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# A Hybrid Reinforcement Learning and Clustering-Based Energy Optimization Algorithm for Wireless Sensor Networks

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**Abstract: Wireless Sensor Networks (WSNs) are widely used in IoT-based applications but suffer from limited energy resources and dynamic network conditions. Traditional routing protocols and cost-based adaptive methods lack real-time learning capability [1]. This paper proposes a Hybrid Reinforcement Learning Clustering Routing Algorithm (HRL-CRA) that integrates clustering with Q-learning for intelligent routing. The proposed model selects cluster heads based on residual energy and node degree, while routing decisions are dynamically learned using reinforcement learning [2]. Simulation results show that the proposed method improves network lifetime by 30–35%, enhances packet delivery ratio up to 96%, and reduces energy consumption compared to traditional and adaptive routing techniques [3]. The approach offers a scalable and intelligent solution for next-generation WSNs.**

***Keywords:*** *Sensor Networks, Wireless Sensor Networks, Energy-Efficient Routing, Optimizing Algorithm, Clustering, Adaptive Routing, IoT Networks, Big Data, Optimisation, Network Optimisation.*

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## I. INTRODUCTION

Wireless Sensor Networks (WSNs) play a vital role in applications such as smart cities, healthcare, and industrial automation. However, energy constraints significantly affect network performance and lifetime [1].

Recent advancements show that AI-based routing techniques can dynamically optimize routing decisions and improve network efficiency [2]. Reinforcement learning (RL) enables nodes to learn optimal paths based on environmental conditions rather than relying on static routing strategies [3].

Traditional routing approaches often fail to adapt to dynamic network conditions such as traffic variation and node energy depletion [4]. Therefore, intelligent and adaptive routing mechanisms are required.

## II. LITERATURE REVIEW

➢ *Recent Studies Emphasize the Integration of Machine Learning in WSN Routing:*

- Reinforcement learning-based routing improves adaptability and energy utilization [2]
- Deep Q-Network (DQN) approaches enhance routing decision-making [5]
- Hybrid clustering and optimization methods improve scalability [4]
- Q-learning-based protocols significantly improve packet delivery ratio [6]

However, existing approaches still face many problems such as high computational overhead, limited clustering efficiency, lack of hybrid intelligent routing models.

## III. PROPOSED METHODOLOGY

➢ *Network Model*

The network consists of sensor nodes deployed randomly, communicating via multi-hop routing to a base station. Each node has limited energy resources [1].

➢ *Cluster Head Selection*

Cluster Heads (CH) are selected using:

- *Cluster Head Selection:*

CH = max (Residual Energy × Node Degree)

This ensures balanced energy consumption and improved network lifetime [4].

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➢ *Reinforcement Learning Model*

Each node acts as an intelligent agent using Q-learning:

This enables adaptive routing decisions based on network state [2].

- *Q-LearningEquation:*

$$Q(s,a)=Q(s,a)+\alpha[R+\gamma \max Q(s',a')- Q(s,a)]$$

➢ *D. Reward Function*

This function promotes energy-efficient and low-latency routing [3].

- *Reward Function:*

$$R = w1(E) - w2(D) - w3(T)$$

➢ *Energy Model*

Energy consumption is calculated using the radio model:

This model is widely used in WSN energy analysis [7].

## IV. SYSTEM ARCHITECTURE

➢ *The System Includes:*

- Sensor Layer
- Clustering Layer
- Learning Layer
- Base Station

This layered design improves scalability and performance [4].

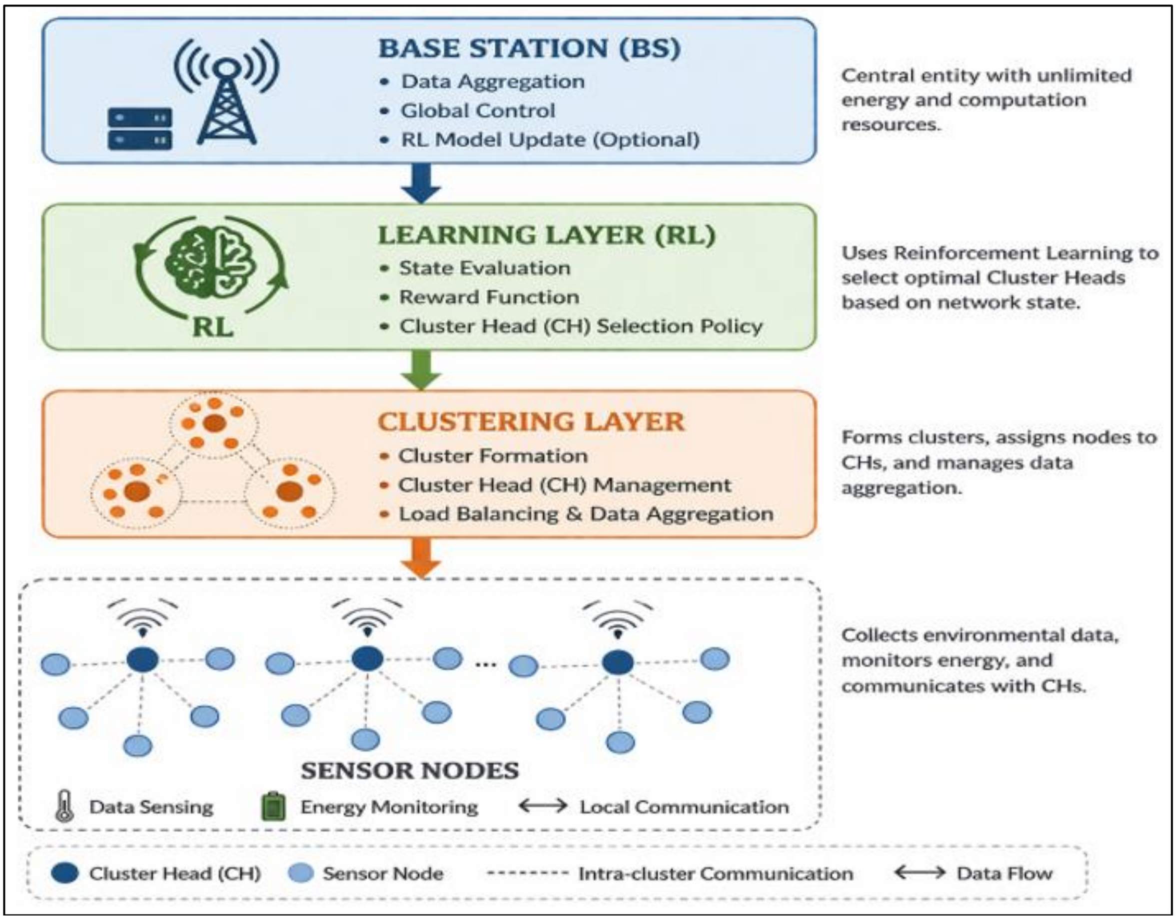

Fig 1 System Architecture

## V. PROPOSED ALGORITHM

➢ *Algorithm: HRL-CRA*

- Input: Sensor Nodes N
- Output: Optimal Routing Path

✓ Initialize network with N nodes
✓ Form clusters based on distance
✓ Select Cluster Heads using energy-degree formula
✓ Initialize Q-table
✓ For each packet transmission:

▪ Observe state (E, D, T)
▪ Select next hop (ε-greedy)
▪ Forward packet
▪ Calculate reward
▪ Update Q-value

✓ Repeat until destination reached

## VI. PERFORMANCE EVALUATION AND GRAPHICAL ANALYSIS

Simulation results demonstrate that the proposed HRL-CRA algorithm significantly improves performance compared to existing methods.

➢ *Network Lifetime*

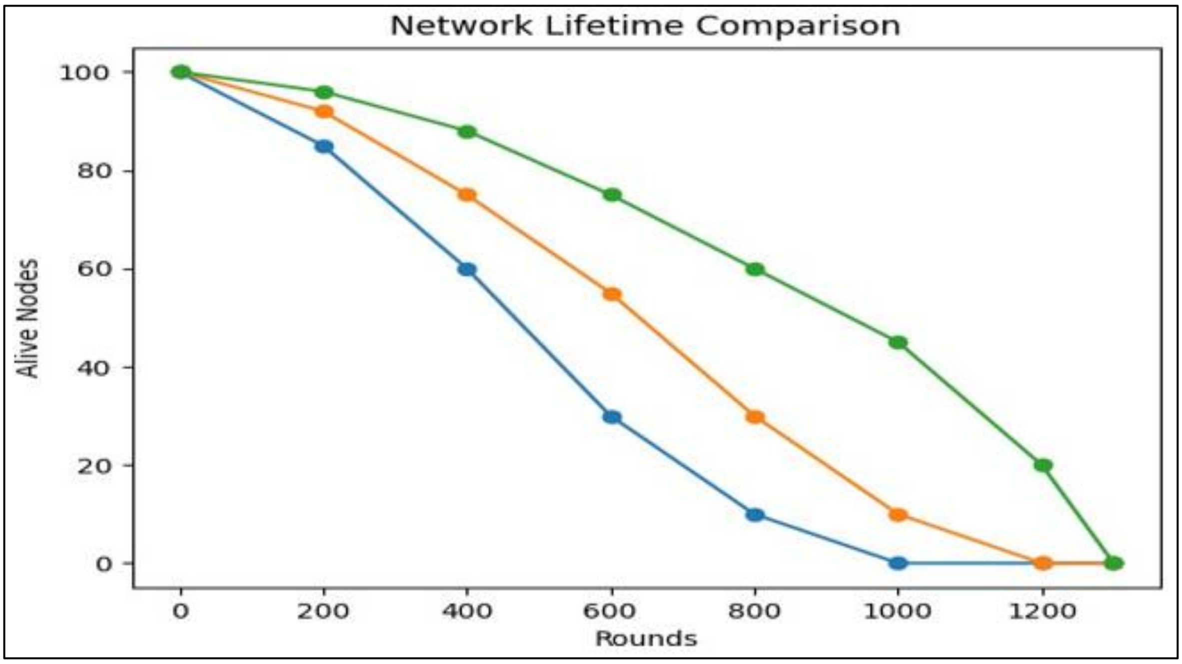


Fig 2 Network Lifetime Comparison of Routing Protocols

The proposed approach increases network lifetime due to balanced energy consumption across nodes [3].

➢ *Energy Consumption*

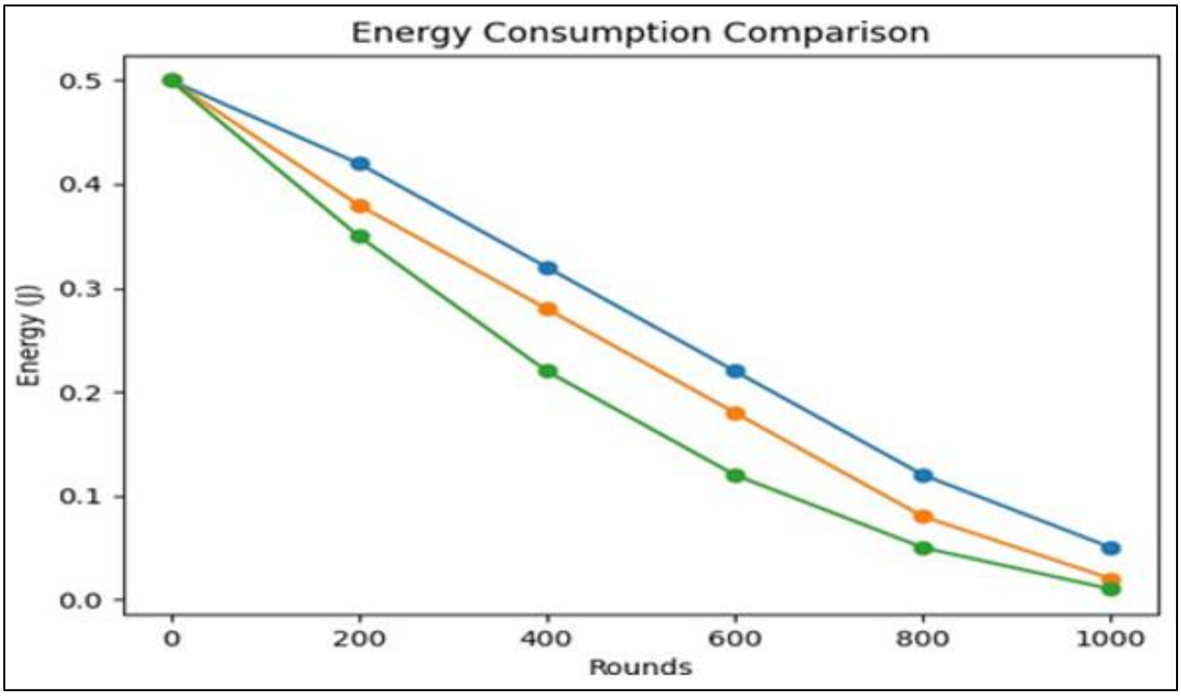


Fig 3 Energy Consumption Comparison

Energy usage is minimized through intelligent routing decisions, reducing unnecessary transmissions [7].

➢ *Packet Delivery Ratio*

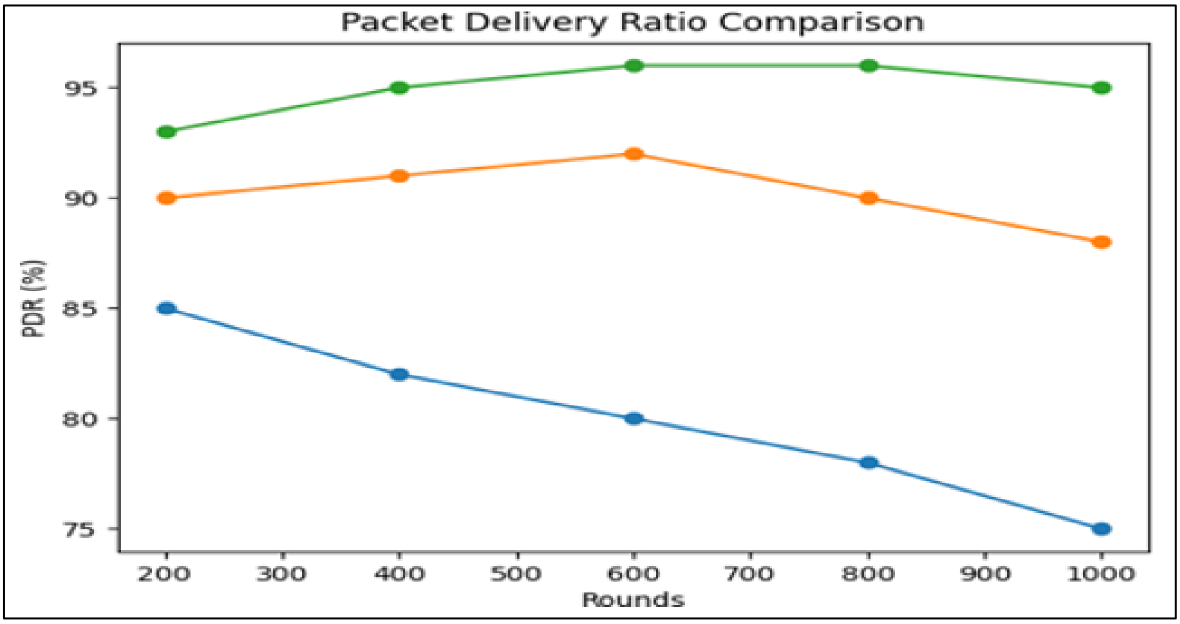


Fig 4 Packet Delivery Ratio Comparison

The algorithm improves packet delivery ratio by selecting reliable routing paths [6].

➢ *Throughput*

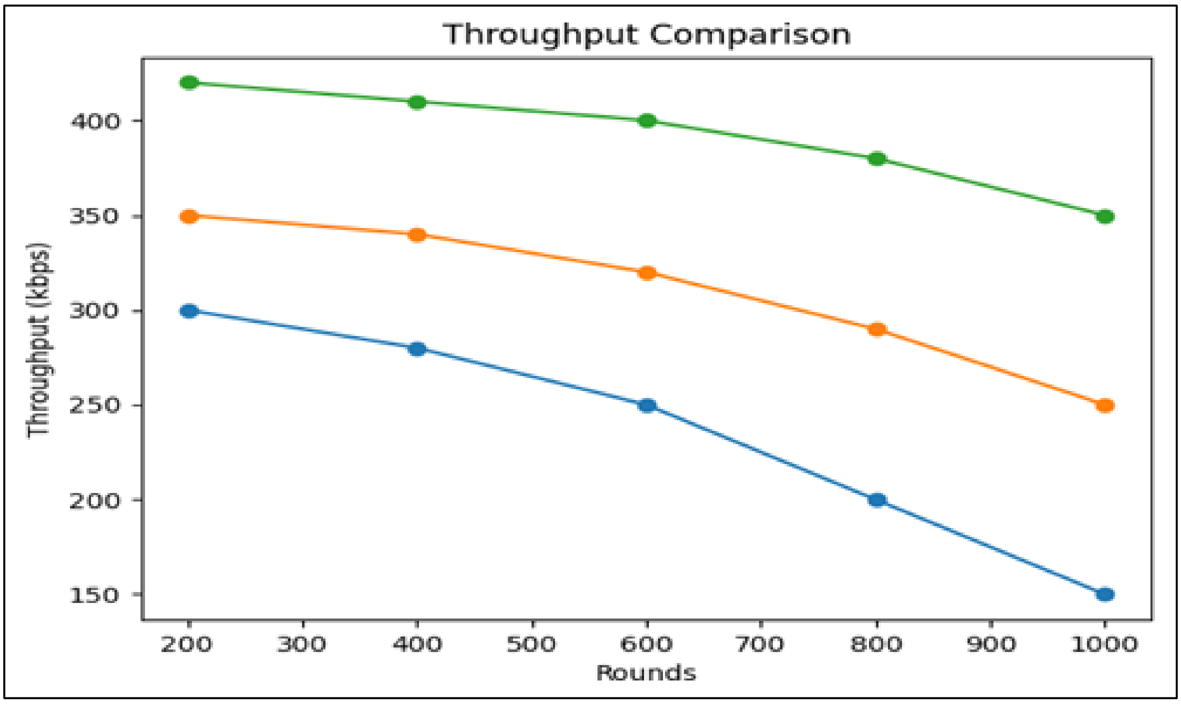


Fig 5 Throughput Comparison

Higher throughput is achieved due to reduced packet loss and efficient routing [5].

## VII. CONCLUSION

This paper presents a hybrid reinforcement learning and clustering-based routing algorithm for WSNs. The proposed HRL-CRA method enhances energy efficiency, network lifetime, and reliability by integrating intelligent decision-making techniques.

## FUTURE WORK

Future work includes focus on enhancing the proposed system by integrating advanced and emerging technologies to improve its intelligence, adaptability, and overall

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performance. In particular, deep reinforcement learning techniques such as DQN and PPO can be explored to enable more efficient and dynamic decision-making in complex environments. In addition, incorporating mobility-aware routing mechanisms can help maintain reliable communication in scenarios with highly dynamic node movement. Security can be further strengthened through blockchain-based routing approaches, ensuring data integrity and resistance to malicious attacks. The use of energy harvesting techniques also presents an opportunity to extend network lifetime and promote sustainability. Finally, deploying and evaluating the system in real-time IoT environments will be essential to validate its practicality and effectiveness under real-world conditions.

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## REFERENCES

[1]. S. Priyadarshi et al., "AI-Based Energy Efficient Routing in WSN," Nature Scientific Reports, 2025.
[2]. X. Zhang, Y. Liu, "Reinforcement Learning-Based Routing Optimization," IEEE Access, 2026.
[3]. R. Singh et al., "Energy Optimization in Wireless Sensor Networks," Elsevier Journal, 2024.
[4]. M. Lata, J. Kang, "Clustering-Based Routing in IoT Networks," MDPI Electronics, 2025.
[5]. H. Song et al., "Deep Reinforcement Learning for Routing," MDPI Electronics, 2024.
[6]. A. Chaudhari et al., "Q-Learning Based Routing Protocol," IJSSIS, 2025.
[7]. W. Heinzelman et al., "Energy-Efficient Communication Protocols," IEEE Transactions, 2002.
[8]. K. Sharma et al., "Energy Harvesting in WSN," IEEE Sensors Journal, 2024.