges. In section 3, simulation is used to compare the energy-efficient hierarchical cluster-based routing algorithms. Section 4 will serve as the manuscript's conclusion.

2. The state of the art

2.1 Efficient routing schemes of WSN

Numerous routing algorithms have been developed to address a variety of issues, including load balance, energy consumption, and transmission costs. Numerous cluster-based routing protocol approaches are being investigated, including PEGASIS, TEEN, LEACH, and HEED. The routing mechanism known as Power-Efficient Gathering in Sensor Information System (PEGASIS) transfers packets from all nodes to the BS sequentially. One of the WSN's energy-efficient routing protocols, the threshold-sensitive Energy Efficient sensor Network (TEEN) protocol, is utilized to minimize energy usage and enhance the network's stability and longevity**[12]**.

2.1.1. LEACH Algorithm

LEACH (Low Energy Adaptive Clustering Hierarchy) is a technique of clustering that includes the following characteristics: local control for transferring data and gathering, adaptable, stochastic, and self-configuring cluster creation. The original data from the sensor nodes is not transferred to the BS in that form. The cluster locally processes the data from all of the sensor nodes before sending the condensed data to the user. The original data is delivered to the BS while retaining its previous effectiveness **[4]**. LEACH's operation is separated into rounds, each of which starts with a set-up phase in which the clusters are arranged and stops with a steady-state phase in which data transmission to the BS happens **[9]**. Each sensor node is assumed by the LEACH protocol to have enough power to connect to the BS.Therefore, if sensor nodes are located far from the BS, more energy will be consumed. Additionally, LEACH made the unfounded assumption that the network's nodes are all homogeneous, which is incorrect in the majority of cases. It must therefore be improved further to accommodate heterogeneous nodes**[13]**.

2.1.1.1. Set-up phase

The node first plays the role of the CH with P probability during setup and then publishes its decision message. The normal nodes select the CH based on whatever CH requires the least amount of communication energy to reach. The cluster's nodes swap as the CH in order to lengthen the lifetime of the network.The decision of the node to generate an arbitrary value ranging from 0 to 1 determines the cluster choice. The node becomes the present round's CH if the value is smaler than a threshold $T(n)$.The fllowing equation is the threshold:

$$T(n) = \begin{cases} \frac{P}{1-P*\left(r \bmod \frac{1}{P}\right)} & if\ n \in G \\ 0 & if\ n \notin G \end{cases} \quad (1)$$

Where G is the group of nodes that were not cluster-heads within the prior 1/P rounds, r is the recent round, and P is the CH's recommended percentage. By applying such a threshold, every node will act as a CH for $\frac{1}{P}$ rounds at a time. Every node has a P probability of being a CH in the initial round (r = 0). The nodes that were cluster-heads in round 0 are unable to hold that position for the following $\frac{1}{P}$ rounds. As a result, because there are lesser nodes that can become CHs, the chance that the rest of the nodes are CHs should be raised. After 1/ P − 1, every nodes are again able to become cluster-heads after 1/ P rounds, and after (1/ P – 1), T = 1 for nodes that have not yet served as CHs **[18]**. Whenever the CH is identified, it broadcasts an advertisement message (ADV) to indicate its location. As an announcement message, this message also contains a brief message made up of the node identity and a header. Every node retains received messages for upcoming rounds. Each node selects the proper CH based on the strength of the signal it is receiving. If a node does not choose its CH at the end of the operation, a CH is chosen at random for that node. A join request message is sent by each node to the CH. The radio hardware of the CHs must be turned on at all times during this phase. The CH is sent messages from its members. CHs serve as local command centers for the LEACH algorithm to coordinate data transit throughout their cluster. A CH creates a schedule using the TDMA approach according to the number of nodes and sends it to member nodes **[19]**,**[20]**.

2.1.1.2. Steady-state phase

Data transfer can start after the clusters are established as well as the TDMA schedule is adjusted. According to the TDMA schedule, the normal node will communicate data to the CH within its assigned transmission period. Each normal node has a radio that can be disabled until its assigned transmission time. To receive all the data from the cluster nodes, the cluster head will keep its receiver turned on. After receiving all the data, the CH performs the operations of data fusion to combine it all into a single signal. The CH then sends the combined signal directly to the BS. This high energy delivery is necessary due to the base station's distance **[9]**. **Figure 5** shows the setup and steady-state workflow of the LEACH **[21]**.

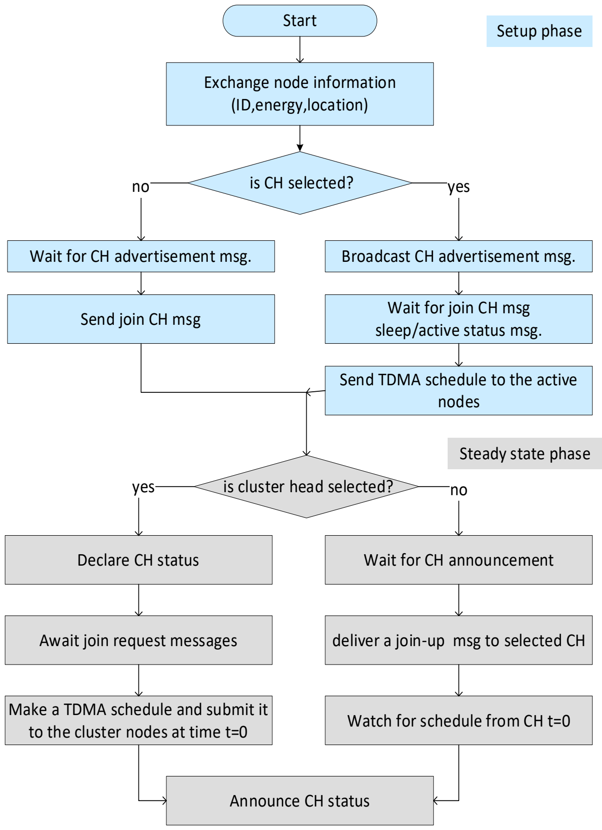


Fig.4 Setup and steady-state workflow of LEACH protocol

2.1.2. HEED algorithm

A clustering protocol called HEED (Hybrid Energy-efficient Distributed) creates equal-sized clusters. The remaining energy of the sensor nodes and either the node degree or the distance of the neighboring nodes from the CHs are used in HEED to choose the CHs. Three stages are used in HEED to construct clusters: initialization, iteration, and finalization. Each node is given an initial CH probability according to the maximal and remaining energy during the initialization phase **[4]**,**[22]**.

$$P_{HEED} = C_{prob} \frac{E_{residual}}{E_{max}} \quad (2)$$

While C_{prob} is the initial CH fraction across all sensors, $E_{residual}$ is the sensor's current level of energy, and E_{max} is the maximum energy.

The sensor node locates the CH during the iteration phase so that it can transfer data there with the least amount of energy. Imagine that a sensor node elects itself as one of the CH if it has not heard from the CH in a while. It transmits the same message to all of its neighbors. Two different status messages can be sent from the sensor node. The first is the preliminary status, where the sensor node changes to the preliminary CH state when less than 1. Additionally, when the sensor node reaches 1, it enters its ultimate status and turns into a permanent CH. The sensor node chooses the CH that it must connect to during the finalization phase. The sensor node delivers data to the CH, which then sends the data in the aggregate to the BS in a multi-hop fashion **[4]**.

2.2 The radio model energy consumption

The transmitter operates the radio electronics as well as the power amplifier, and the receiver operates the radio electronics as well. Both processes use energy. **Figure 6** displays the energy consumption model for radio hardware.

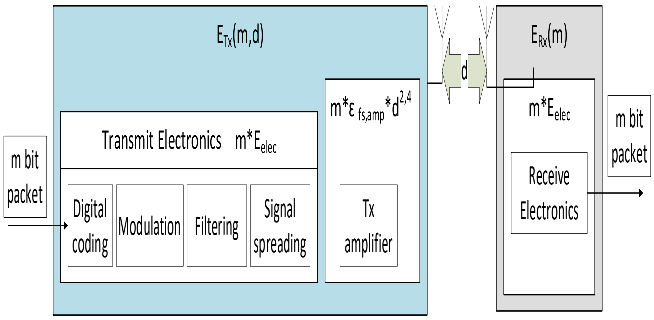


Fig.5 Radio energy dissipation model

This model uses the free space and the multipath channel having $(distance)^2$ and $(distance)^4$ energy usage according to the distance between transmitter and receiver. Therefore, the energy required to send a packet of m bits over a distance d is determined by the following equation **[15]**,**[23]**:

$$E_{Tx} = \begin{cases} m * E_{elec} + m * \epsilon_{fs} * d^2 & d \leq d_0 \\ m * E_{elec} + m * \epsilon_{mp} * d^4 & d > d_0 \end{cases} \quad (3)$$

where d_0 is a threshold distance and evaluated by:

$$d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{\mathrm{mp}}}} \quad (4)$$

while E_{elec} is the amount of energy of radio electronics, and

The amplification coefficients of the transmitting circuitry for $d \leq d_0$ and $d > d_0$ are represented by the parameters ϵ_{fs} and ϵ_{mp}.

According to the signal's modulation, digital coding, spreading, and filtering, electronic energy E_{elec} is utilized. The specific energy expression of the receiver is the opposite of the transmitter. To get a message with m bits, the receiver energy dissipation is based on:

$$E_{Rx} = m * E_{elec} \quad (5)$$

2.3 Significant WSN performance challenges

Several parameters can be used to assess the performance of the WSN under various routing protocols. The metrics used to assess performance are throughput, energy usage, PDR, and end to end (E2E) delay**[24]**, which can be characterized as :An average E2E delay is the length of time in seconds it takes for a packet to travel from source to destination across a network. The overall rate during which energy is spent by sensor nodes in a WSN over a predetermined time period is called energy consumption. PDR is defined as the overall proportion of correctly delivered packets from the source to the BS that is transmitted by all sensor nodes in the network. Average throughput is the average number of packets that the BS successfully receives per unit of time. It is measured in bits per second **[25]**. Energy efficiency and throughput are the most crucial parameters in the design phase of any routing protocol in WSN.

3. Network model and simulation results

The network model and simulation outcomes are presented and discussed in this section. ensuring that the circumstances and fundamental premise used to compare all clustering techniques are the same.

3.1 Network model

With the following presumptions, sensor nodes are dispersed arbitrarily in a square area. Each sensor node has the same beginning energy (homogeneous), the same data processing, and communicating capabilities. A distinctive ID is used to identify each sensor node; Based on how far away the receivers are, sensor nodes can send at different power levels; Since they are stationary, sensor nodes are not movable; The field's sensor nodes are evenly dispersed and send data at the same pace. The BS is immobile. The parameters for simulation scenarios are packed in **table 2**.

Table 2 A package of simulation utilized parameters.

Parameters	Assignments
Deployment area	100*100 m2
Node’s Initial energy	2 J
Probability of CH	5%
Sink/BS position	Center (50,50) m
Number of rounds	1500
Electronic energy (Eelec)	50 nJ/bit
Aggregation energy (Eag)	5 nJ/bit
Free space energy (Efs)	10 pJ/bit/m2
Data packet size	(1,3,5) kbit
No. of sensor nodes	50,150,500
Logical Topology	Random
Radio model	First order

3.1 The simulation setup

In this section, two different scenarios are presented with the purpose of illustrating and comparing the performance of the routing algorithms LEACH and HEED in WSNs.

3.2.1 The first scenario

Some strategies propose a distributed clustering strategy for WSNs as a solution to the energy conservation issue. However, these studies examined the throughput optimization problem without taking into account the effect of network density or how network throughput grows as the network increases from small to large. This scenario includes node density variation. From **table 3**, it is clear that LEACH throughput is more than HEED throughput for each case. This is due to the higher number of clusters (CH)being formatted in LEACH in comparison to HEED based on the following formula:

$$no.of\ bits\ sent(throughput) = no.of\ CH * 5000 + no.of\ CN * 200 \quad (6)$$

When the node number rises, the throughput improvement increases linearly. LEACH obtained throughput improvements of 22% to 66% for node number variations from 50 to 500. **Figure 7(a)** shows that as the node number rises, the throughput increase of LEACH is faster than that of HEED, which means that LEACH throughput is more sensitive to node number variation. However, both protocols have the same expression for energy consumption. LEACH is more energy-consumptive than HEED but with a little difference, as depicted in **figure 7(b)** and **figure 9(a)** demonstrates that the increase in energy dissipation versus node density is nearly identical for both protocols.

3.2.2 The second scenario

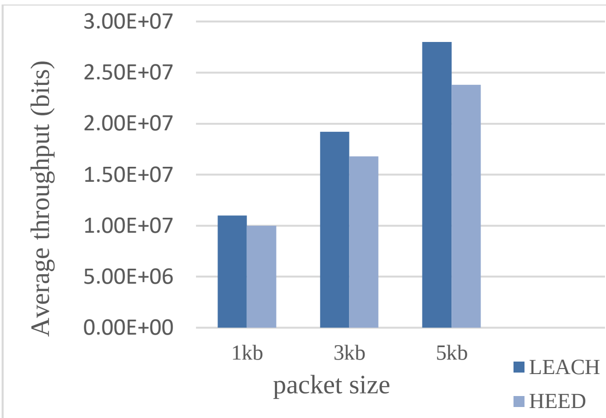
In order to maximize WSN lifetime and energy efficiency improvements, packet size is of extreme significance. In this scenario, the packet size for CH per round is changed while the cluster node packet size is fixed at 200 bits. **Table 4** shows that, according to equation 6, LEACH throughput exceeds HEED throughput. This is once again a result of LEACH having more cluster numbers. LEACH obtained throughput improvements of 9% to 15% for packet size variations from 1000 to 5000. **Figure 8(a)** shows that the throughput of both LEACH and HEED increases as packet size increases. LEACH is more energy-consuming than HEED , as depicted in **Figure 8(b)** and **Figure 9(b)** shows that this consumption rises as the rate of packet errors requiring retransmission increases with packet size. Therefore, more retransmission will increase energy dissipation.

Table 3 First scenario performance metrics outcomes.

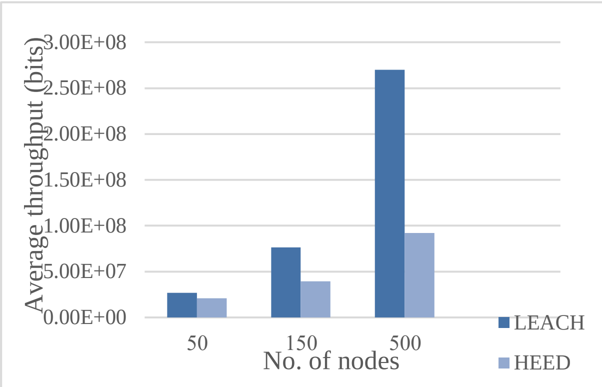
No. of nodes	Throughput		Throughput improvement (%)	Average consumed energy (J)in both CHs and Non-CH		Energy improvement (%)
	LEACH	HEED		LEACH	HEED	
50	2.67 e7	2.08 e7	22.1	13.7	12.95	5.47
150	7.65 e7	3.94 e7	48.5	39.4	38.8	1.5
500	27 e7	9.2 e7	65.9	130.2	127.8	1.84

Table 4 Second scenario performance metrics outcomes.

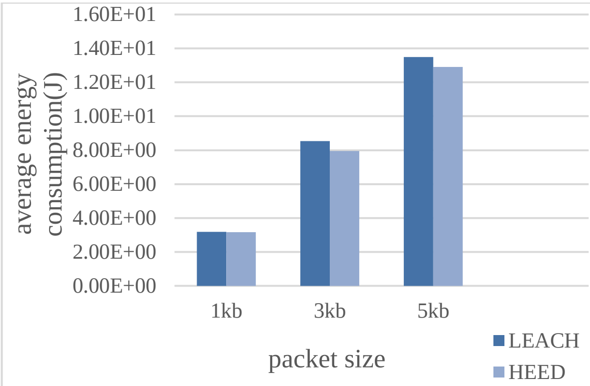
Packet size	Throughput		Throughput improvement (%)	Average consumed energy (J)in both CHs and Non-CH		Energy Improvement (%)
	LEACH	HEED		LEACH	HEED	
1000	1.1e7	1e7	9.1	3.18	3.17	0.3
3000	1.92 e7	1.68 e7	12.5	8.54	7.95	6.9
5000	2.8e7	2.38 e7	15	13.5	12.9	4.44



(a)

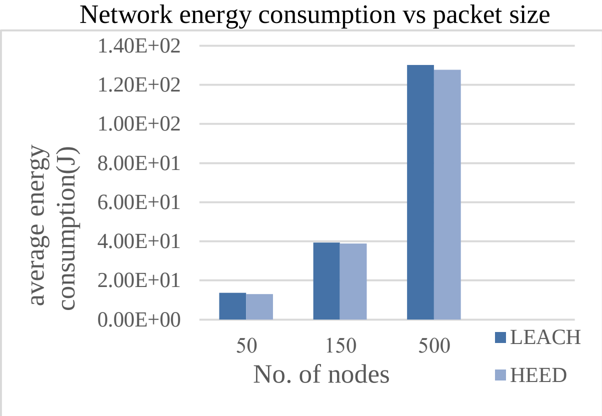


(a)



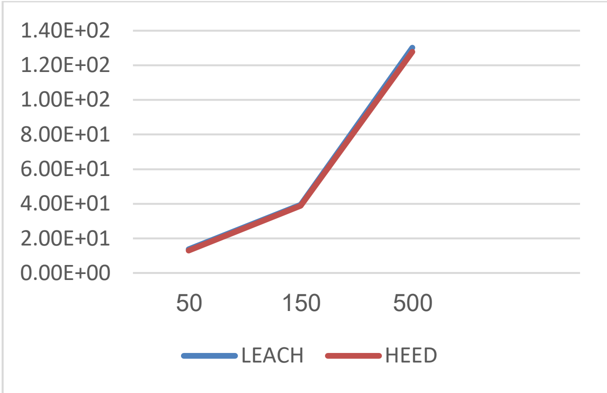
(b)

Fig.7 The second scenario compared results for node density=50 (a)Average throughput vs packet size (b) Network energy consumption vs packet size

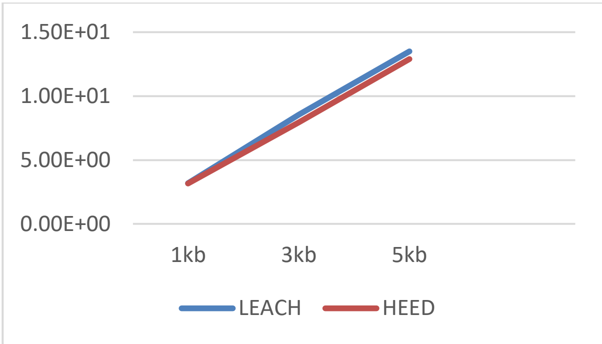


(b)

Fig.6 The first scenario compared results for packet size 5,000 bits(a)Average throughput vs node density (b) Network energy consumption vs node density



(a)



(b)

Fig.8 LEACH and HEED energy consumption increase for (a) node density variation (b) packet size variation

Conclusion

Wireless sensor networks are growing and becoming increasingly common. The main issue with sensor networks is energy conservation. They are now extremely active research areas where improvements are continually sought.

Numerous routing techniques have been examined and studied in this article, many performance parameters of LEACH and HEED are analyzed and simulated for different dynamic parameters. The more representative protocols utilized by WSN are LEACH and HEED.

Different dynamic parameters are considered while analyzing and simulating a number of LEACH and HEED performance metrics. LEACH and HEED are the more typical protocols used by WSN. With two scenarios, namely different node density and packet sizes, the HEED protocol reduced network energy usage while the LEACH routing protocol increased throughput. The LEACH routing protocol increased throughput in the first and second situations by 45.5% and 12.2%, respectively, whereas HEED reduced energy consumption by 2.94% and 3.88%, respectively. These outcomes revealed that, in all of the examined scenarios, LEACH surpasses HEED in terms of throughput and that, in terms of energy dissipation, they are almost comparable.

References

[1] T. M. Behera, S. K. Mohapatra, U. C. Samal, M. S. Khan, M. Daneshmand, and A. H. Gandomi, "I-SEP: An improved routing protocol for heterogeneous WSN for IoT-based environmental monitoring," *IEEE Internet of Things Journal* , 2019, 7, 710.

[2] D. Sulaiman, I. Hamarash, and M. Ibrahim, "Adaptive supply and body voltage control for ultra-low power microprocessors," *IEICE Electronics Express*, 2017, 14, 306.

[3] P. Saheb, K. J. I. J. f. E. Sharma, and Communication, "Improved LEACH Protocol Based on K-Means Clustering Algorithm for Wireless Sensor Network," *International Journal of Electronics and Communication Technology*, 2017,8.

[4] A. Gandhi, V. Kumari, and S. Thangavelu, "A Comprehensive Study and Analysis of LEACH and HEED Routing Protocols for Wireless Sensor Networks – With Suggestion for Improvements," *Indonesian Journal of Electrical Engineering and Computer Science*, 2018, 9, 778.

[5] S. R. Khiani, C. Dethe, and V. Thakare, "Unequal energy aware secure clustering technique for wireless sensor network," in *International Conference on Inventive Computation Technologies*, 2019, Springer, 29.

[6] R. J. Ismail, S. J. Ismae, and W. H. Ali, "Energy Management in Wireless Sensor Networks for Internet of Things Applications," *Cihan University-Erbil Scientific Journal*, 2019, 3 , 48.

[7] A. M. Jubair, R Hassan, A. H. M. Aman, H. Sallehudin, Z. G. Al-Mekhlafi, B. A. Mohammed, M. S. Alsaffar, "Optimization of Clustering in Wireless Sensor Networks: Techniques and Protocols," *Applied Sciences*, 2021,11, 11448.

[8] N. Pradhan, K. Sharma, and V. Kumar, "A Survey on Hierarchical Clustering Algorithm for Wireless Sensor Networks," *International Journal of Computer Applications*, 2016, 134, 30.

[9] N. Wang , H. Zhu, "An Energy Efficient Algrithm Based on LEACH Protocol," *International Conference on Computer Science and Electronics Engineering*, 2012, 2, 339.

[10] D. Sulaiman, I. Hamarash, and M. Ibrahim, "Microprocessors optimal power dissipation using combined threshold hopping and voltage scaling," *IEICE Electronics Express*, 2017, 14, 1046.

[11] J.-Y. Lee, D. Lee, "K-means clustering-based WSN protocol for energy efficiency improvement," *International Journal of Electrical and Computer Engineering*, 2021, 11, 2371.

[12] M. Shafiq, H. Ashraf, A. Ullah, and S. Tahira, "Systematic Literature Review on Energy Efficient Routing Schemes in WSN – A Survey," *Mobile Networks and Applications*, 2020, 25, 882.

[13] M. Elshrkawey, S. M. Elsherif, M. E. Wahed, "An enhancement approach for reducing the energy consumption in wireless sensor networks," Journal of King Saud University - Computer and Information Sciences, 2018, 30, 259.

[14] A. Amaithi, A. Swaminathan, B. Pajila, Brundha, "A Comparative Analysis of LEACH and HEED in Hierarchical Clusterin Algorithm for Wireless Sensor Networks," *International Journal of Applied Engineering Research*, 2018,13, 465.

[15] Y. Liu, Q. Wu, T. Zhao, Y. Tie, F. Bai, and M. Jin, "An Improved Energy-Efficient Routing Protocol for Wireless Sensor Networks,"*sensors*, 2019, 19, 4579.

[16] T. Chang, W. Liu, Y. Zhang, "Optimized Algorithm for Clustering Routing for Wireless Sensor Networks," *Journal of Computer and Communications*, 2018, 6, Springer Singapore. 1.

[17] M. Omari and S. Laroui,2015. Simulation, comparison and analysis of wireless sensor networks protocols: LEACH, LEACH-C, LEACH-1R, and HEED. IEEE 4th International Conference on Electrical Engineering (ICEE), Boumerdes: Algeria., 1.

[18] A. Kaur, S. Vatta, "Implementation of LEACH, Hetero-LEACH, SEP and EEHC protocols using MATLAB in wireless sensor network," *International Journal of Engineering Research & Technology*, 2016, 5.

[19] A. A. Kazerooni, H. Jelodar, J. Aramideh, "Leach and heed clustering algorithms in wireless sensor networks: a qualitative study," *Advances in Science and Technology Research Journal*, 2015, 9, 7.

[20] S. Noureddine, B. Khelifa, B. Mohammed, "Approach to minimizing consumption of energy in wireless sensor networks," *International Journal of Electrical and Computer Engineering*, 2020, 10, 2551.

[21] M. Mufid, U. Al Rasyid, and I. Syarif, "Enhanced PEGASIS using Dynamic Programming for Data Gathering in Wireless Sensor Network," *EMITTER International Journal of Engineering Technology*, 2019, 7, 06.

[22] Z. Ullah, L. Mostarda, R. Gagliardi, D. Cacciagrano, and F. Corradini, 2016. A comparison of heed based clustering algorithms--Introducing ER-HEED. IEEE 30th international conference on advanced information networking and applications (AINA), 339.

[23] I. Daanoune, A. Baghdad, A. Ballouk, "An enhanced energy-efficient routing protocol for wireless sensor network," *International Journal of Electrical and Computer Engineering* , 5, October 2020,10, 5462.

[24] G. K. Nigam and C. Dabas, 2017.Performance Analysis of Heed Over Leach and Pegasis in Wireless Sensor Networks.The World Congress on Engineering and Computer Science , Springer Singapore, 259.

[25] G. Arumugam, T. Ponnuchamy, "EE-LEACH: development of energy-efficient LEACH Protocol for data gathering in WSN," *EURASIP Journal on Wireless Communications and Networking*, 2015, 2015, 1.