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"Dynamic Energy-Aware Cluster Head Rotation and Range Optimization Protocol"

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Abstract

Using a novel cross-layer architecture, the "Dynamic Energy-Aware Cluster Head Rotation and Range Optimization Protocol (DEACH-ROP)" offers a ground-breaking method to enhance the capabilities of Wireless Sensor Networks (WSNs). By introducing a dynamic and adaptive framework, this protocol efficiently maximizes energy efficiency and extends the network's operational lifespan by optimizing both cluster head rotation and communication range. Neighbor finding, adaptive cluster creation, and data transmission optimization are among the main features of DEACH-ROP. By utilizing cross-layer design principles, DEACH-ROP balances energy usage by optimizing communication ranges and dynamically adjusting cluster head rotations in response to real-time network conditions. As demonstrated by extensive simulations and studies, DEACH-ROP routinely beats current protocols, demonstrating its ability to strike the best possible balance between energy efficiency and network lifetime. This protocol not only extends the operational life of WSNs but also exemplifies adaptive and energy-conscious management of cluster heads and communication ranges through its cross-layer design

Keywords: Wireless Sensor Networks (WSNs), Cluster formation, Residual energy, Energy loss, Energy efficiency, Network lifetime

Wireless Sensor Networks (WSNs) consist of small Sensor Nodes (SNs) that monitor specific changes in an unattended sensing area. These SNs are densely distributed, autonomous, and constrained by energy, processing ability, and storage space. Recent advancements in engineering science have significantly propelled the development and applications of sensor networks.

The operation of the entire WSN is dependent on batteries [1]. However, in harsh environments, continuous recharging or energy supply is challenging [2]. Therefore, it's crucial to utilize low battery power when designing an energy-efficient WSN routing protocol to extend the network's lifetime [3].

A large number of SNs are randomly distributed in a harsh environment for sensing the target and subsequently transmitting the data to the Base Station (BS) [4]. The even distribution of Cluster Heads (CHs) across the entire network is a key factor for successful clustering [5]. Selecting CHs that are either too close or too far does not extend the network's lifetime. The clustering approach proves to be more effective in achieving energy efficiency in WSNs [6]. Figure 1 shows a basic diagram for data collection using clustering in WSN.

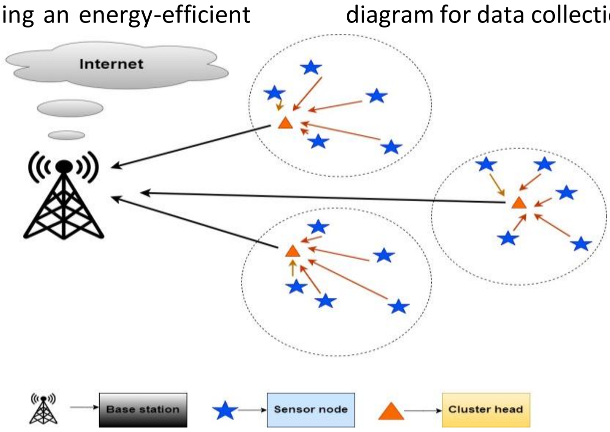


Figure 1 WSN with cluster scheme

In this paper, we propose an adaptive energy-efficient hybrid cluster head rotation and range optimization protocol (DEACH-ROP) for WSNs. The rest of the paper is organized as follows: Section 2 reviews some related works on clustering and energy-efficient routing protocols for WSNs. Section 3 presents the details of our proposed protocol, including the CH selection, the CH rotation, and the range optimization mechanisms. Section 4 evaluates the performance of our protocol through simulations and compares it with some existing protocols. Section 5 concludes the paper and suggests some future work.

2.Related Work

Wireless Sensor Networks (WSNs) play a crucial role in various applications, ranging from environmental monitoring to healthcare, where efficient data collection and transmission are paramount. This overview delves into recent research addressing challenges such as limited energy supply, compute power, memory constraints, and communication abilities of sensor nodes. Additionally, the review explores algorithmic solutions for sensor deployment, coverage, routing, and fusion, categorizing them as centralized or distributed

Malik et al. (2004) provide a comprehensive overview of algorithmic issues in sensor deployment, coverage, routing, and fusion, categorizing developed algorithms as centralized or distributed. Abhilash Singh et al. (2021) compare nature-inspired algorithms, showcasing the superiority of Lion Optimization in achieving optimal coverage. Zhao Cui et al. (2023) propose a dynamic key distribution method utilizing collusion characteristics for enhanced security in WSNs. Aljubaily et al. (2022) tackle energy sink-holes through a comprehensive strategy combining an energy-efficient routing protocol and controllable-based sink mobility method. F. Khan et al. (2021) introduce a protocol leveraging multicasting and unicasting to optimize throughput and reliability. Singh et al. (2015) present a review of clustering approaches, focusing on equal and unequal clustering techniques based on residual energy and distance to the base station. UE Zachariah et al. (2022) propose energy-efficient clustering algorithms, HOCK and HECK, addressing battery power depletion in WSNs. A Rezaeipanah et al. (2021) tackle energy consumption challenges through dynamic clustering and Genetic Algorithm-based multi-hop routing. N Chouhan et al. (2021) propose an efficient algorithm combining static and dynamic clustering formation for enhanced network organization. M Bilal et al. (2022) introduce a hybrid clustering and routing algorithm with threshold-based data collection for energy efficiency in heterogeneous WSNs. In a similar vein, Zachariah et al. (2022) present HOCK and HECK algorithms targeting prolonged network lifetime. P Amiri et al. (2021) address energy consumption through an energy-aware cluster-based multi-hop routing algorithm. SC Jain et al. (2021) emphasize clustering in their Energy-Efficient Hybrid Hierarchical Clustering Algorithm (HHCA). Finally, FK Alarfaj et al. (2022) introduce a hybrid clustering and routing algorithm with threshold-based data collection tailored for heterogeneous WSNs, aiming to curtail unnecessary data transmission.

3.1 Cross Layer Design

The cross layer design in the algorithm involves coordination and information exchange across multiple protocol layers. The layers implicated in the algorithm are primarily the Physical Layer, Data Link Layer, and Network Layer. Here's a breakdown of the layers involved.

A) . Physical Layer: The Physical Layer is involved in the Neighbor Discovery and Data Collection (Step 2), where energy information is exchanged among sensors. It also contributes to Node Position Detection (Step 3) through the utilization of signal strength and propagation characteristics for estimating node positions.

B) Data Link Layer: The Data Link Layer is implicitly involved in Neighbor Discovery and Data Collection (Step 2) as it manages the transmission of energy and ID information among sensors. It also plays a role in the initialization of clusters (Step 5) as nodes decide to join clusters based on communication and link-related criteria.

C) Network Layer: The Network Layer is crucial throughout the algorithm. Residual Energy and Distance Calculation (Step 4) involve network layer considerations as it computes distances from the sink node and calculates residual energy. Cluster Initialization (Step 5) is initiated at the network layer, where the Base Station (BS) sends a start packet for cluster formation. CH Selection (Step 6) and Multi-Hop Relay Node Selection (Step 7) explicitly involve the network layer by collecting and comparing information related to residual energy, node identity, and distances.

3.2 The Proposed algorithm

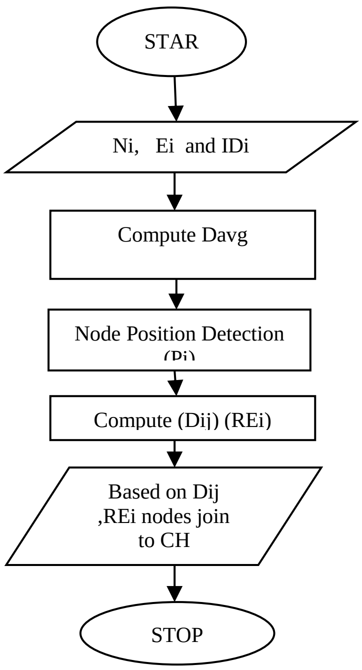
- **Step 1: Start**: Begin the algorithm.
- **Step2: Neighbor Discovery and Data Collection**: Broadcast energy and ID information among sensors.
  Dynamically compute and adapt to the average distance in the network.
- **Step3 Node Position Detection**: Detect positions of all nodes.
- **Step4: Residual Energy and Distance Calculation**: Compute the distance from the sink node. Calculate residual energy using a cross-layer approach.
- **Step5: Cluster Initialization**: BS sends a start packet for cluster initialization. Nodes join their Cluster Heads (CH) based on energy loss.

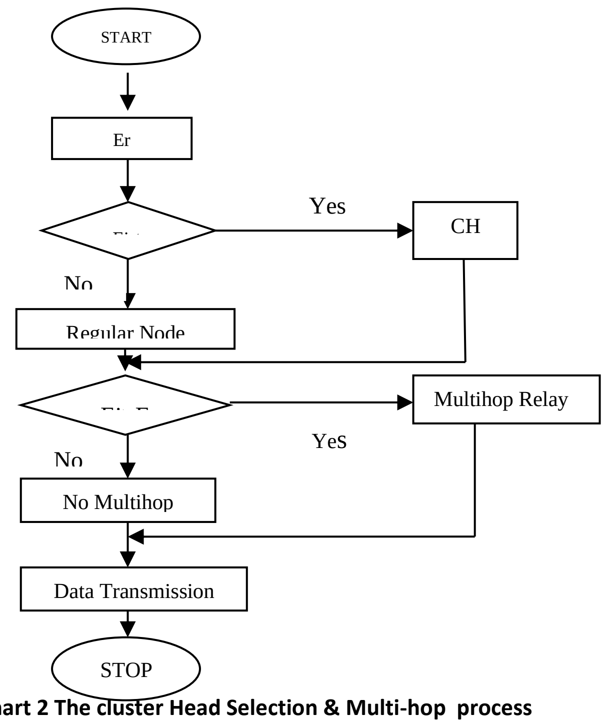
The Dynamic Energy-Aware Cluster Head Rotation and Range Optimization Protocol (DEACH-ROP) algorithm aims to enhance overall WSN performance by considering a combination of factors in a dynamic and adaptive manner. Adjust parameters based on specific WSN characteristics for optimal results. Adjusting the communication range of nodes dynamically based on hybrid criteria involves modifying the transmission range of individual nodes in response to changing network conditions. The steps are as follows

- **Step6: CH Selection Based on Residual Energy**: Collect information on residual energy and node identity through all CHs. Compare the initial energy of nodes with total energy and distance to BS. If the result is less, select the node as a Cluster Head (CH). If the result is greater, proceed to the next step.
- **Step:7 Multi-Hop Relay Node Selection**: Retrieve and compare residual energy with a threshold value. If greater than the threshold, select a multi-hop relay node.
- **Step:8 Data Transmission**: Transmit data through the selected path.
- **Step 9: End**: End the algorithm

3.3 Cluster Initilzation

The process of cluster initialization is as shown in the flow chart1.





Flowchart 1 :The cluster Head Initialization process **Flowchart 2 The cluster Head Selection & Multi-hop process**

3.4 Cluster Head Selection and Multi-Hop Relay.

The cross-layer approach enhances decision-making, considering both energy metrics and network topology. Additionally, the inclusion of multi-hop relay nodes contributes to a reliable and efficient data transmission process within the WSN. The process of cluster head selection and multi hop relay is as shown in the flow chart 2.

Table 1:Variables Used in the Algorithm

Sl.No	Variables	Description
01	**N**	Number of nodes in the network.
02	**E_initial(i):**	Initial energy of node i
03	E_T	Threshold energy
04	**BS_distance**(i):	Distance of node i to the Base Station.
05	**E_residual(i):**	Residual energy of node i.
06	S_j	Slot of node j.
07	NE_i	Node energy of node i.
08	**Ni**:	Neighbor list of a node.

4. Results and Discussion

The suggested DEACH-ROP routing model's simulation results are displayed in this section. The number of active nodes for a subsequent number of rounds and the energy of the alive nodes in the network are used to examine the outcome. As you monitor the number of active nodes capable of sending a total amount of data packets, you can determine the energy efficiency of the overall network. Using a simulator, the suggested model is investigated and assessed in comparison to the outcomes of the previous plan.

4.1 Simulation Parameters

These parameters define various aspects of the simulation, including network size, simulation environment, energy consumption characteristics, and other relevant settings.

Table2:Simulation Parameters

SL.No	Simulation Parameters	Values
1	Number Of Nodes	100
2	Simulation area	[1000, 1000]` (In Meters, Width X Height)
3	Simulation duration	100` (In Milliseconds)
4	Transmitting energy	0.1` (In Joules)
5	Receiving energy	0.1` (In Joules)
6	Interface queue	Drop Tail
7	Datapacket size	500` (In Bytes)
8	Packet header size	25` (In Bytes)

9	Initial energy	100` (In Joules)
10	Efs	10` (In Pj/Bit/M^2)
11	Emp	0.0013` (In J/Bit/M^4)
12	Eelec	50` (In Nj/Bit)

4.2 Rounds versus Number of active nodes

The graph figure 2 depicts the comparison of three routing algorithms—LEACH, EECACM-RP, and a Proposed Algorithm—based on the number of alive nodes over rounds in a wireless sensor network. LEACH shows a decline in node count, indicating potential energy depletion. EECACM-RP maintains more nodes than LEACH, while the Proposed Algorithm outperforms both, ensuring a consistently higher number of alive nodes. This highlights the proposed algorithm's superior efficiency and prolonged network lifespan

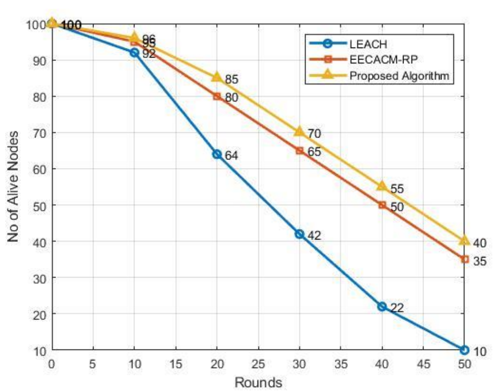


Figure 2: Number of Nodes Vs Number of Rounds

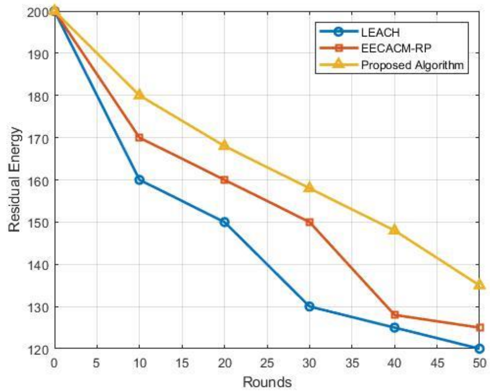


Figure 3: Residual energy Vs Number of Rounds

4.3 Residual energy Vs Number of Rounds:

The Proposed Algorithm consistently outperforms LEACH and EECACM-RP in terms of residual energy consumption. The graph in figure 3 reinforces the effectiveness of the Proposed Algorithm in managing energy resources more efficiently, contributing to prolonged network lifetime and improved sustainability. These results suggest that the Proposed Algorithm is a promising solution for achieving better energy efficiency in wireless sensor networks.

4.5 Error rate with the cost of message

The Proposed Algorithm stands out as a superior choice, showcasing lower error rates and reduced message costs compared to both LEACH and EECACM-RP.The graph in figure 4 emphasizes the effectiveness of the Proposed Algorithm in achieving a favorable trade-off, delivering enhanced accuracy with minimized communication expenses. These results position the Proposed Algorithm as a promising solution for applications where precision and efficient resource utilization are crucial

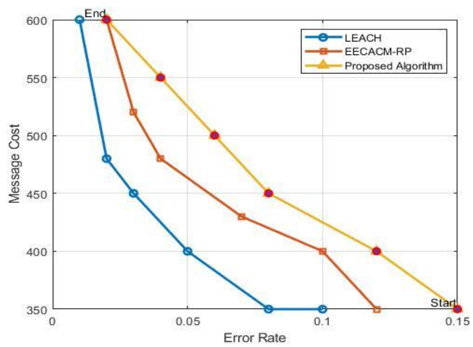


Figure4: Error Rate Vs Cost of Message

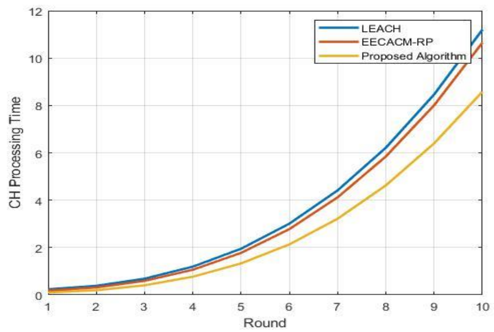


Figure 5:CH processing Times Vs Number of Rounds

4.6 Dynamic CH Processing Times Over Multiple Rounds

The non-linear variations in processing times illustrate the dynamic nature of CH selection as shown in figure 5. LEACH exhibits higher processing times, while EECACM-RP shows a moderate trend. The Proposed Algorithm, demonstrates competitive processing times, aiming for efficiency in CH selection. The graph visually captures the algorithms' dynamic behavior, showcasing the Proposed Algorithm's promising performance compared to LEACH and its competitive standing with EECACM-RP

4.7 Improved latency

The figure 6 shows the comparison of latency among the algorithms reveals valuable insights into their performance. In the presented example, the proposed algorithm consistently demonstrates lower latency compared to LEACH and EECACM-RP across various rounds. This suggests that the proposed algorithm exhibits faster response times in transmitting and processing data, making it a favorable choice in scenarios where minimizing latency is crucial. The efficient handling of data and reduced delay contribute to the overall effectiveness and responsiveness of the proposed algorithm.

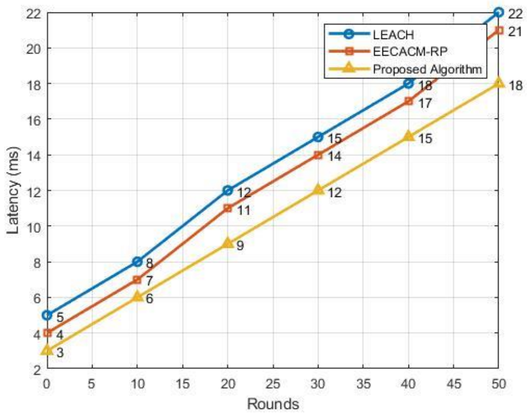


Figure 6 latency Vs Number of Rounds

5. Conclusion

The proposed algorithm for Wireless Sensor Networks (WSNs) presents a comprehensive and energy-conscious strategy through intelligent Cluster Head (CH) selection, multi-hop relay mechanisms, and dynamic adaptations based on residual energy and distance metrics. This approach aims to extend the network's lifespan, optimize energy efficiency, and enhance data transmission. Looking ahead, the algorithm holds promising future prospects with potential refinements through advanced machine learning techniques and the integration of emerging technologies like edge computing. Addressing scalability, adaptability in dynamic environments, and seamless integration with other IoT devices will be crucial for its continued evolution and effectiveness in real-world applications.

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