Reinforcement Learning Driven Hybrid Clustering for Energy Optimization in IoT-WSNs

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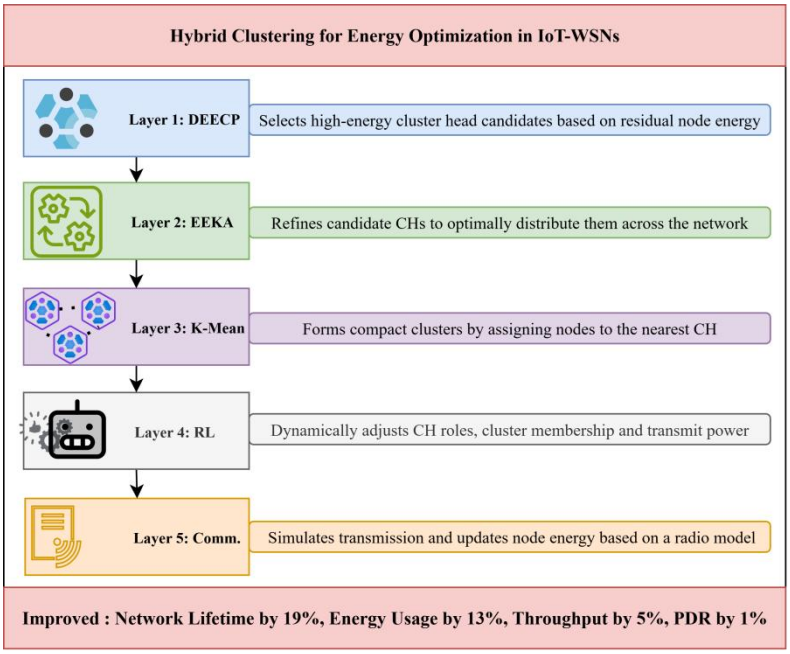
***Abstract*—In the realm of the Internet of Things (IoT), Wireless Sensor Networks (WSNs) serve as a core technology, enabling diverse applications that include urban infrastructure management, industrial automation and environmental observation. Despite their widespread adoption, the energy efficiency and adaptive clustering remain key challenges in prolonging the lifetime of WSNs within IoT environments. Traditional clustering algorithms such as Low-Energy Adaptive Clustering Hierarchy (LEACH) and Distributed Energy-Efficient Clustering (DEEC) often suffer from uneven energy consumption and static decision making, limiting it's scalability in dynamic network conditions. To address these limitations, this paper proposes a Reinforcement Learning Driven Hybrid Clustering (RLHC) framework that integrates DEEC, Energy Efficient Knapsack Algorithm (EEKA) and K-Means with the Q-Learning based adaptive optimization. In the proposed method, DEEC identifies high-energy cluster head (CH) candidates, EEKA ensures energy balanced as well as uniform spatial distribution of CHs and K-Means forms compact clusters to minimize intra cluster distances. The Q-Learning agent dynamically learns the optimal adjustment strategy by observing network states defined by residual energy, cluster load and packet delivery ratio (PDR) and executes actions such as CH switching, member reassignment and transmission power tuning. Through continuous interaction with the environment, the agent gradually converges toward energy-optimal configurations. Simulation results demonstrate that the proposed RLHC method significantly enhances network lifetime, PDR and energy balance compared to optimized algorithms built on top of LEACH and DEECP. The improvements include a 19% increase in network lifetime, 13% reduction in energy consumption, 5% higher throughput and 1% improvement in PDR. This hybrid intelligence approach provides a scalable and adaptive solution for next-generation IoT based WSN applications.**



***Keywords*—Reinforcement Learning (RL), Q-learning, Wireless Sensor Networks (WSNs), Distributed energy-efficient clustering (DEEC), Energy Efficient Knapsack Algorithm (EEKA), Energy Optimization, Internet of Things (IoT), K-Means Clustering.**

I. Introduction

Wireless Sensor Networks (WSNs) have emerged as a fundamental component of modern Internet of Things (IoT) ecosystems, enabling intelligent monitoring and data acquisition across diverse domains such as environmental observation, healthcare, smart agriculture and industrial automation [1], [2]. A WSN typically consists of numerous sensor nodes that collaboratively sense, process and transmit data to a base station. However, these nodes operate with constrained energy, limited computation and short communication ranges, making energy management a critical concern [3]. The efficient utilization of energy resources directly determines the network lifetime, data delivery reliability and overall system performance. Consequently, energy-aware clustering and routing protocols have become the cornerstone of sustainable WSN design.

Traditional clustering protocols such as LEACH and DEEC, along with their optimized successors such as EEKA have demonstrated notable improvements in balancing energy consumption through probabilistic cluster head (CH) selection and hierarchical communication [4]–[6]. However, these algorithms often rely on static parameters and lack adaptability to dynamic network states, resulting in premature node death and uneven energy distribution.