

ENERGY-EFFICIENT ROUTING AND CLUSTERING IN WSN AND IOT NETWORKS USING ARTIFICIAL INTELLIGENCE ALGORITHMS

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Abstract. This paper reviews AI-based approaches for energy-efficient routing and clustering in WSN and IoT networks, including Particle Swarm Optimization, Ant Colony Optimization, Genetic Algorithms, fuzzy logic, and Artificial Neural Networks. Reviewed methods are compared using energy consumption, network lifetime, reliability, scalability, and computational complexity as key criteria. Results show that different AI techniques offer distinct advantages depending on network conditions, while computational complexity, parameter tuning, and multi-objective optimization remain key challenges. Joint and adaptive optimization of routing and clustering is identified as a promising direction for sustainable WSN/IoT networks.

Keywords: Wireless Sensor Networks, Internet of Things, Artificial Intelligence, Energy Efficiency, Routing, Clustering, Cluster-Head Selection, PSO, ACO, Genetic Algorithm.

INTRODUCTION

Wireless Sensor Networks (WSNs) are an important communication technology for Internet of Things (IoT) applications, enabling distributed sensing and wireless data transmission. However, sensor nodes have limited energy resources, making energy consumption a major factor affecting network lifetime and reliability [1]. Routing and clustering strongly influence energy consumption. Clustering groups sensor nodes and uses cluster heads to collect and aggregate data, while routing determines how information reaches the sink or base station. Cluster-head selection is a multi-criteria problem involving factors such as residual energy, distance, and network conditions [2].

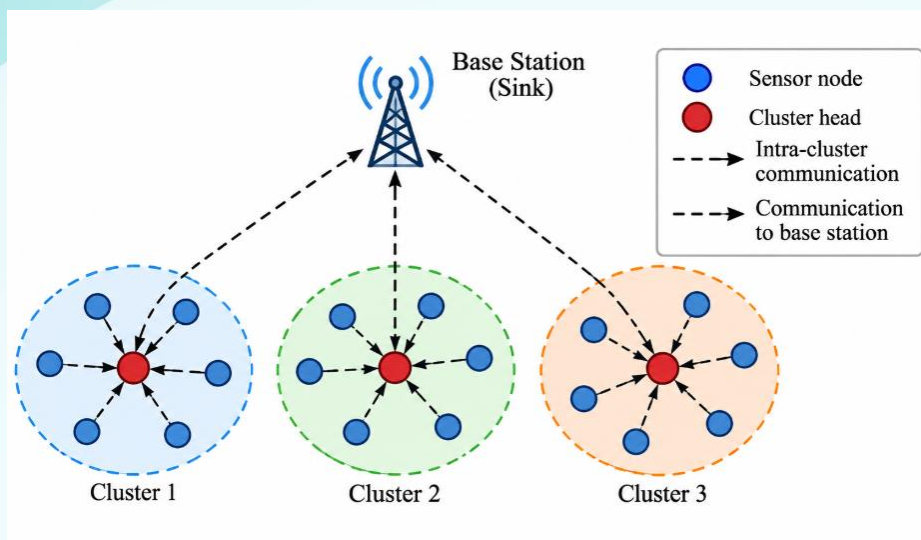


Figure 1. Architecture of a clustered Wireless Sensor Network (WSN)

Artificial Intelligence (AI) techniques, including Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Genetic Algorithms (GA), fuzzy logic, and neural networks, have therefore been investigated for clustering, cluster-head selection, routing, and data aggregation [1], [3]. Their application can improve decision-making and energy distribution, but computational complexity, parameter tuning, scalability, and adaptation to dynamic networks remain important challenges [3], [4], [9]. This review analyzes AI-based approaches for energy-efficient routing and clustering in WSN and IoT networks, comparing their applications, advantages, limitations, and research gaps.

METHODS AND METHODOLOGY

This study uses a comparative literature-review methodology to analyze AI-based approaches for energy-efficient routing and clustering in Wireless Sensor Networks (WSNs) and Internet of Things (IoT) networks. The reviewed studies are classified according to the AI techniques used, including fuzzy logic, Artificial Neural Networks (ANN), Genetic Algorithms (GA), Particle Swarm Optimization (PSO), and Ant Colony Optimization (ACO) [1], [4], [5], [6]. The analysis focuses on the main applications of these techniques in routing, clustering, cluster-head selection, and data aggregation. Particular attention is given to network parameters such as residual energy, communication distance,

link quality, and network conditions. The approaches are compared using energy consumption, network lifetime, Packet Delivery Ratio (PDR), delay, throughput, scalability, and computational complexity as the main evaluation criteria [2], [3], [7], [8]. The reviewed methods are also analyzed according to whether routing and clustering are optimized separately or jointly. Finally, their main advantages, limitations, and research gaps are identified, with particular attention to computational complexity, scalability, multi-objective optimization, and adaptation to dynamic network conditions [1], [4], [9], [10].

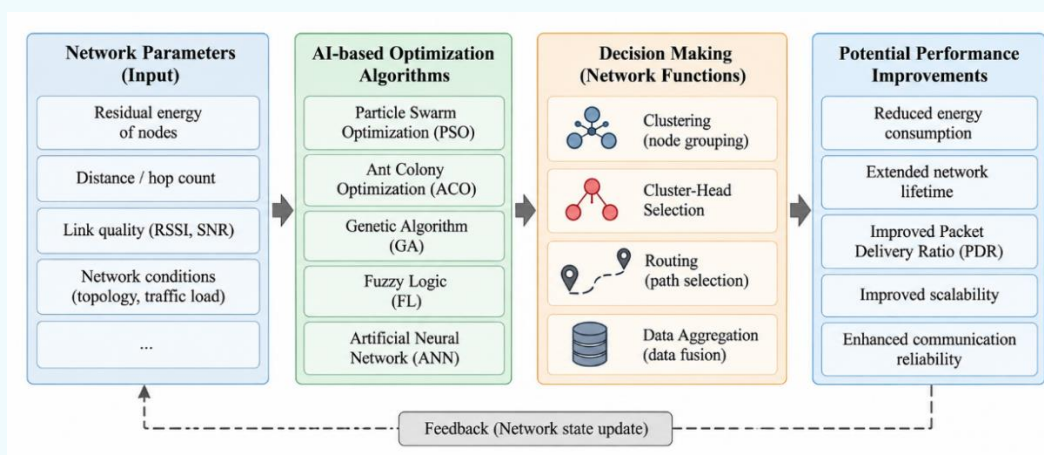


Figure 2. Conceptual representation of AI-based routing and clustering in WSN/IoT networks

This methodology provides a basis for identifying the most promising AI-based approaches for developing energy-efficient and sustainable WSN and IoT networks.

RESEARCH RESULTS

The analysis of the reviewed studies shows that AI-based methods can improve routing, clustering, and data aggregation in WSNs, although their effectiveness depends on the network architecture and optimization objectives [1], [2], [5], [7]. Particle Swarm Optimization (PSO) is commonly used for clustering and cluster-head selection. It can optimize several network parameters simultaneously and improve energy distribution, but its performance depends on parameter settings and may introduce computational overhead [1], [3]. Ant Colony Optimization (ACO) is mainly applied to routing and multi-hop path selection,

where it can reduce transmission distance and energy consumption. However, its iterative nature and parameter tuning can increase computational requirements [1], [2], [6], [8]. Fuzzy logic supports cluster-head selection and routing by combining parameters such as residual energy and distance. Its main limitation is the dependence on predefined rules and membership functions [1]. Artificial Neural Networks (ANNs) provide learning-based optimization for routing and data management, but training and execution may require additional computational resources [9], [10]. Genetic Algorithms (GAs) and hybrid methods can address complex multi-objective optimization problems, although their computational complexity may increase with network size [1], [4].

Table 1.

Comparative analysis of AI-based approaches for WSN/IoT routing and clustering

AI method	Main application	Main advantage	Main limitation
Fuzzy Logic	Clustering, CH selection, routing	Adaptive decision-making	Dependence on rules and membership functions
PSO	Clustering, CH selection	Effective optimization of multiple parameters	Parameter sensitivity and computational overhead
ACO	Routing and path selection	Suitable for multi-hop routing	Iterative search and parameter tuning
ANN	Routing, prediction, optimization	Learning-based decision-making	Training and computational requirements
GA	Clustering, routing, data aggregation	Flexible global optimization	High computational complexity
Hybrid methods	Routing and clustering	Combination of complementary	Increased algorithmic complexity

		techniques	
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The comparison indicates that no single AI technique is optimal for all WSN and IoT scenarios. PSO and GA are mainly suitable for clustering and optimization, while ACO is commonly applied to routing. Fuzzy logic supports decision-making under uncertain conditions, whereas ANN provides learning capabilities [1], [4]. The literature also indicates a growing need for joint routing and clustering optimization, since cluster-head selection directly affects routing efficiency and energy consumption [2], [3]. However, computational complexity, parameter tuning, scalability, and multi-objective optimization remain important challenges. Future approaches should therefore focus on adaptive and computationally efficient methods that jointly optimize routing and clustering while balancing energy consumption, network lifetime, reliability, and communication performance [2], [4], [7], [9].

CONCLUSION

This review shows that artificial intelligence has significant potential for improving energy efficiency in WSN and IoT networks through intelligent routing and clustering. Different AI techniques provide different advantages: optimization methods are effective for routing and cluster-head selection, while fuzzy and learning-based approaches offer adaptive decision-making. However, computational complexity, parameter tuning, training requirements, and scalability remain important challenges. The most promising direction is the joint optimization of routing and clustering, considering residual energy, communication distance, link quality, and network load. Future AI-based solutions should aim not only to reduce energy consumption but also to extend network lifetime while maintaining reliable data transmission and acceptable performance. Therefore, adaptive and computationally efficient AI-based approaches can provide a strong basis for developing more sustainable WSN and IoT networks.

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