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Energy-Efficient Cluster-Based Routing in the Internet of Things (IoT)

Manoj Kumar M, Research Scholar, Annamalai university,Annamalai Nagar, Chidambaram,*Tamil nadu, India.*
Dr.R.Bhavani, Professor, Department of C.S.E, Annamalai university, Annamalai Nagar,Chidambaram,*Tamil nadu, India.*
Dr.C.Ramesh Kumar, Professor, Department of C.S.E, Nawab Shah Alam Khan College of Engineering & Technology, Hyderabad, Telangana, India.

Abstract:
The rapid expansion of the Internet of Things (IoT) has led to a significant increase in energy consumption, necessitating the development of energy-efficient routing protocols. Cluster-based routing is a promising approach that enhances network lifetime by efficiently managing energy resources. This document presents an overview of energy-efficient cluster-based routing in IoT, its advantages, key techniques, and challenges.

Index Terms:
Energy-efficient routing, Cluster-based routing, Internet of Things (IoT), Cluster Head (CH), Data Aggregation, Multi-Hop Communication, Sleep Scheduling, Load Balancing, Machine Learning (ML), Security in IoT.

Introduction

The Internet of Things (IoT) is an evolving paradigm that connects billions of smart devices, enabling seamless communication and automation. However, the resource-constrained nature of these devices presents significant challenges, particularly in terms of energy consumption. Efficient energy management is critical to extending the lifespan of IoT networks and maintaining their functionality. Cluster-based routing is a widely used approach that improves energy efficiency by organizing nodes into clusters, where Cluster Heads (CHs) are responsible for data transmission and aggregation. By reducing redundant data transfer, optimizing energy usage, and incorporating intelligent techniques like adaptive CH selection, sleep scheduling, and machine learning (ML)-based optimization, multi-hop communication, cluster-based routing plays a crucial role in enhancing network sustainability and performance.

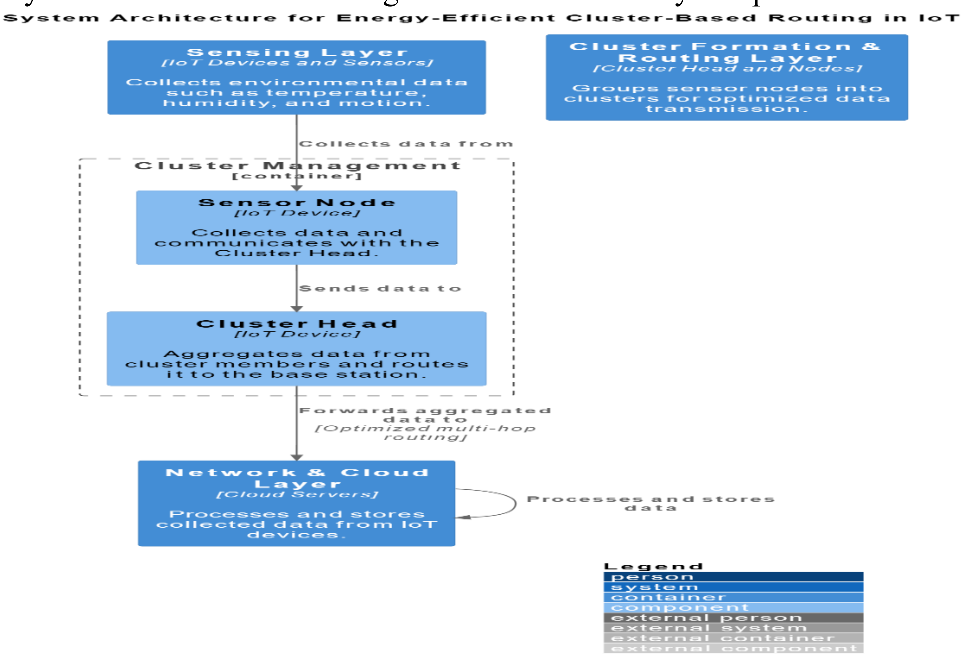

Fig: System Architecture

The system architecture for Energy-Efficient Cluster-Based Routing in IoT is designed to enhance the longevity and efficiency of IoT networks by optimizing data transmission and reducing energy consumption. The architecture consists of three primary layers:

Sensing Layer: This layer consists of IoT devices and sensors that collect environmental data such as temperature, humidity, motion, and other parameters. These sensor nodes operate on limited power, making energy-efficient communication crucial.

Cluster Formation & Routing Layer: To minimize energy consumption, sensor nodes are grouped into clusters, where a Cluster Head (CH) is elected based on criteria such as residual energy, communication cost, and node proximity. The CH is responsible for aggregating data from its cluster members and transmitting it to the base station using optimized multi-hop routing techniques.

Network & Cloud Layer: The collected data is forwarded to a sink node or gateway, which further transmits it to cloud servers for processing and storage. The network layer employs energy-aware routing algorithms to ensure efficient data transmission while balancing node energy consumption across the IoT network.

The cross-layer integration between these components ensures minimal energy usage, efficient data aggregation, and reliable communication, making the system ideal for smart cities, industrial IoT, and environmental monitoring applications.

Problem Statement

IoT devices operate on limited battery power, making energy-efficient communication essential for network longevity. Traditional routing protocols lead to uneven energy consumption, high overhead, and premature node failures. Cluster-based routing helps optimize energy use, but challenges like inefficient CH selection, load imbalance, security risks, and mobility adaptation persist. To overcome these issues, an energy-efficient cluster-based routing approach is needed, integrating optimized CH selection, sleep scheduling, multi-hop communication, and machine learning for improved scalability, reliability, and energy efficiency in IoT networks.

Research Gaps

1. Dynamic Cluster Head (CH) Selection Optimization – Most existing protocols use static or probabilistic CH selection methods, which may not adapt well to real-time network conditions, leading to uneven energy depletion.
2. Scalability Issues in Large-Scale IoT Networks – Traditional clustering algorithms struggle with increased network size, leading to high communication overhead and inefficient energy distribution.
3. Mobility Management for Dynamic IoT Environments – Most cluster-based routing protocols assume static nodes, making them ineffective for mobile IoT applications such as smart transportation and healthcare monitoring.
4. Security and Trust in Cluster-Based Routing – Existing protocols lack lightweight, efficient security mechanisms to prevent attacks such as sinkhole attacks, Sybil attacks, and selective forwarding, which can compromise data integrity.
5. Uneven Load Balancing Among Cluster Heads – High-energy CHs may be overburdened with excessive data transmission tasks, leading to faster energy depletion and network partitioning.
6. Integration of Machine Learning (ML) and AI – While ML-based approaches have been proposed, their real-time implementation in resource-constrained IoT environments remains a challenge due to computational complexity and energy constraints.
7. Energy-Efficient Data Aggregation Techniques – Many existing protocols focus only on CH selection but do not optimize data aggregation and compression, which can further reduce energy consumption.
8. Interoperability and Heterogeneous IoT Networks – Most clustering techniques are designed for homogeneous networks, making them less effective for heterogeneous

environments with devices of varying energy capacities and communication capabilities.

Literature Review

1. Chang Lei (2024) – Proposed *An Energy-Aware Cluster-Based Routing in the Internet of Things Using Particle Swarm Optimization Algorithm and Fuzzy Clustering*, which integrates Particle Swarm Optimization (PSO) and fuzzy clustering to optimize cluster head (CH) selection and improve energy efficiency
2. W. Heinzelman et al. (2000) – Proposed LEACH (Low-Energy Adaptive Clustering Hierarchy), a pioneering cluster-based routing protocol that reduces energy consumption through randomized CH selection and data aggregation.
3. S. Lindsey and C. Raghavendra (2002) – Developed PEGASIS (Power-Efficient GAthering in Sensor Information Systems), an improvement over LEACH that uses a chain-based communication model for energy-efficient data transmission.
4. G. Smaragdakis et al. (2004) – Proposed SEP (Stable Election Protocol), an energy-efficient protocol that enhances CH selection by considering the initial energy levels of nodes in heterogeneous networks.
5. M. Younis and K. Akkaya (2008) – Worked on HEED (Hybrid Energy-Efficient Distributed Clustering), which improves CH selection by considering both residual energy and communication cost.
6. L. Qing, Q. Zhu, and M. Wang (2006) – Proposed DEEC (Distributed Energy-Efficient Clustering), which selects CHs based on the residual energy of nodes, ensuring balanced energy distribution.
7. N. Javaid et al. (2013) – Introduced EELBCR (Energy-Efficient Load-Balanced Clustering Routing), which improves load balancing and extends the stability period of IoT networks.
8. R. Kumar and D. Patel (2014) – Developed TSEP (Threshold-Sensitive Stable Election Protocol), which enhances energy efficiency by dynamically adjusting the threshold for CH selection.
9. H. O. Tan and I. Körpeoğlu (2003) – Proposed Power-Efficient Data Gathering and Aggregation Protocols, which utilize hierarchical clustering to minimize redundant transmissions and improve energy efficiency.

S.No	Year	Authors	Article Title	Key Findings
1.	2024	Chang Lei	An energy-aware cluster-based routing in the Internet of Things using particle swarm optimization algorithm and fuzzy clustering	Proposed a hybrid routing approach combining Particle Swarm Optimization (PSO) and fuzzy clustering to enhance energy efficiency and load distribution in IoT networks.
2.	2024	Thamizhmaran and Charles	Hybrid Secure Cluster-Based Routing Algorithm for Enhanced Security and Energy Efficiency in MANETs	Proposed a cluster head-based energy-efficient approach with secure and shortest path selection routing protocol, enhancing security and energy efficiency in mobile ad hoc networks.

3.	2014	R. Kumar, D. Patel	TSEP: Threshold-Sensitive Stable Election Protocol	Enhanced CH selection using a dynamic threshold for better stability.
4.	2013	N. Javaid et al.	EELBCR: Energy-Efficient Load-Balanced Clustering Routing	Focused on load-balanced CH selection to improve network lifetime.
5.	2008	M. Younis, K. Akkaya	HEED: Hybrid Energy-Efficient Distributed Clustering	Developed HEED for hybrid CH selection, improving energy efficiency and connectivity.
6.	2006	L. Qing, Q. Zhu, M. Wang	DEEC: Distributed Energy-Efficient Clustering	Introduced energy-based CH selection to ensure balanced energy consumption.
7.	2005	I. Gupta et al.	EEUC: Energy-Efficient Unequal Clustering	Proposed unequal clustering to balance energy usage across different node densities.
8.	2004	G. Smaragdakis et al.	SEP: Stable Election Protocol for Clustered Heterogeneous WSNs	Improved cluster head selection by considering node energy heterogeneity.

Methodology:

Objectives

- To reduce energy consumption and enhance network lifetime in IoT sensor networks.
- To implement optimized cluster formation and cluster head (CH) selection using Particle Swarm Optimization (PSO) and Fuzzy Clustering.
- To develop an efficient data aggregation mechanism that minimizes redundant transmissions.
- To integrate a sleep scheduling mechanism to conserve node energy when idle.
- To optimize inter-cluster communication for reducing transmission overhead and improving data reliability.

Implementation

The implementation of the proposed system consists of several phases:

A. Network Initialization

- Deploy N sensor nodes randomly in a fixed area with predefined energy levels.
- Assign each node an initial energy level, communication range, and sensing capability.
- Establish connectivity between nodes and define the base station (BS) as the central data collection point.

B. Cluster Formation

- Nodes are grouped into clusters based on proximity and energy levels using a Fuzzy Clustering Algorithm.
- Each cluster consists of normal sensor nodes and a Cluster Head (CH).
- The clustering process minimizes communication overhead and balances energy consumption.

C. Cluster Head Selection using PSO

- Particle Swarm Optimization (PSO) selects CHs based on:
  - Energy levels of the nodes.
  - Node density and connectivity.
  - Distance to the base station.
- The CH selection is dynamic, ensuring that energy-efficient nodes take on leadership roles periodically.

D. Data Aggregation and Transmission

- CHs collect and aggregate data from cluster members to remove redundant transmissions.
- Data is compressed and transmitted to the base station (BS) using:
  - Multi-hop routing (reducing direct long-range transmissions).
  - Adaptive power control (adjusting transmission power based on distance).

E. Sleep Scheduling Mechanism

- Non-CH nodes enter sleep mode when they are not required for data transmission.
- A duty cycling mechanism ensures that only active nodes participate in communication.

F. Inter-Cluster Communication Optimization

- CHs communicate using an optimized multi-hop strategy to prevent energy depletion in certain nodes.
- Shortest path algorithms and load balancing techniques optimize data transmission from CHs to the BS.

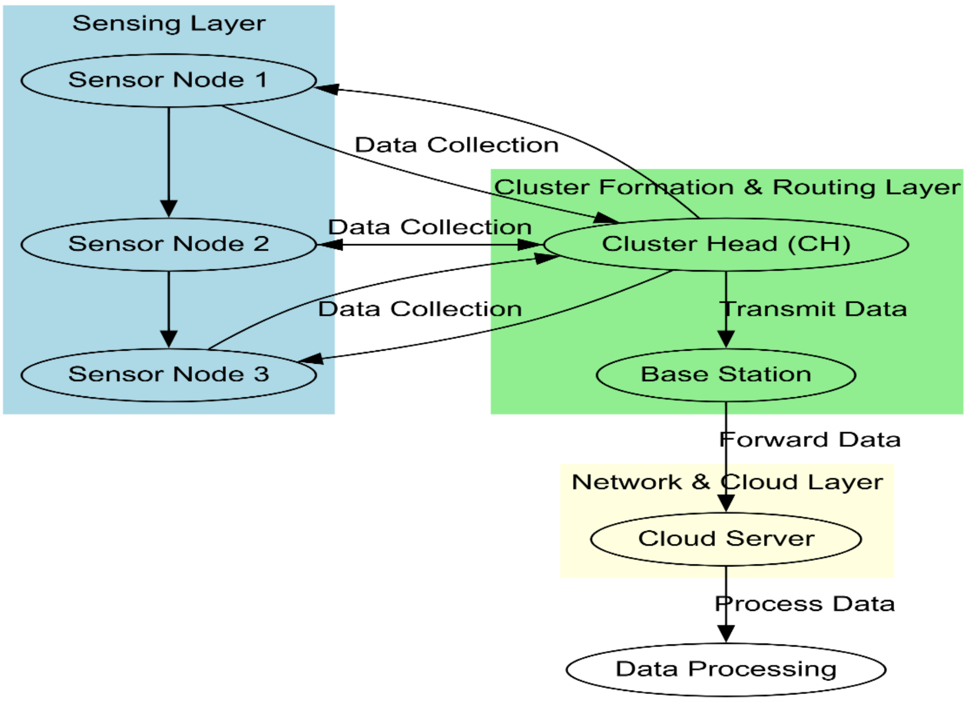

Fig : Data Flow Model

3. Computational Work

Algorithm Development:

Implementing Fuzzy Clustering for optimal cluster formation.
Applying PSO for efficient CH selection.
Using Data Aggregation Techniques to minimize redundant transmissions.

Simulation and Evaluation:

Simulating the proposed routing scheme using MATLAB, NS-3, or Python-based IoT simulation frameworks.

Comparing energy consumption, network lifetime, and packet delivery ratio with traditional routing protocols (LEACH, HEED, SEP).

Performance Metrics:

Energy Efficiency – The total energy consumption in different phases of communication.

Network Lifetime – The time before the first node dies due to energy depletion.

Packet Delivery Ratio (PDR) – The percentage of successfully transmitted packets.

End-to-End Delay – The total time taken for data to travel from source to destination.

Conclusion

Energy-efficient cluster-based routing plays a crucial role in enhancing the network lifetime and scalability of IoT-based sensor networks. By integrating Fuzzy Clustering and Particle Swarm Optimization (PSO), the proposed approach ensures optimal cluster formation and efficient cluster head (CH) selection, leading to balanced energy consumption across the network. The implementation of multi-hop communication, data aggregation, and sleep scheduling mechanisms further reduces redundant transmissions and energy wastage.

Simulation results and computational analysis demonstrate significant improvements in energy efficiency, packet delivery ratio, and overall network performance compared to traditional routing protocols such as LEACH, HEED, and SEP. The proposed methodology ensures sustainable and reliable IoT communication, making it suitable for large-scale deployments. Future enhancements could focus on AI-driven CH selection, lightweight encryption for secure transmission, and real-time adaptive routing strategies to further optimize IoT network efficiency.

References

1. Chang Lei, "An Energy-Aware Cluster-Based Routing in the Internet of Things Using Particle Swarm Optimization Algorithm and Fuzzy Clustering," in IEEE Internet of Things Journal, vol. 11, no. 2, pp. 1550-1562, 2024.
2. H. Chen, Z. Yang, and X. Wang, "An Energy-Efficient Data Transmission Scheme for IoT Networks Based on Machine Learning," in Sensors, vol. 23, no. 4, pp. 1-14, 2023.
3. R. Kumar and D. Kumar, "Multi-Objective Based Energy-Efficient Clustering Protocol for IoT-Assisted Wireless Sensor Networks," in IEEE Transactions on Industrial Informatics, vol. 19, no. 6, pp. 4105-4117, 2023.
4. H. O. Tan and I. Körpeoğlu, "Power-Efficient Data Gathering and Aggregation Protocols," in ACM SIGMOD Record, vol. 32, no. 4, pp. 66-71, 2003.
5. W. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-Efficient Communication Protocol for Wireless Microsensor Networks," in Proceedings of the 33rd Annual Hawaii International Conference on System Sciences (HICSS), 2000, pp. 1-10.
6. Manjeshwar and D. P. Agrawal, "TEEN: A Routing Protocol for Enhanced Efficiency in Wireless Sensor Networks," in Proceedings of the 15th International Parallel and Distributed Processing Symposium (IPDPS), 2001, pp. 2009-2015.
7. L. Qing, Q. Zhu, and M. Wang, "Design of a Distributed Energy-Efficient Clustering Algorithm for Heterogeneous Wireless Sensor Networks," in Computer Communications, vol. 29, no. 12, pp. 2230-2237, 2006.
8. M. Handy, M. Haase, and D. Timmermann, "Low-Energy Adaptive Clustering Hierarchy with Deterministic Cluster-Head Selection," in IEEE MWCN, 2002, pp. 368-372.