Proposed Algorithm

The proposed algorithm integrates Ant Colony Optimization (ACO) for clustering, dynamic segmentation based on residual energy, the LEACH protocol for energy-efficient communication, and anomaly detection using machine learning techniques, including Isolation Forest, One-Class SVM, and Levenberg–Marquardt Neural Network (LMNN). The steps of the algorithm are outlined below to achieve optimal energy consumption and reliable anomaly detection in Wireless Sensor Networks (WSNs).

1. Initialization

The network is initialized with nodes, each having a random position on a 2D plane and an initial energy level Parameters such as the number of clusters , pheromone evaporation rate , and contamination level for anomaly detection are set.

* Number of nodes:
* Number of clusters:
* Number of iterations:
* Pheromone evaporation rate:
* Importance of pheromone information:
* Importance of heuristic information (node distance):
* Residual energy threshold:
* Contamination level for anomaly detection:

Nodes are placed at random positions , and their initial energy levels are assigned.

2. Ant Colony Optimization (ACO) for Clustering

ACO is used to create energy-efficient clusters by balancing both distance and residual energy in node-to-cluster assignments.

* Pheromone Matrix:  
  Initialize the pheromone matrix for each node and cluster centre with the initial value
* Fitness Function:  
  A fitness function that accounts for both distance and residual energy is defined. The distance between node and cluster centre is:

The fitness function for cluster selection is:

* + Ant Path Construction:  
    Ants probabilistically choose cluster centers based on pheromone and heuristic information:   
       
      
    where is the probability of node and cluster centre .
  + Pheromone Update:  
    After each iteration, the pheromone levels are updated as follows:  
      
       
      
    where is the pheromone evaporation rate and is a constant related to the quality of the path.

3. Dynamic Segmentation for Energy Optimization

Once cluster heads are selected, nodes are assigned to the nearest cluster based on residual energy and distance. Nodes with lower energy levels are penalized to ensure balanced energy consumption.

* Cluster Assignment:  
  Each node s assigned to cluster if:
* Energy Update:  
  After every communication round, the residual energy of each node is updated based on the energy cost for transmitting data. The updated energy for node is:  
    
     
    
  where represents the number of cluster heads for node .

4. LEACH Protocol for Energy-Efficient Routing

The LEACH protocol is employed for both intra-cluster and inter-cluster communication, with cluster members transmitting their data to the cluster head. The cluster head aggregates and forwards the data to the base station.

* Cluster Communication:  
  In each round, nodes communicate with their respective cluster heads, reducing communication distance and energy consumption.
* Energy Consumption:  
  The residual energy of each node is updated based on the energy model and the communication distance.

5. Anomaly Detection

The proposed algorithm incorporates machine learning techniques to detect compromised or faulty nodes in the network.

* Isolation Forest:  
  Outliers are detected based on tree depth and path length, with the probability of a node being an outlier calculated as :
* One-Class SVM:  
  The SVM identifies anomalies by modeling normal node behavior. The anomaly score for a node is computed as:
* LMNN (Levenberg-Marquardt Neural Network):  
  LMNN applies metric learning to minimize intra-class distances and maximize inter-class distances, aiding in anomaly detection.

6. Evaluation of Energy Efficiency and Anomaly Detection

* Energy Efficiency:  
  The energy efficiency s calculated as the proportion of nodes that have exhausted their energy:
* Anomaly Detection Accuracy:  
  Accuracy is evaluated based on true positive and false positive rates. The overall accuracy is given by: