ACTA SCIENTIAE
ISSN: 2178-7727
DOI: 10.17648/acta.scientiae.6369

GENETIC ALGORITHM OPTIMISED LEACH PROTOCOL FOR ENERGY EFFICIENCY IN WIRELESS SENSOR NETWORKS

A. P. Karthikeyan[a] & K. Senthilkumar[a]*
[a]Department of Electronics and Communications Engineering, Dr. MGR Educational and Research Institute, Maduravoyal, Chennai, Tamil Nadu, India.

**Corresponding author:*
K. Senthilkumar,
Professor, Department of Electronics and Communications Engineering,
Dr. MGR Educational and Research Institute, Maduravoyal, Chennai, Tamil Nadu, India

Abstract
Research in wireless sensor networks (WSN) has traditionally prioritized characteristics such as extensive integration, energy efficiency, and energy consumption. Researchers are highly enthusiastic about energy-efficient solutions, since they have the potential to conserve energy in sensor-nodes in energy constraint environment. Conserving energy is a major obstacle that WSNs face, and it plays a critical role in determining the network's longevity. WSN protocols encompass several approaches, but clustering-based hierarchical routing protocols are particularly emphasized because of their enhanced scalability. Sensors, being battery-operated, often have constraints in terms of available energy, which is often fixed and cannot be altered in most cases. The Low Energy Adaptive Clustering Hierarchy (LEACH) protocol is extensively employed as an energy-efficient solution for sensor networks. This study involved the development of an enhanced LEACH protocol using genetic algorithm (GA) optimization. Analytical study and simulations utilizing the MATLAB software environment were conducted to evaluate the performance of the proposed GAO-LEACH methodology. The assessment technique incorporated metrics such as latency, throughput, energy usage, and Packet Delivery Ratio. The simulation findings indicate that the suggested GAO-LEACH strategy has exhibited greater performance when compared to other techniques such as the classic LEACH method and Distributed Energy Efficient Clustering (DEEC) methodology. Comparing the GAO-LEACH technique with the regular LEECH protocol, the findings demonstrated significant improvements. The GAO-LEACH strategy exhibited a staggering 22.38% increase in throughput, 27.71% increase in Packet Delivery Ratio, 80.09% decrease in energy consumption rate, and 46.37% reduction in network latency.

Keywords: Wireless sensor network; energy-efficiency; LEACH; DEEC; Ggenetic Algorithm

1. Introduction
Wireless sensor networks (WSNs) are comprised of many compact, battery-powered sensors that are commonly used to collect diverse and valuable data from the surrounding environment. These sensors detect physical attributes, such as sound, humidity, pressure, brightness, temperature, or

chemical concentration, and send the collected data to a base station (BS) for additional analysis and processing. Wireless Sensor Networks (WSNs) have been successfully utilized in many scenarios such as tactical warfare situations, habitat monitoring, home security, and more [1-5]. Given that Wireless Sensor Networks (WSNs) are comprised of several sensors that have limited energy resources, it is crucial to prioritize the implementation of an energy-efficient network protocol in WSN applications.
Several routing protocols for Wireless Sensor Networks (WSNs) have been documented in the literature. In applications utilizing direct transmission (DT) protocols [6], sensor nodes broadcast their detected data directly to a base station (BS). Therefore, the nodes that are situated at a significant distance from the base station would experience rapid depletion of their energy reserves because to the high energy consumption involved in transferring data packets. Direct transmission (DT) protocols exhibit inefficiency due to the quick depletion of energy levels in nodes when the base station (BS) is situated at a considerable distance. Alternatively, minimal transmission energy (MTE) protocols [7, 8] use multi-hop relay to deliver data packets to the base station (BS). Consequently, nodes in close proximity to the base station (BS) experience rapid depletion since they are burdened with the task of transmitting a large amount of data on behalf of distant nodes. Undoubtedly, the use of DT and MTE leads to an inadequate allocation of energy consumption among nodes. Some subregions have had complete sensor node failure, whereas nodes in other regions remain operational. Consequently, there may be a failure to detect data for a specific portion of the sensor field.

2. Background and Related Work

Clustering is the inherent method to optimize the utilization of energy in networks and prolong the lifespan of Wireless Sensor Networks (WSNs) [9]. In the cluster-based technique, nodes are distributed randomly to available clusters, resulting in clusters of different sizes due to the random distribution of nodes. Each cluster consists of a single Cluster Head (CH) and many nodes. The CH collects data packets from the cluster members, merges them, and subsequently transmits them to the relevant destination. Due to the significant energy consumption of these CHs, it is necessary to maximize the quantity of CHs. In addition, the uneven distribution of nodes in the cluster leads to increased energy consumption for densely loaded CH, which in turn reduces the lifetime of the WSN [10] [11]. Consequently, several research have suggested energy-efficient approaches for cluster-based routing in order to distribute the workload evenly among all CHs [12- 15] . Clustering algorithms have made it possible to decrease energy usage and extend the lifespan of networks by minimizing congestion through power management or node scheduling. However, achieving scalability is still a difficult task.
The remaining portion of the article is structured in the following manner. Section 3 provides an overview of the LEACH and DEEC procedures. The problem addressed in this paper is presented in section 4. Section 5 discuss on the materials and methods, followed by an exposition of the outcomes and analysis of the simulation in section 6. Section 7 serves as the final part of the current work and includes a discussion of the results and conclusions.

3. LEACH and DEEC Protocol

Heinzelman et al. [16] proposed the Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol as an effective solution to resolve the issues related with energy consumption in the WSN. LEACH protocol works by forming clusters in which the elected cluster heads (CH) gather and aggregate the data collected by their member nodes in the cluster before transferring it to the base station. The CH acts as the leader of the cluster for a specific period of time called "round". At the start of each round, each node of the network determines whether it complies with the protocol. The node becomes CH if this number is smaller than a threshold T(n). The threshold T(n) is given by the relation:

$$T(n) = \frac{p}{1 - p * \left[r mod \left(\frac{1}{p}\right)\right]}, n \in G \tag{1}$$

With p representing the proportion of CHs in the network, r representing the number of the current round, and G representing the number of nodes that were not chosen as CHs in the previous 1/p rounds. Once the clusters are created, each CH broadcasts its identifications to the network's nodes using the CSMA protocol and assigns a time interval to each member node of its cluster using the TDMA technique. The main goal of LEACH was to use rotational based cluster head (CH) selection method to save energy in the network. First, all of the network's CH are chosen, and then clusters are constructed in a dispersed way. Every round, the cluster head is changed, and once chosen, the cluster head does not have another opportunity for the following 1/p rounds. Cluster heads are rotated and clusters are reassembled after each round (Fig. 1). The disadvantage of the LEACH is that the CH selection procedure was random, and the energy aware parameter was not included.

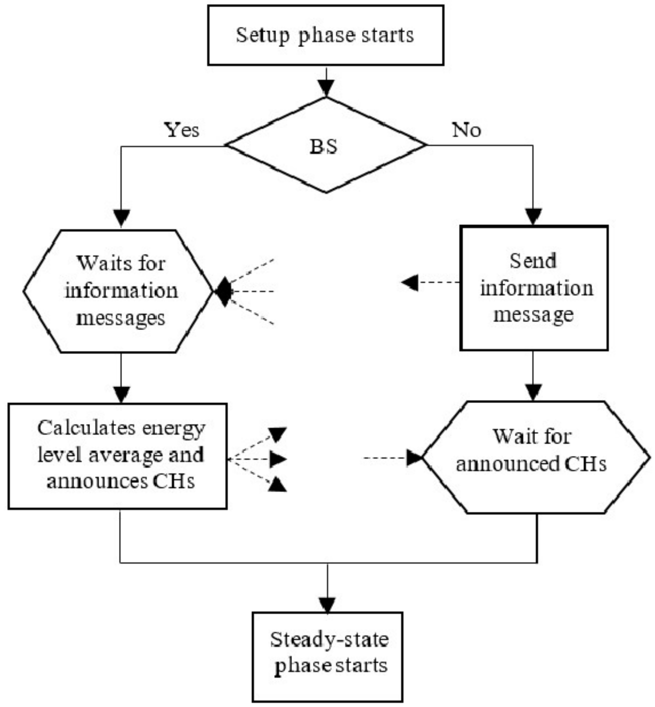

Fig. 1 Setup Phase of LEACH (Heinzelman *et al.* 2000)

Qing et al. [17] have proposed a new distributed energy-efficient clustering (DEEC) strategy for heterogeneous wireless sensor networks that we propose and analyse. The cluster-heads in DEEC are chosen using a probability based on the ratio of each node's residual energy to the network's average energy. The epochs in which nodes are cluster-heads differ depending on their initial and residual energy. Cluster-heads will be more likely to be nodes with high initial and residual energy than nodes with low energy. Overall, simulated results reveal that DEEC achieves longer lifespan and more effective messages in diverse settings than existing essential clustering techniques.

4. Problem Statement - Genetic Algorithm Based LEACH

In this work, the proposed task of selecting CH was performed using the genetic algorithm (GA). Genetic Algorithm (GA) is considered to be one of the most exceptional optimization techniques. Genetic algorithm (GA) has been utilized to address computational issues that are classified as NP-hard. Existing literature demonstrates that Genetic Algorithms (GAs) have been effectively utilized for the selection of CH (Cluster Head) [18 - 20]. This study employs a Genetic technique (GA) as the chosen metaheuristic technique to enhance network performance. Genetic Algorithm (GA) is an algorithm used for search and optimization purposes. It continues to be one of the most often used optimization methods that involves looking for the most optimal solution. It substantially increases the process of optimization exploration by emulating the flexible evolution mechanism seen in nature [21]. Genetic algorithms (GA) have effectively been employed in a proactive manner to develop solutions for optimizing issues in several fields such as wireless networking, artificial intelligence, and biomedical engineering [22]. Genetic algorithms (GAs) are metaheuristic optimization algorithms that mimic the natural process of genetic selection and evolution. Initially, individuals are randomly picked as candidate solutions and then added to the population.. Afterwards, the individuals have progressed through many stages, which include selection, crossover, and mutation. A new population of individuals is generated by selecting the most suitable or qualified individuals. The preference for genetic algorithms (GAs) in metaheuristics is driven by their robustness and ability to do parallel calculations, in addition to their effectiveness in single point operations. Furthermore, it aids in circumventing the local optimum and facilitates the attainment of the global optimum solution. Genetic algorithms (GAs) can be employed to reduce the complexity of applications derived from derivative information by transferring the ability to the fitness function [23].

In general, LEACH protocol has been used in several past studies as a means to reduce energy consumption in sensor nodes and address the problem of excessive energy usage. The number of Cluster Heads (CHs) is the primary factor that affects the performance of the present LEACH routing system. When the concentration of CH (cluster heads) is low, each CH must cover large areas, which might result in some cluster members being far away from the CH and consuming more energy. The transmission between the CH (cluster head) and the base station (BS) consumes a higher amount of energy compared to regular nodes. Increasing the number of CHs might further increase the energy consumption of the overall network and reduce its lifespan. Therefore, it is necessary to select CH for reduced energy usage. GAO-LEACH utilizes GA to choose CHs with higher residual energy (Figure 3).

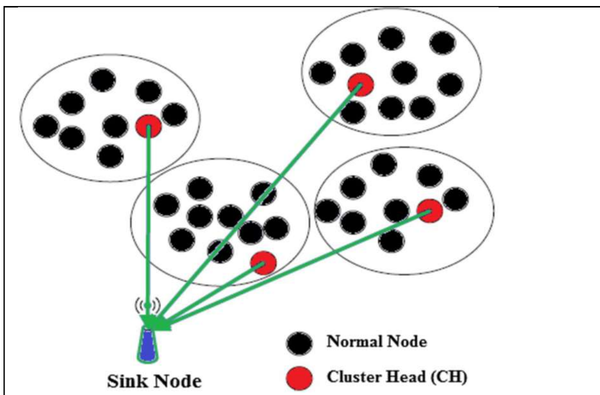

Fig. 2 Network topology of LEACH

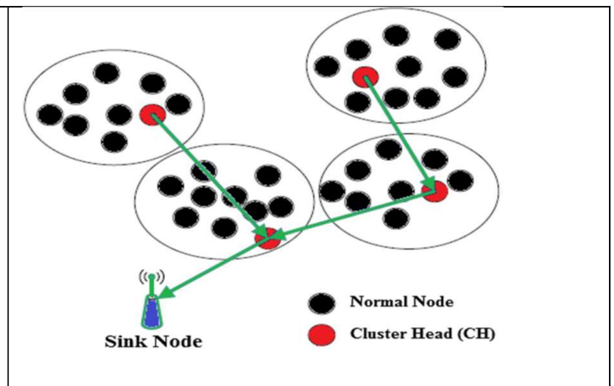

Fig. 3 Network topology of GAO-LEACH

The arbitrary selection of the LEACH algorithm might lead to an imbalance in the energy levels of the sensory nodes, which in turn increases the overall energy consumption of the system. In order to achieve a balanced energy distribution in the network, other criteria such as residual energy and spent energy for the sent data should be considered to optimize the process of selecting cluster heads. The primary objective of the upgraded CH selection algorithm is to prioritize nodes with higher residual energy over nodes with higher energy consumption when selecting cluster heads. The new threshold is defined as below:

$$T_{new}(n) = \frac{p}{1 - p * \left[r mod \left(\frac{1}{p} \right) \right]} * \frac{E_{ORE}}{E_{init}}, n \in G \tag{2}$$

E_{ORE} is the optimised residual energy for the communicating nodes and E_{init} is initial energy for nodes being generated during initialization of WSN. By utilizing the variable "$T_{new}(n)$", the ratio of nodes with lower residual energy acting as cluster heads (CH) decreases, while the ratio of nodes with higher residual energy acting as CH increases. The selection of CH is based on the increased residual energy.

5. Materials and Methods

This section provides a comprehensive discussion of the detailed processes involved in the methodology of the planned research effort. In order to enhance the effectiveness of the wireless sensor network, Genetic Algorithm (GA) was used in conjunction with the Low Energy Adaptive Clustering Hierarchy (LEACH) routing protocol. By utilizing the fitness function of GA, the node transmission may be determined more efficiently throughout the transmission process, resulting in reduced energy consumption. The procedure for the planned work is outlined below:

- **Step 1:** Create and implement a simulator to simulate the proposed Wireless Sensor Network (WSN) with specified network dimensions. The dimensions of the simulator are 1000 meters by 1000 meters.
- **Step 2:** Provide a description of N sensor nodes inside the network region for the simulator.
- **Step 3:** Provide a detailed description of both the source node and the destination node from the total number of nodes, denoted as N.
- **Step 4**: This step involves the selection of cluster heads for the network is done using Equation 1.
- **Step 5**: Initialize the coverage area of each node, which includes the source, destination, and CHs (Cluster Heads).
- **Step 6**: In this step, the route source and destination nodes are identified using the LEACH protocol, and the network's performance is evaluated. If performance of network is deteriorated then move to next step
- **Step 7**. Initialize the Genetic Algorithm (GA) using a fitness function in order to optimize the route based on the given fitness function. The fitness function of GA optimised LEACH algorithm is presented below:

$$f_{(GAfit)} = \begin{cases} 1, & f_{res} < f_{th} \\ 0, & f_{res} \geq f_{th} \end{cases} \tag{3}$$

Where f_{res} is the residual energy of selected node expressed as $\sum_{n=1}^{N} E_R(n)$ and f_{th} is the threshold energy of the communicating nodes expressed as $\sum_{n=1}^{N} \frac{E_R(n)}{N}$, where N is the number of nodes. The nodes with higher energy consumption are excluded from the route, and the route is adjusted in real-time to transport the data to the node with lower energy consumption utilizing the following step.

- **Step 8**: Here the optimal cluster head is chosen to optimize the route by utilizing Equation 2, which relies on the residual energy of each node. Once the best CH (Cluster Head) is selected inside the network, a reliable route is established to record the route together with its intermediate nodes. The notion of a trusted route is implemented in order to decrease the search time when data transmission is repeated several times between fixed source and destination nodes.
- **Step 9**: Store the optimal route, which includes the best cluster head, in the trusted route table.

The algorithm utilized in the proposed study is outlined below, along with the corresponding findings. Initially, the algorithm helped in identifying the communication nodes that possess the highest amount of energy.

Table 1 Algorithm for Determining Active Nodes

Input: Number of nodes with their properties
Output: Active nodes list
Calculate average EA using given equation

$$E_{active} = \frac{\sum_{init=1}^{N} E_{init}}{N} \quad (6)$$

If $E_{normal} > E_{active}$
Active Node = E_{normal}
Else
Dead Node = E_{normal}
End
Return: Active nodes list = Active Node
End

Using the improved LEACH routing protocol, the cluster head was determined based on the active node list. The optimized LEACH routing protocol is described below.

Table 2 Optimized LEACH

```
Initialize network with N nodes and base station
Set initial energy for all nodes
Set cluster head probability, p
For each round r:
  Reset cluster head eligibility if r mod (1 / p) == 0
  For each node i:
    Calculate threshold T(i) = p / (1 - p * (r mod (1 / p)))
    If rand < T(i) and energy(i) > threshold:
      Set node i as cluster head
  For each non-cluster head node j:
```

```
        Find and join nearest cluster head
    Cluster heads aggregate and transmit data to base station
    Update energy levels of all nodes
Check termination condition
End
```

The algorithm for GA in optimised LEACH is written below. The network topology is shown in Fig. 4.

Table 3 Genetic Algorithm

Input: Residual energy of nodes & fitness function
Output: Feasible list of routes

1. Initialize the genetic algorithm:
   - Set population size to 50
   - Define selection, mutation, and crossover functions
2. Define the fitness function using Equation 3
3. Iterate over all nodes:
   - Calculate the property of each node as the average of its attributes
   - Call the fitness function
4. Optimize the residual energy of nodes
5. Determine if a node meets the condition in Equation 2:
   - If it does, consider it as a Cluster Head (CH) and create an optimal route
   - Otherwise, reject it
6. Return the feasible list of routes, which is the optimal route

End of function

6. Results of the Simulation and Performance Analysis

The simulations were conducted using MATLAB R2016a, with the area kept constant at 1000m X 1000m. A total of 50 nodes were monitored. The simulations were carried out with all the initial parameters of the nodes were provided randomly. The sensor nodes were deployed in a random manner over the simulation region. The most commonly used metrics for performance evaluation in WSNs are delay, throughput, packet delivery ratio, and energy consumption.

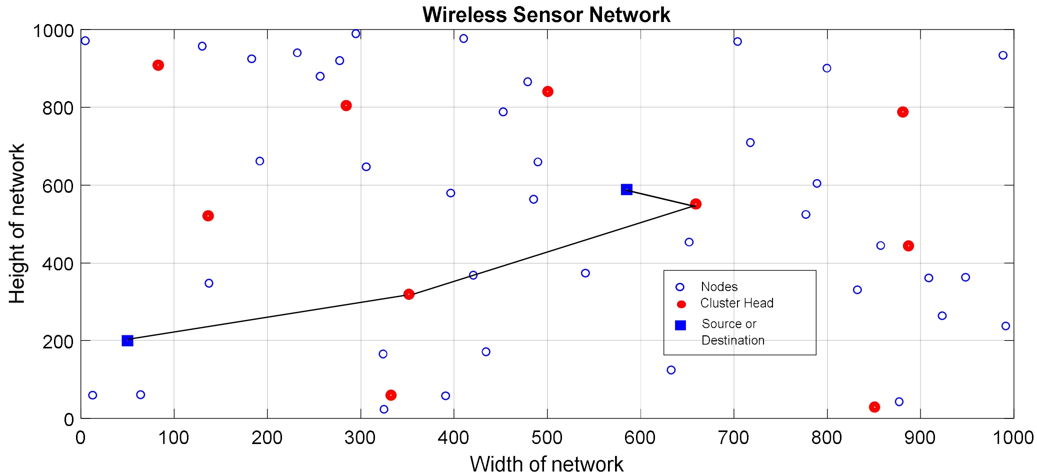

Figure 4 Network topology of GAO-LEACH

This work has focused on the LEACH protocol as a means of reducing energy consumption in sensor nodes to address the problem of excessive utilization of energy in WSNs. Genentic Algorithm Optimized LEACH (GAO-LEACH) encompasses the identical notion as the preexisting LEACH. The number of cluster heads is the primary factor that affects the performance of the present LEACH routing system. When there are fewer cluster heads, each cluster head must cover large areas, which might result in some cluster members being far away from the cluster head and consuming more energy. The connection between the cluster head and the base station (BS) consumes more energy compared to the regular nodes. Having a larger number of cluster heads might increase the overall energy consumption of the network and reduce its lifespan. Therefore, it is necessary to select a cluster head in order to minimize energy usage. In the GAO-LEACH algorithm, genetic algorithm (GA) is employed to choose a cluster head based on its higher residual energy.

Throughput

Throughput in a wireless sensor network (WSN) is the rate at which data packets or messages are successfully received by a recipient over a given period of time. It's also known as data transfer rate and is usually measured in bits per second (bps), megabits per second (Mbps), or gigabits per second (Gbps) or Kili bits per seconds (Kbps). The throughput value measured for the three protocols DEEC, LEACH and GAO-LEACH are shown in Figure 5. The charts shows that the average throughput value of GAO-LEACH are higher than both LEACH and DEEC. The average delay for DEEC, LEACH and GAO-LEACH were 324.08, 368.93 and 451.49 respectively. GAO-LEACH has outperformed LEACH in throughput by 22.38%.

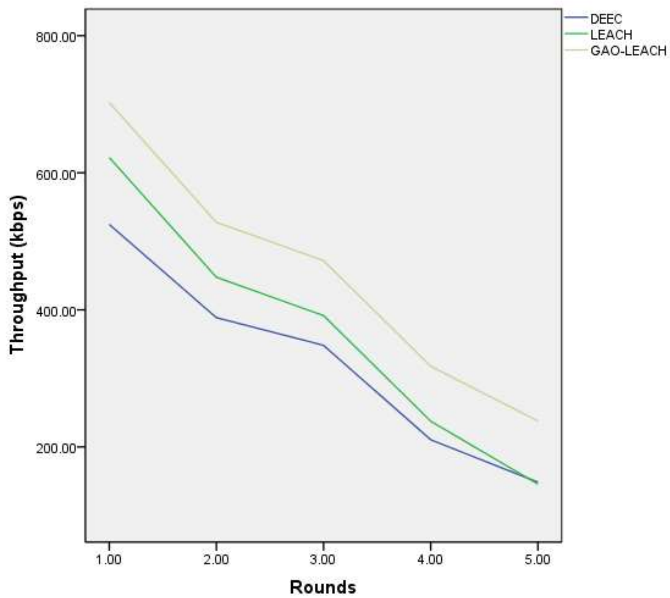

Fig. 5 Throughput

Delay

Delay is an important QoS parameter for forwarding data in a time constraint WSNs environment. The Delay value of the three protocols DEEC, LEACH and GAO-LEACH are shown in Figure 6. The charts shows that the delay by the GAO-LEACH are lower than both LEACH and DEEC. The average delay for DEEC, LEACH and GAO-LEACH were 16.59s, 14.19s and 6.58s respectively. GAO-LEACH has outperformed LEACH by reducing the delay by over 46.37%.

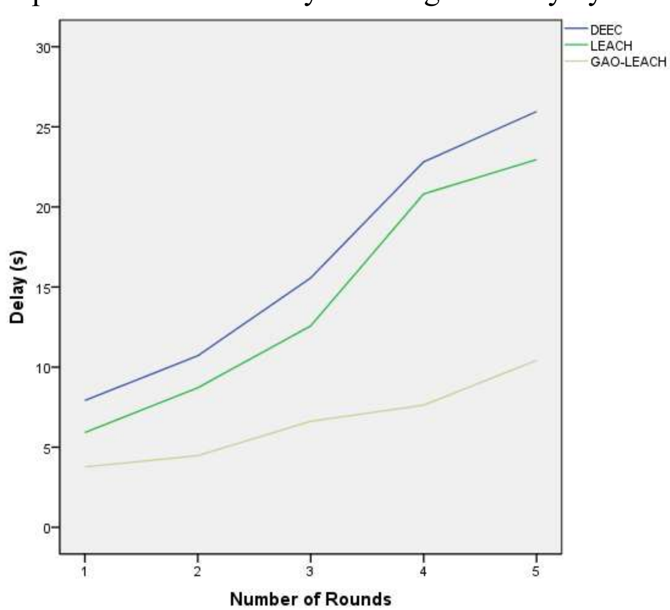

Fig 6. Delay

Packet Delivery Ratio

The packet delivery ratio is the proportion of successfully received packets at the sink in relation to the total number of data packets delivered by a node. A protocol's performance improves as the packet delivery ratio increases. The Packet Delivery Ratio of the three protocols DEEC, LEACH and GAO-LEACH are shown in Figure 7. The charts shows that the packets delivered by the GAO-LEACH are higher than both LEACH and DEEC. The average PDR for DEEC, LEACH and GAO-LEACH were 50.14%, 52.57% and 67.14% respectively. GAO-LEACH has outperformed LEACH in Packet Delivery Ratio by 27.71%.

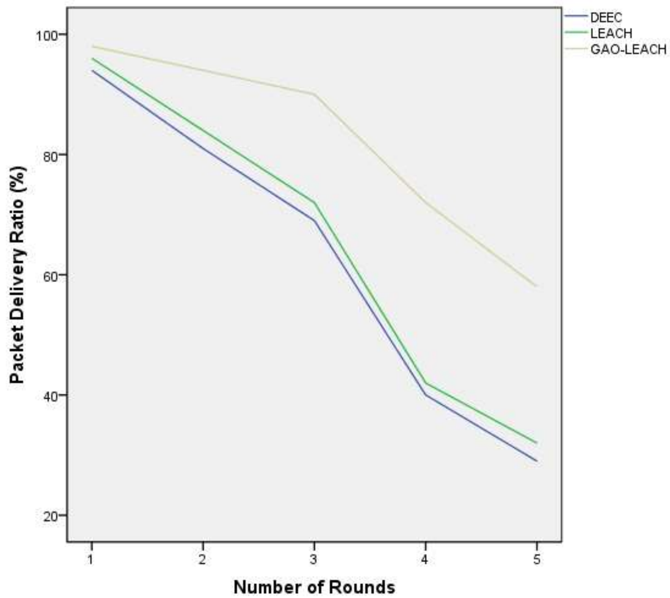

Fig. 7 Packet Delivery Ratio

Energy Consumption

Figure 8 illustrates the energy utilization of the sensor nodes during data transmission from the source to the destination. Based on the above picture, it is evident that the energy consumption of the GAO-LEACH routing method is lower than that of the LEACH routing protocol. The mean energy consumption rates for DEEC, LEACH and GAO-LEACH are 73.04 J, 66.15 J and 52.98 J, respectively. The adoption of the GAO-LEACH routing protocol when compared with LEACH protocol resulted in a significant drop of 80.09% in the energy consumption rate.

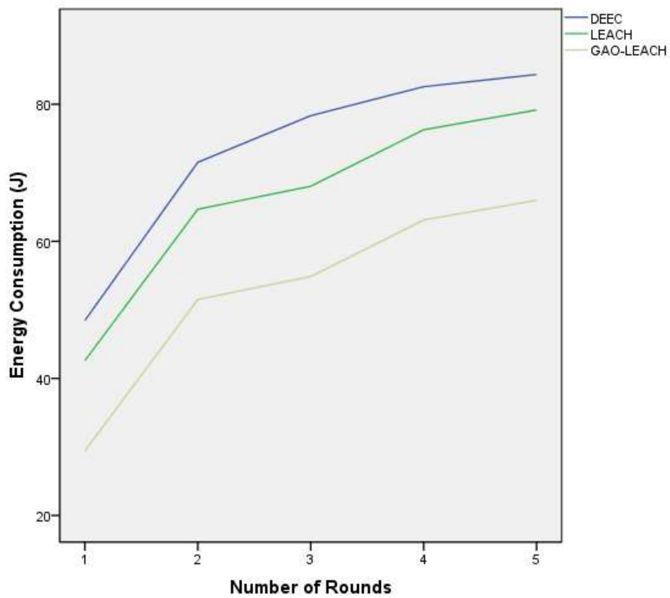

Fig. 8 Energy Consumption

7. Conclusions

In this work, a modified LEACH protocol has been developed by utilizing the features of genetic algorithm. The proposed GAO-LEACH algorithm was evaluated by comparing the performance with traditional DEEC and LEACH algorithms. GAO-LEACH has enhanced the performance of LEACH in terms of different evaluation metrics like throughput by 22.38%, Packet Delivery Ratio by 27.71%, energy consumption rate by 80.09% and reduced network delay by 46.37%. The results clearly showed that the proposed GAO-LEACH approach has exhibited significant enhancement over the traditional LEACH and DEEC protocols. The Genetic Algorithm (GA) improves the overall performance of the system, extends the lifetime of the network, and enhances energy efficiency by dynamically selecting cluster heads based on parameters such as energy levels and other relevant considerations. Further study and testing may be carried out to examine and improve the genetic algorithm (GA) and its parameters in order to achieve greater energy efficiency in wireless sensor networks that use the GAO-LEACH protocol. Simulations are important for evaluating the feasibility of a strategy, but they do not directly address the practical challenges and real-world problems that occur during the implementation of the solution in WSN deployments.

When implementing real-world WSNs, it is important to consider numerous challenges and aspects. In order to successfully use a theoretical method in a real situation, it is crucial to identify and solve various issues, as well as make modifications needed to improve the effectiveness and reliability of the proposed solution. Additional study and experimentation are required for academics and practitioners who want to use the proposed method of selecting cluster heads using Genetic Algorithms in real-world Wireless Sensor Networks. These investigations and trials are necessary to authenticate the effectiveness of the strategy in various scenarios and constraints. This procedure involves doing hardware testing, performing field trials, and making appropriate modifications to the algorithm to accommodate the inherent difficulties in specific deployment situations. Thoroughly assessing realistic deployment issues is crucial when moving from theoretical research to actual implementations.

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