LOW EFFICIENT ADAPTIVE CLUSTERING HIERARCHY METHOD FOR ENERGY EFFICIENT ROUTING IN WIRELESS SENSOR NETWORKS

**Abstract:**

Wireless sensor networks (WSNs) consist of many sensor nodes that can sense data from where they are placed and send this to the gateway in energy efficient links for monitoring or processing. The present of approach to clustering through the Low Efficient Adaptive Clustering Hierarchy (LEACH) method, which aims to improve the energy efficient routing in WNS. Cluster Header is a term commonly used in wireless sensor networks (WSNs) and mobile networks, especially in the context of aggregation protocols. In this type of network, data from a sensor node is sent to a central location for aggregation, processing, or sharing. Social spider optimization (SSO) is a fairly recent swarm-based optimization algorithm motivated by spiders' social behaviour, specifically how they create colonies, communicate, and collectively search for food. This is a heuristic optimization method and is mainly utilized to solve optimization problems that are complicated or hard to solve with conventional methods. 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. The HC method is used to find the energy-efficient, and then SSO algorithms are used to select the cluster Head. The LEACH method is used to efficiently transmit data and then reduce energy consumption. The simulation result, purpose method contains.

**Key words:** Energy Efficient (EE)**,** Network Life Time (NLT),Low Efficient Adaptive Clustering Hierarchy (LEACH), Social spider optimization **(**SSO),Clustering (C), Routing(R).

**1. Introduction**

Wireless sensor networks (WSNs) consist of many sensor nodes that can sense data from where they are placed and send this 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 CH(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]. CH(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) is created to improve Wireless Sensor Networks' (WSNs') energy efficiency. The clustering principle underlies LEACH's operation, in which sensor nodes join together and a 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. 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 CH by the hierarchical LEACH protocol, which then collects, compresses, and transmits the data to the target node.[5]. This component seeks to enhance the network service life and reduce energy use. In order to solve these problems, first select the best CH from the list of accessible nodes using LEACH. These can be utilised to determine how much energy left and distance of a node from its neighbours.

**2. Literature Survey**

A highly dynamic CH selection framework based on GWO efficiency (EECHIGWO) solves the problems of demand-service mismatch, reduced isolation, and rapid convergence in the GWO framework. This study aims to maximize the energy consumption, flow, traffic, and traffic lifetime in WSNs by using EECHIGWO for optimal CH selection. Although the proposed BEA-SSA model shows good performance in terms of power output, RSSI, and PDR, ther still has some limitations. In this main drawback is the lack of fault tolerance, which is critical for the robustness of WSNs.[6].

Through the resolution of problems in the CH selection process, this research suggests the golden eagle optimisation algorithm and enhanced grasshopper optimisation algorithm based on the energy efficient cluster-based routing protocol 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 is not fault tolerant, since the research does not explain how the protocol deals with unforeseen node failure or energy exhaustion of CH. [7].

This study suggests a Gateway Clustering Energy-Efficient Centroid based routing protocol in which CHis chosen from the centroid location and gateway nodes are chosen from every cluster. Gateway node minimizes the data burden from CHnodes 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 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 CH, the leader node. The Adaptive Remora Optimization Algorithm is used for the election of the CH, considering parameters such as energy, distance, throughput, Packet Delivery Ratio and path loss. The protocol enhances the selection of CH by positioning they close to the energy centroid and using a gateway node for multihop transmission, thereby lowering the CH load. And the 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].

WSN have limited processing capacity, storage, bandwith, and data transfer. Energy-efficient strategies are essential to optimize their lifespan and performance. The 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 GCEEC to optimize load balancing, energy efficiency, and network lifespan. The protocol optimizes CH selection by locating and near the energy centroid and using a gateway node for multihop communication, reducing the workload of the CH. [10].

Technique, the dot-stretching procedure is used to test threshold-sensitive spatial efficiency. As a result, threshold-based protocols and diverse sensing are the suggested problems for next-generation wireless sensor networks. According to the simulation results, the threshold-based energy-aware node integrity enhances the method's performance in terms of detection, lifetime, and network stability.[11].

Research on real-time routing algorithms that are suitable for real-time applications and balance reliability and energy efficiency. In order to optimize the large-scale IWSN problem, first convert the real-time routing problem into a 0/1 integer-time linear programming (ILP) problem, and then propose a real-time energy-efficient traffic authentication technique (RTERTA) according to the simulation results. Considering these factors, and the believe that real-time applications can be implemented and the overall performance of WSNs can be improved.[12]

Therefore, a more efficient and effective delivery system requires higher QoS. Dempster–Shafer (DS) proof theories require less knowledge and can predict the performance of sensor nodes under reasonable assumptions. Experimental and simulation results show that DS-EERA is an effective method that can increase the system lifetime. They can reduce the risk of packet loss and increase the reliability of data transmission. [13].

The book points out that most traditional methods consider routing path selection and data aggregation to be independent considerations. In this study, consider the potential data aggregation level of neighboring nodes when a node needs to decide on a routing path. The propose a new data aggregation-aware energy-efficient routing algorithm based on Q-learning. The results show that protocol exploration can effectively reduce data and extend the lifetime of wireless sensor networks. The protocol study of Q-DAEER is characterized by low energy consumption and long network lifetime under dense node conditions in random and grid topologies. [14].

The proposed invention solves the routing problems of relay node placement and energy storage in HWSN. These issues are rarely discussed simultaneously in the literature. This study establishes for the first time a mathematical model for these phenomena. The report demonstrates that whale enhancement strategies impact three adaptation strategies. Numerical simulations confirm the proposed HWSN method. This technique can raise the cost of relay nodes while lowering the energy usage for data transmission in a global HWSN. [15].

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

The Energy-Aware Rational Multi-User Routing (EPFMR) framework for WSNs is an energy-aware routing system developed in this study. Timing is used to implement EPFMR in the WSN environment. In WSNs, proportional fair routing determines the optimal routing channel for a packet flow based on the ratio of request durations in different SNs. In this section, and consider two existing techniques for WSNs, TULA and SCF, and compare them with the innovation of the EPFMR framework.[17].

The novel reports trust-based security energy-efficient method of routing to overcome these problems. TBSEER's adaptive direct, indirect, and energy trust values ​​are used to calculate the overall trust value, which is not affected by hello flooding, sinkholes, black holes, and selective forwarding attacks. Based on simulation data, the proposed TBSEER network reduces energy consumption, accelerates the identification of malicious nodes, and avoids common threats.[18].

In this context, energy efficiency is a factor that has attracted many researchers. In this study, a new improved LEACH routing protocol is proposed. This proposed protocol is based on the current energy to select cluster-heads, and use the root cluster-head with the highest current energy and the shortest distance to the sink to collect all the data, and then sends it to the sink. By using these measurements, this format of communication lowers the network's energy usage and increases the WSN network lifetime. In this paper, of contribution is the improved LEACH algorithm. The overall objective of the proposed protocol is to select the CH according to the residual energy of the nodes to avoid the participation of nodes with low energy as CH. [19].

The random distribution area for sensor nodes is partitioned into clusters. The node with the highest residual energy that is closest to the cluster centre is known as the cluster head. 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 is tested only in a normal simulation environment ignoring dynamic real-world situations like drone-aided WSNs, wireless body area networks, or smart transportation systems. They flexibility towards high-mobility environments is unknown.[20]

**3. Proposed Methodology**

The initial process is 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 those who are part of the group together and sends and, 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. Routing protocols determine the best path based on 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—CHSelection, 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.

Nodes

HC

LEACH

Improve the Energy

Maximize the Network Lifetime

SSO

**Figure 1: Architecture Diagram for Proposed LEACH Method**

This method follows an energy-aware approach to improve the efficiency and lifespan of a WSN by using LEACH, adaptive energy management, and optimal path selection techniques.

**3.1 Hierarchical Clustering (HC):**

The HC algorithm is a proposed fast clustering technique. The combined clustering is performed independently based on the node location. During the clustering step, humans do not need to choose the CH or the number of clusters. To reduce human involvement, this study proposes an alternative context-adaptive hierarchical clustering technique. When WSN nodes cluster spontaneously, the clustering technique based on node adaptive ordering is completed. The coordinates of each node are assumed to be predefined, and also assumed that the N nodes are arranged as optimally as possible within the fitting area. According to Equation 1 of the hierarchical combination clustering method theory, these nodes will be considered as the original clusters.

(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. The two nearest clusters will then merge to produce a new cluster, and either the final requirement is satisfied or the necessary number of clusters is reached.

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)

This shows the startingth point and th nodes' coordinates as and the ratio of the lengths among nodes within a trusted distance is known as the practical factor, or s.

Below offers a comprehensive explanation of sigma. A trustworthy distance for reliable data transmission, , can first be established by employing sending data simulations in the real target area.

Subsequently, the gap 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 .

Increasing the distance between target nodes and increasing the reliability of the data transfer rate strengthens the clustering results and reduces the bias of the current cluster. Therefore, improving the node topology and trust distance improves node clustering, ensures reliable data transfer speed and maximum distance between nodes to complete the cluster and reduces the current gap. However, as the number of connections decreases, the number of data packets also decreases. They may need to adjust the height of the door. Therefore, adaptive distribution schemes can improve the MLC of WSNs by optimizing the node structure.

**3.2 Social Spider Optimization**

SSO is a metaheuristic efficiency algorithm that emulates Spiders' behaviour towards others, 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, use of 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. Based on each spider's position in the search area and the corresponding objective function value, they calculate its fitness using equation 6.

(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, to 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, too 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, the 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, to 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, by guiding the search over the solution space, SSO strikes the ideal balance amongst exploration and exploitation. Male-female labor division increases diversity, regions in search space that show promise, and mimicking cooperative behaviors in actual spider colonies. SSO minimizes 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, the viable solution for enhancing WSN communication and optimizing the performance of such systems.

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

In order to balance node energy consumption and extend the Network life Time of WSNs, The node can hardly function in the energy-harvesting mode for EH-WSNs. 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 CH 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 LEACH 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 amount of energy used by the radio modes of transmission and receiving. The channel transmission model states that the transmission's energy usage would be equal to the square of the distance.

The equation 10 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,

(10)

where represents the distance threshold, represents the distance of transmission, The transmission energy is represented the , 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 required to receive bit of data as shown in equation 12:

(12)

Transmission and receipt of data, as well as the creation and upkeep of routing structure, are all included in the CH node's energy consumption, which shows that it uses significantly more energy than the other cluster nodes. After a full data transmission cycle, the CH node must sleep, use collecting energy 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 CH node.

The energy usage of the CH nodes in a single cycle in the network depicted in comprise the energy consumption used to receive data from the nodes, the power consumption used for data fusion, and the power usage used to send the data package to BS. 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 CH 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 CHnode 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 CHnode with the goal of achieving target that cannot be interrupted, coverage with energy harvesting. Assume that the power usage of data transmission for various nodes is represented by the Estimation as shown in equation 15.

(16)

where the energy necessary for the CH to send data to the BS and the energy required for nodes to transmit data to the CH are included in the . Assume that the probability of being selected as a CH 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, the collection of unchosen nodes is represented by the letter C. The estimate rises as the nodes go farther away from the CHbase station and CHnode. To guarantee that the successor CH is the node with a highest probability , there should be a minimal amount of energy needed for data distribution about the successor CH and EE left over in the successor CHas shown in equation 18:

(18)

where EBs is the energy usage when node s is selected as the CH, and is the energy expenditure when delivering data to the successor CH as a non-CH node. Assume that Es 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, can be operate continuously under specific energy harvesting circumstances and the CH 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 CHnode in sleep mode has enough time for energy collection to support the WSNs' operations.

**4. Result and Discussion**

The applications of the proposed LEACH protocol will be discussed in this section. To compare the proposed approach with existing RTERTA schemes, to present numerical results. Furthermore, after studying the energy consumption of cluster communication, to lower energy usage and increase network longevity, the suggest implementing the LEACH protocol. The accuracy of resource management can be determined by many factors such as network lifetime, throughput, energy efficiency, packet delivery rate, and packet loss performance.

**Parameter for Simulation**

|  |  |
| --- | --- |
| **variable** | **Significant** |
| Language | NS2 |
| Vitality | 0.5J |
| First Power | 1J |
| Number of Nodes | 400 |
| Packet Number | 4000bit |
| Threshold Range | 75m |
| Nodes' Transmission Radius | 20m |
| Area covered by the network | 200X200 |
| Electronic Energy Transporter | 40 nJ/bit |
| Aggregation energy of data | 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 is able to optimize both energy efficiency and data optimization.

**Figure 2: Analysis in Throughput**

Figure 2 shows how a WSN uses cloud-based resource management to save energy and extend network lifetime. Using performance analysis improves accuracy. The accuracy of the LEACH protocol is 59% higher than the RTERTA and EPFMR methods included in the literature review. The LEACH management system takes into account the distance between nodes. By taking into account the continuous energy of the nodes to switch BS and CH and evaluating the importance of power and distance in the structural response, different weight variables can be provided.

**Figure 3: Analysis of Performance Latency**

Figure 3 illustrates the methods used in quantifying the performance of resource management using performance latency. In comparison with three other approaches, and the performance delay measuring accuracy to increased by 70%. Moreover, in comparison among different types such as RTERTA and EPFMR, their accuracy also enhanced. WSN's resource management assignment is beneficial since the increases network lifespan and conserves energy.

**Figure 4: Analysis of Performance Latency**

This figure shows the effect of three routing protocols, RTERTA, EPFMR, and LEACH, on transmitting data in a wireless sensor network (WSN). Packet Delivery Ratio (PDR) indicates how many packets successfully reach their destination. LEACH performs best at 100 nodes, which means also can deliver more packets. Both RTERTA and EPFMR perform well in this regard. However, as the number of nodes increases, the PDR of all protocols decreases. This occurs due to network congestion, packet loss, and energy consumption. EPFMR performs best on nodes, while LEACH has the lowest PDR and performs poorly when the number of nodes is large. RTERTA is somewhere in between. LEACH is more suitable for small networks, but EPFMR is more reliable for large networks with complex congestion. However, their accuracy is still 56% lower than the suggested LEACH.

**Figure 5: Analysis of Energy Consumption**

Figure 5, Extending the network's lifespan and lowering energy use. Several methods are used to gauge how healthy resources are managed for energy usage. They found, after the investigation of several methods such as RTERTA and EPFMR, that the usage of energy consumption contributes to greater precision. Further, the precision of energy consumption decreases to 70% in a comparison between the suggested LEACH and the remaining three approaches.

**Figure 6: Study of Packet Loss Efficiency**

Figure 6 shows several techniques for evaluating the impact of resource management on packet loss performance. After comparison, to found that the accuracy of various methods such as RTERTA and EPFMR has improved. Furthermore, found that the packet loss rate of the LEACH protocol is only 43% lower than the other three techniques.

**Figure 7: Survey of Energy Efficiency**

A number of methods for evaluating node and energy efficiency resource management performance are shown in Figure 7. Further, these node-based resource allocation in WSN helps reduce energy consumption and extend network lifespan. Thus, the accuracy of energy efficiency when testing the proposed LEACH protocol increased their estimate to 93%.

**Figure 8: Network Lifetime Analysis**

In this figure 8, three protocols, LEACH, RTERTA, and EPFMR, are compared in terms of their performance on 100-400 sensor nodes. LEACH (purple) performs best and has the most extended network lifetime. EPFMR (green) performs poorly, consumes energy quickly, and reduces network lifetime. As the number of nodes increases, the trend remains the same: LEACH is the best, RTERTA is intermediate, and EPFMR has the lowest performance. This indicates that LEACH is highly scalable and is well suited for long-term WSN applications.

**5. Conclusion**

This study proposes an energy-efficient routing strategy for WSN by combining the LEACH technique with Social Spider Optimization (SSO). The strategy improves network longevity, minimizes energy expenditure, and enhances data transmission efficiency. Through the utilization of SSO, the system optimally resolves the exploration-exploitation trade-offs, achieving dynamic adaptability in sensor node communication. The LEACH-based clustering scheme allows for best CH selection, minimizing energy drain and communication overhead. Furthermore, the LEACH protocol further optimizes energy efficiency with intelligent resource management, maximizing data transmission and network stability. According to simulation results, the approach outperforms conventional techniques in terms of transmission latency, energy economy, packet delivery speed, and network lifetime. In summary, combining SSO with LEACH clustering provides an adaptable and scalable approach to WSNs with continual network coverage, effective data transportation, and an increased sensor node lifetime. Incorporating fault tolerance mechanisms as the focus for future work may aid in improved resiliency toward node loss, as well as enhanced adaptation processes for massive implementation.

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