ENERGY EFFICIENT ROUTING PROTOCOL FOR WSN USING ADAPTIVE CLUSTER SELECTION

**Abstract:**

Wireless sensor networks (WSNs) consist of many sensor nodes that can sense data from where they are placed and send it to the gateway in energy-efficient links for monitoring or processing. We present a approach to clustering through the Low Efficient Adaptive Clustering Hierarchy (LEACH) method, which aims to improve the efficiency and scalability of traditional clustering techniques in data-driven applications. SSO is mostly applied for routing optimization, clustering, and energy consumption so as to enable long network longevity and effective transmission of data in WSNs. The approach effectively explores and exploits trade-offs and allows dynamic response of the sensor nodes according to changing conditions of the network. SSO achieves load balance optimization, circumvents energy drainage, and optimizes communication overhead by leveraging distributed cognition of the artificial spider colony. Based on the simulation result, it is clear that I-SEENIHR consumes less energy and also outperforms in terms of network lifetime, packet sending rate, and transmission delay.

**Key words:**

1. Introduction

Wireless sensor networks (WSNs) consist of many sensor nodes that can sense data from where they are placed and send it to the gateway in energy-efficient links for monitoring or processing. The secret to energy limits in WSNs is routing protocols, and clustering in particular. The Cluster Head (CH) plays a crucial role in enabling efficient data transfer and energy conservation. Numerous sensor nodes that collect and transmit data to a base station (BS) make up a WSN.[1].

Cluster head (CH) selection and cluster formation are power-intensive tasks in WSN applications. In order to increase network lifetime, the CH is selected probabilistically, disregarding real-time variables like the amount of energy left, the number of clusters, the distance, the location, and the number of functional nodes.[2].

This can be difficult for resource-constrained devices. Additionally, there can be unbalanced energy consumption if CHs are not optimally distributed, resulting in quick energy drain on some nodes, particularly those that are repeatedly selected as CHs.[3].

A popular hierarchical routing technique called Low-Energy Adaptive Clustering Hierarchy (LEACH) was created to improve Wireless Sensor Networks' (WSNs') energy efficiency. The clustering principle underlies LEACH's operation, in which sensor nodes join together and a Cluster Head (CH) is chosen for each cluster. In addition to minimising direct communication and energy consumption.[4].

The availability of finite energy resources is the primary issue in WSN. Low energy adaptive clustering hierarchy (LEACH), an energy-efficient routing system, has been introduced in this study to increase energy efficiency while extending the lifespan of sensor nodes. Sensor nodes are transformed into cluster heads (CH) by the hierarchical LEACH protocol, which then collects, compresses, and transmits the data to the target node.[5].

This component seeks to extend network service life and reduce energy consumption. In order to solve these problems, we first select the best CH from the list of accessible nodes using LEACH. These can be used to calculate the remaining energy and distance of a node from its neighbours.

**2. Literature Survey**

An energy-efficient CH selection algorithm based on an enhanced GWO algorithm (EECHIGWO) solves problems such as unbalanced exploration and exploitation, decreased population diversity, and premature convergence in the standard GWO algorithm. The objective in this study is to maximize energy efficiency, average throughput, network stability, and network lifetime in WSNs through optimal selection of CH using EECHIGWO. In spite of the superior performance of the proposed BEA-SSA model in terms of residual energy, RSSI, and PDR, it is burdened with several drawbacks. The main drawback is that it lacks fault tolerance, which is vital for the robustness of WSNs.[6].

Through the resolution of problems in the cluster head (CH) selection process, this research suggests the golden eagle optimisation algorithm (GEOA) and enhanced grasshopper optimisation algorithm (IGHOA), based on the energy efficient cluster-based routing protocol (GEIGOA), to ensure energy stability and enhance network lifetime longevity. Although the suggested hybrid routing protocol improves energy efficiency and prolongs the lifetime of WSNs, some limitations exist. One major limitation is that it is not fault tolerant, since the research does not explain how the protocol deals with unforeseen node failure or energy exhaustion of cluster heads (CHs). [7].

This study suggests a Gateway Clustering Energy-Efficient Centroid- (GCEEC-) based routing protocol in which cluster head is chosen from the centroid location and gateway nodes are chosen from every cluster. Gateway node minimizes the data burden from cluster head nodes and sends the data towards the base station. Simulation has been done to analyze the suggested protocol with state-of-the-art protocols. The protocol is based on optimal CH selection and rotation but does not indicate how it copes with unforeseen node failure. In case a CH or gateway node fails, network communication would be interrupted, which would result in data loss and lower reliability.[8].

The Wireless Sensor Networks (WSNs), clustering is done through the election of a Cluster Head (CH), the leader node. The Adaptive Remora Optimization Algorithm (AROA) is used for the election of the CH, considering parameters such as energy, distance, throughput, Packet Delivery Ratio (PDR), and path loss. The protocol enhances the selection of CH by positioning it close to the energy centroid and using a gateway node for multihop transmission, thereby lowering the CH load. It is limited by not having a fault tolerance mechanism. In case a CH or gateway node runs out of energy, communication failures may be experienced.[9].

Wireless Sensor Networks (WSNs) have limited processing capacity, storage, bandwith, and data transfer. Energy-efficient strategies are essential to optimize their lifespan and performance. The Cluster Head (CH) gathers and relays data from cluster nodes. An efficient CH selection process enhances data delivery, energy efficiency, and clustering performance. This project introduces the Gateway Clustering Energy-Efficient Centroid-based Routing Protocol (GCEEC) to optimize load balancing, energy efficiency, and network lifespan. The protocol optimizes CH selection by locating it near the energy centroid and using a gateway node for multihop communication, reducing the workload of the CH. [10].

A protocol, namely, Threshold-based Energy-aware Zonal Efficiency Measuring hierarchical routing protocol. It is a heterogeneity-aware and threshold-based protocol that provides a better solution to existing problems in next-generation wireless sensor networks. Simulation results verify the improved performance of the proposed Threshold-based Energy-aware Zonal Efficiency Measuring hierarchical routing protocol in terms of network stability, lifetime, and throughput.[11].

The study of routing algorithm that balances energy efficiency and reliability and is suitable for real-time applications as well. It reduces the real-time routing problem to 0/1 Integer Linear Programming (ILP) problem and then proposes a Real-time Energy-Efficient Traffic-Aware approach (RTERTA) to optimize the problem of large-scale IWSN. According to the results obtained from the simulation. They believe that the overall performance of the WSNs will be enhanced as well as the real-time applications will be designed considering such parameters.[12]

Therefore, rational and effective routing protocols should possess better Quality of Service (QoS). For Dempster–Shafer (DS) evidence theory, it can combine properties of sensor nodes with solid theoretical inference and has low prior-knowledge requirements. Theoretical analysis and simulated results show that DS-EERA is promising, which can efficiently extend the network lifetime. At the same time, it can also achieve a lower packet loss ratio and improve the reliability of data transmission.[13].

The book postulated that in most traditional methods, routing path selection and data aggregation are treated as independent considerations. In this research, we take the degrees of the neighbour nodes' potential data aggregation into account when a node has to decide on the routing path. propose a new Q-learning-based energy-efficient routing algorithm with data-aggregation awareness. The findings reveal that the protocol study can effectively minimize the data and prolong the WSN's lifetime. the protocol study of Q-DAEER consumed less energy and had longer network lifetime for both random and grid topology at even dense node conditions.[14].

The proposed novel indicated that solutions for the relay node placement and energy efficient routing issues for HWSN. Both issues rarely have been addressed at the same time in the literature. The paper initially develops a mathematical model for both issues. The proposed novel indicated that the influence of whale optimizer approach with three adaptive strategies. Numerical simulations are performed to verify the proposed approach for HWSN. The technique is applicable for optimizing the relay nodes' cost and minimizing data transmission energy consumption in partitioned HWSN.[15].

The novel reports, by employing multi-hop routing hopes to increase the lifespan of Wireless Sensor Networks (WSNs) while satisfying dependability requirements. Using relay nodes, the source node transmits data to the base station (BS) in this manner. The BS determines the best routes and keeps track of the network's energy state in a lookup table. The BS refreshes and broadcasts these routes to every node following each packet transmission, guaranteeing effective load balancing while preserving dependability.[16].

This study designed energy-efficient routing system named Energy-aware Proportional Fairness Multi-user Routing (EPFMR) framework in WSN. EPFMR is implemented in the WSN environment with the instance time. The proportional fairness routing in WSN chooses the optimal route path for the packet flow according to the proportion between the periods of requests between various SN. In this section, the new framework results of EPFMR were compared and tested with two existing TULA and SCF techniques in WSN.[17].

The novel suggested new trust based secure and energy efficient routing protocol (TBSEER) to address these issues. TBSEER determines the overall trust value by adaptive direct trust value, indirect trust value and energy trust value, which are immune to black hole, selective forwarding, sinkhole and hello flood attacks Simulation results indicate that proposed TBSEER decreases energy consumption of the network, accelerates the detection of malicious nodes, as well as resists all usual attacks.[18].

This context, energy efficiency is the factor most attracted by many researchers. In this study new improved LEACH routing protocol. This proposed protocol based on the current energy to select cluster-heads, and it uses a root cluster-head with more current energy and low distance to the sink to gather all data, then sends it to the sink. This protocol uses these metrics to minimize the energy consumption in the network and extend the network lifespan in WSNs. In this document, our contribution is an enhanced LEACH algorithm. The overall purpose of the proposed protocol is selecting CH according to the residual energy of nodes to avoid the participation of nodes with less energy as CH.[19].

The random distribution area for sensor nodes is partitioned into clusters. Each cluster has its cluster head which is the node closest to the centre of a cluster with maximum residual energy. For making the selection, there is a use of a greedy strategy and artificial neural network approaches. Besides that, in order to minimize cluster heads' energy consumption. the protocol was tested only in a normal simulation environment ignoring dynamic real-world situations like drone-aided WSNs, wireless body area networks, or smart transportation systems. Its flexibility towards high-mobility environments is unknown.[20]

3. Proposed Methodology

The initial process is Cluster Head (CH) Selection, in which the network is segmented into clusters and a CH is selected on the basis of energy levels, position, and communication range. The CH collects information from its cluster members and transmits it, minimizing redundant transmissions. Low-Energy Adaptive Clustering is then used to balance energy usage by adapting the network dynamically. This avoids any one node using up energy too rapidly, making the network last longer. After clustering is established, the system targets Improving Energy Efficiency using data aggregation, multi-hop transmission, and power control. Aggregation of similar data minimizes redundant transmissions, and multi-hop transmission conserves energy by transmitting data through intermediary nodes rather than directly to the base station. The second step is Choosing the Best Path for transmitting data. The routing protocol decides the best path depending on attributes such as link quality, distance, and energy cost. Advanced algorithms that stop vital nodes from using up their energy, such as machine learning or bio-inspired solutions like Ant Colony Optimisation, are in place. Lastly, Maximizing Network Lifetime provides sustained operation. By keeping energy consumption balanced throughout the network, node failures are reduced, and the WSN becomes more efficient and sustainable. Through these steps—Cluster Head Selection, Adaptive Clustering, Energy Efficiency Improvements, Optimal Path Selection, and Network Lifetime Maximization—WSNs attain improved performance while saving energy. This systematic approach facilitates applications like environmental monitoring, industrial automation, and smart city management.

Wireless Sensor Network

Cluster Head

Improve Energy-Efficient

Select optimal Path

Maximize the Network Lifetime

Low-Energy Adaptive Clustering Hierarchy (LEACH)

Figure 1. Architecture Diagram for Proposed LEACH Method

This method follows an energy-aware approach to improve the efficiency and lifetime of a WSN by using Low-Energy Adaptive Clustering Hierarchy (LEACH), adaptive energy management, and optimal path selection techniques.

**Hierarchical Clustering (HC):**

One suggested quick clustering method is the hierarchical clustering (HC) algorithm. autonomously carry out agglomerative clustering based on the placement of nodes. Neither the cluster head nor the number of clusters must be chosen by humans during the clustering phase. This research proposes an environment-adaptive hierarchical clustering technique to decrease the participation of the human experience. The clustering method achieves the spontaneous clustering of the WSN nodes and is terminated based on the adaptive deployment of the nodes. Assume that N nodes are positioned in the positioning region in the best possible way and that each node's coordinates are predetermined. These N nodes would be considered the original clusters in accordance with the theory of the aggregate hierarchical clustering algorithm, equation 1.

(1)

where theth created cluster is denoted by . For every clustering iteration, the clustering cost would be determined by taking the maximum Euclidean distance between any two groups. Until the desired number of clusters or the termination condition is met, the two clusters that are closest to one another will then combine to form a new cluster.

Considering that following multiple clustering procedures, the cluster has as well as the cluster has . The and are the nodes that are furthest distant from one another out of all the included nodes. The HC algorithm's concept of the greatest distance between clusters is that are the more widely spaced nodes. The HC algorithm's concept of the greatest distance between clusters is that the greatest distance between these two groups can be shown as equation 2.

(2)

where M+ i and M+ j stand for the clusters' labels.

The greatest separation between the deployed nodes in this study To act as the clustering termination threshold D, C is chosen and modified. equation 3.

D =

(3)

where the coordinates of the th and th nodes are indicated by and s stands for the practical factor, which is the ratio of the distances between nodes within the confidence distance.

Here is a thorough explanation of . First, by using data transmission simulations in the actual target area, the confidence distance for dependable data transmission can be predetermined as .

Next, the distance between theth and th nodes is determined and noted as . The percentage of can then be determined and noted as . According to the derived proportion s might therefore be used to determine the threshold .

The maximum distance and dependable data-transmission distance between the deployed nodes, which can ensure a difference between clusters and lessen the difference within the established cluster, work in concert to determine the clustering termination. Consequently, a more sensible node clustering might be achieved by combining the confidence distance and the node topology.

Each cluster's energy usage would rise as the threshold distance increased in order to send a specific volume of data to the base station. Nonetheless, the number of clusters would correspondingly decline, lowering the data package's transmission volume. When it comes to increasing energy efficiency, threshold distance optimisation may be significant. Thus, by optimizing the node topology, the suggested environment-adaptive hierarchical clustering could raise the MLC of WSNs.

**SOCIAL SPIDER OPTIMIZATION (SSO):**

Social Spider Optimization (SSO) is a metaheuristic optimization algorithm that emulates the social behaviour of spiders, especially their web-spinning and cooperative behaviours. For Wireless Sensor Networks (WSN), SSO utilizes these social behaviours to support anomaly detection and communication within the network. In this algorithm, every node is a spider, and they cooperate by exchanging information to detect and isolate any suspicious or anomalous behaviour in the network. Based on a spider colony's intelligence, the SSO strategy effectively balances exploration and exploitation to maximize WSN communication, detect hostile activity, and reduce false alarms, increasing the system's resistance to attacks. The first step of this method is to use equation 4 to update the exploration and exploitation positions.

(4)

We'll introduce the following variables: x for the spider, j for the solution, p for the position, β for the strength of attraction towards the global optimum solution, stressing exploitation, γ as the stochastic factor controlling the random vector S to avoid premature convergence, and J best as the best solution. This equation updates the position of every spider in the search space by blending movement towards the best solution so far (exploitation) with random exploration. This technique is meant to move the spiders closer towards the best-known solution and explore other areas in the search space to find potentially better solutions. This guarantees a balance between optimizing current solutions and venturing into new possibilities. After this, we use the attraction model to enable spiders' communication, as stated in equation 5.

(5)

Let B be the attraction model, x and y be spiders, u be the fitness weights, and ‖Jx - Jy‖ be the Euclidean distance between spiders x and y such that nearby spiders have a larger impact on one another. The equation replicates the social interaction between the spiders, illustrating how they communicate and cooperate based on distance and fitness. Spiders that are nearer to one another and have greater fitness values have a greater impact on each other, promoting cooperative behaviour in the more favourable areas of the search space. This behaviour is similar to how actual spiders react to vibrations in their webs due to neigh boring individuals. They use equation 6 to compute each spider's fitness based on its location in the search space and the associated objective function value.

(6)

Let us assume that represents the objective function's value at the spider's position, with lesser values usually expressing better solutions (for minimization problems). The equation normalizes the fitness measures so that their values are all positive and equivalent. The more optimal solutions will be assigned by spiders with increased fitness weights. This difference enables the optimization process to give more importance to individuals which are performing better, leading the swarm towards the global optimum. From equations 6 and 7, we update the male and female spider positions accordingly.

(7)

Let us denote as the best female spider position, α as the control parameter for attraction strength to the best female spider, and as the randomness factor that keeps the swarm from becoming stuck in local opticalities. Here, we update the male spider's position. Male spiders mostly follow the best-performing female spider within the swarm, exploring prospective areas of the search space. They are intensifiers, taking their efforts in narrowing down solutions that have been discovered by the leading female spiders. The presence of random perturbations in this case helps the male spiders occasionally stray and add diversity to the search. Subsequently, we update the female spider's position.

(8)

Let E be the neighboring spiders within a certain distance. The female spiders traverse the search space by exchanging information with their neighbors and using the attraction model for improving solutions in collaboration. Since female spiders are the major explorers, they exchange information with numerous individuals in an effort to create a diversified and distributed search process. By exchanging information, the search space is traversed by different parts of the space. In an effort to identify when to stop the optimization process, we use a stopping criterion function, as shown in equation 8. The function stops the process immediately after convergence, hence there is no wasteful computation,

(9)

Let us assume ϵ to be a minor threshold value, usually user-specified, to represent a minimal deviation from the optimal solution. These equations represent a step of the SSO algorithm, while emulating the socially intelligent behavior of spiders in solving optimization problems, including problems caused by WSN communication. In order to demonstrate that the swarm has converged to the global optimum, the process is repeated until the quality of improvement of the optimal solution is almost nil. This method allows for effective computing without sacrificing the calibre of the result. By adding position updates, communication models, and fitness-based interactions, SSO achieves the best possible balance between exploration and exploitation, steering the search through the solution space.

Male-female labor division increases diversity, targeting promising regions of the search space, and mimicking cooperative behaviors in actual spider colonies. SSO minimises false alarms, detects issues, and computes system parameters optimum in WSN communication. The algorithm works well for real-time network security problems since its core idea is to imitate cooperative behavior and learn to adapt in changing situations. Therefore, SSO converges to the solution without sacrificing accuracy and is computationally efficient. Thus, it is a viable solution for enhancing WSN communication and optimizing the performance of such systems.

**Low-Energy Adaptive Clustering Hierarchy (LEACH)**

In order to balance node energy consumption and extend the MLC of WSNs, clustering-based routing algorithms, like the low-energy adaptive clustering hierarchy (LEACH), can dynamically create clusters and randomly choose CHs in each cycle. But without energy harvesting, nodes' energy would eventually run out. The node can hardly function in the energy-harvesting mode for EH-WSNs. Therefore, one of the key issues in achieving continuous network coverage is the design of the transmission modes based on the environment-adaptive node cluster.

This work proposes a distributed data transmission mode modification strategy that aims to optimise the data transmission mode of the WSN nodes. Depending on the amount of energy left, the cluster head node might switch places, and the depleted node could be recharged in time for the subsequent cycle. To ensure the regular functioning of WSNs with high energy efficiency, each cluster may adaptively carry out the distributed control of the data transmission mode to restrict the number of sleeping nodes in each data collection cycle. Therefore, the suggested HCEH-UC routing algorithm can achieve continuous coverage of the target area for EH-WSNs.

Data transmission up to a specific distance can be supported by the amplification constants, efs and emp, which reflect energy expenditure during signal amplification. As a result, these constants are connected to both the transmission distance and the size of the data.

is a symbol for the energy consumption of the radio transmission and reception modes. The channel transmission model states that the transmission's energy usage would be equal to the square of the distance.

The literature states that a wireless channel propagation model is established using the free space and multipath attenuation models, and that the energy consumption for transmitting y -bit data can be explained as shown in equation 10:

(10)

where represents the distance threshold, represents the transmission distance, The transmission energy is represented by , while the amplification energy needed to send data to a distance of is represented by as shown in equation 11:

(11)

Simultaneously, (11) can be used to illustrate the energy needed to receive of data as shown in equation 12:

(12)

Data transmission and reception, as well as the creation and upkeep of the routing structure, are all included in the cluster head node's energy consumption, which shows that it uses significantly more energy than the other cluster nodes. After a full data transmission cycle, the cluster head node must sleep and use energy harvesting in order to take part in the following cycle and maintain continuous WSN coverage. The cluster's remaining node energy and node location data are used to choose the successor cluster head node.

The energy consumption of the cluster head nodes in a single cycle in the network depicted in comprise the energy consumption used to receive data from the nodes, the energy consumption EDf used for data fusion, and the energy consumption used to send the data package to base station. These can be characterised as shown in equation 13:

(13)

where stands for the data fusion energy consumption constant. Assume that in a single data transmission cycle, node sends bits of data to the cluster head nodes, as shown in equation 13.

(14)

As a result, the th node's energy usage for transferring this data may be explained as follows equation 14.

(15)

operation, in order to gather energy, the worn-out cluster head node should transform into the sleep node. The data delivery task can hardly be carried out by the sleep node. Thus, depending on the location data and condition of the other nodes in the cluster, the suitable node would be chosen as the new cluster head node with the goal of achieving uninterruptible target coverage with energy harvesting (UC-EH). Assume that the energy usage of data transmission for various nodes is represented by the Estimation as shown in equation 15.

(16)

where the energy necessary for the cluster head node to send data to the base station and the energy required for nodes to transmit data to the cluster head are included in the . Assume that the likelihood of being chosen as a cluster head for the th is represented by r, and that can represent the remaining node energy as shown in equation 16:

(17)

In the current data transfer cycle, stands for the set of nodes that have not been chosen. The estimate rises as the nodes go farther away from the cluster head base station and cluster head node. To ensure that the node with the highest probability r becomes the successor C, there should be a minimal amount of energy needed for data distribution to the successor cluster head and enough energy left over in the successor cluster head as shown in equation 18:

(18)

where Eqs represents the energy expenditure when sending data to the successor cluster head as a non-cluster head node, and EBs represents the energy consumption when the node s is chosen as the CH. Assume that sE is the necessary charging time up to ED and that DT is the time needed to finish gathering data for a single cluster. If the network has enough sensor nodes, it can operate continuously under specific energy harvesting circumstances and the cluster head node's operating mode. However, the network would use more energy as a result of the redundancy issue. The necessary condition to guarantee the network's regular functioning might be shown as.

(19)

states that a minimum of Q nodes are needed to maintain the network's regular operation based on node location, communication details, and energy collection efficiency. This could guarantee that the cluster head node in sleep mode has enough time for energy collection to support the WSNs' operations.

**4. Result and Discussion**

In this segment, the uses of the IENCHR protocol that has been proposed will be discussed. The resource allocation platform's WSN, which is cloud-based, improves the network's durability. We present numerical results to compare the proposed algorithm with existing schemes in IPENCHP. Also, after analysing the energy consumption of cluster communication, we offer to use the IPENCHP protocol to reduce energy consumption and restore network lifetime. Various parameters, including performance, energy efficiency, packet delivery speed, and packet loss efficiency, and network lifetime, can determine the accuracy of cloud-based resource management.

**Simulation Parameter**

|  |  |
| --- | --- |
| **Parameter** | **Value** |
| Language | NS2 |
| Energy | 0.5J |
| Initial Energy | 1J |
| No of Nodes | 400 |
| No of Packet | 4000bit |
| Threshold Distance | 75m |
| Transmission Radius of nodes | 20m |
| Network coverage area | 200X200 |
| Transmitter electronic Energy | 40 nJ/bit |
| Data aggregation energy | 5nJ/bit/signal |

According to Table 1, the simulation parameter models being discussed can be achieved in NS2 experimental findings. Through this analysis, the suggested method was able to optimize both energy efficiency and data optimization.

In Figure 3, we can see that WSN utilizes cloud-based resource management to conserve energy and prolong the life of the network. Throughput analysis is utilized to enhance accuracy. LEACH protocol accuracy is 59% greater than the SSO, and HC techniques discussed in the literature review. The LEACH management algorithm considers node distance. It can provide multiple weighting factors by considering the nodes' continuity energy for BS and CH conversion and evaluating the importance of distance and power on structural response.

**Figure 4. Analysis of Performance Latency**

Figure 4 illustrates the methods used in quantifying the performance of resource management using performance latency. In comparison with three other approaches, its performance delay measuring accuracy was increased by 70%. Moreover, in comparison among different types such as SSO, and HC, their accuracy was also enhanced. Cloud-based resource management assignment in WSN is advantageous because it saves energy and prolongs the network life.

Figure 5 shows that WSN employs cloud-based resource allocation to reduce energy usage and enhance the network's lifespan. The packet delivery rate serves as a metric for evaluating resource management efficiency. After analysing the accuracy of packet delivery rates in the literature using SSO, and HC methods, it is evident that their accuracy has improved. However, their accuracy is still 56% lower than the suggested LEACH.

[1] Daanoune, Ikram, Abdennaceur Baghdad, and Waheed Ullah. "Adaptive coding clustered routing protocol for energy efficient and reliable WSN." Physical communication 52 (2022): 101705.

[2] Behera, Trupti Mayee, et al. "Energy-efficient routing protocols for wireless sensor networks: Architectures, strategies, and performance." Electronics 11.15 (2022): 2282.

[3] Karthikeyana, A. P., and K. Senthilkumara. "GENETIC ALGORITHM OPTIMISED LEACH PROTOCOL FOR ENERGY EFFICIENCY IN WIRELESS SENSOR NETWORKS." ACTA SCIENTIAE 7.1 (2024): 117-130.

[4] Mittal, Nitin, Urvinder Singh, and Balwinder Singh Sohi. "A stable energy efficient clustering protocol for wireless sensor networks." Wireless Networks 23 (2017): 1809-1821.

[5] Bhola, Jyoti, Surender Soni, and Gagandeep Kaur Cheema. "Genetic algorithm based optimized leach protocol for energy efficient wireless sensor networks." Journal of Ambient Intelligence and Humanized Computing 11 (2020): 1281-1288.

[6] Rami Reddy, M.; Ravi Chandra, M.L.; Venkatramana, P.; Dilli, R. Energy-Efficient Cluster Head Selection in Wireless Sensor Networks Using an Improved Grey Wolf Optimization Algorithm. Computers 2023, 12, 35.

[7] Roberts, Michaelraj Kingston, and Poonkodi Ramasamy. "Optimized hybrid routing protocol for energy-aware cluster head selection in wireless sensor networks." Digital Signal Processing 130 (2022): 103737.

[8] Qureshi, Kashif Naseer, et al. "Optimized cluster‐based dynamic energy‐aware routing protocol for wireless sensor networks in agriculture precision." Journal of sensors 2020.1 (2020): 9040395.

[9] Kaviarasan, Solayan, and Rajkumar Srinivasan. "Developing a novel energy efficient routing protocol in WSN using adaptive remora optimization algorithm." Expert Systems with Applications 244 (2024): 122873.

[10] Pradeep, S., et al. "Energy efficient routing protocol in novel schemes for performance evaluation." Applied System Innovation 5.5 (2022): 101.

[11] Jaffri, Zain ul Abidin, et al. "TEZEM: A new energy-efficient routing protocol for next-generation wireless sensor networks." International Journal of Distributed Sensor Networks 18.6 (2022): 15501329221107246.

[12] El-Fouly, Fatma H., and Rabie A. Ramadan. "Real-time energy-efficient reliable traffic aware routing for industrial wireless sensor networks." IEEE Access 8 (2020): 58130-58145.

[13] Tang, L.; Lu, Z.; Fan, B. Energy Efficient and Reliable Routing Algorithm for Wireless Sensors Networks. Appl. Sci. 2020, 10, 1885.

[14] Yun, Wan-Kyu, and Sang-Jo Yoo. "Q-learning-based data-aggregation-aware energy-efficient routing protocol for wireless sensor networks." IEEE Access 9 (2021): 10737-10750.

[15] Xie, Jiazu, Baoju Zhang, and Cuiping Zhang. "A novel relay node placement and energy efficient routing method for heterogeneous wireless sensor networks." IEEE Access 8 (2020): 202439-202444.

[16] Almazaideh, Mohammed, and Janos Levendovszky. "Novel reliable and energy-efficient routing protocols for wireless sensor networks." Journal of Sensor and Actuator Networks 9.1 (2020): 5.

[17] Mehbodniya, Abolfazl, et al. "Proportional Fairness Based Energy Efficient Routing in Wireless Sensor Network." Computer Systems Science & Engineering 41.3 (2022).

[18] Hu, Huangshui, et al. "Trust based secure and energy efficient routing protocol for wireless sensor networks." IEEE access 10 (2021): 10585-10596.

[19] Daanoune, Ikram, Abdennaceur Baghdad, and Abdelhakim Ballouk. "An enhanced energy-efficient routing protocol for wireless sensor network." International Journal of Electrical & Computer Engineering (2088-8708) 10.5 (2020).

[20] Aydin, Muhammed Ali, Baybars Karabekir, and Abdül Halim Zaim. "Energy efficient clustering-based mobile routing algorithm on WSNs." Ieee Access 9 (2021): 89593-89601.