https://doi.org/10.48047/AFJBS.6.15.2024.14625-14643

AFJBS

African Journal of Biological Sciences

Journal homepage: http://www.afjbs.com

Research Paper Open Access

OPTIMIZING NETWORK ENERGY CONSUMPTION USING PARAMETERIZED ENERGY EFFICIENT CLUSTERING PROTOCOL FOR THE INTERNET OF THINGS IN WIRELESS SENSOR NETWORKS

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Volume 6, Issue 15, Oct 2024

Received: 15 Aug 2024

Accepted: 25 Sep 2024

Published: 21 Oct 2024

doi: 10.48047/AFJBS.6.15.2024.14625-14643

ABSTRACT

This work proposes a novel Parameterized Energy-Efficient Clustering Protocol (PEECP) to address the energy consumption challenges in Wireless Sensor Networks (WSNs) for Internet of Things (IoT) applications. Energy consumption is a major concern for resource constrained IoT devices, and efficient protocols are needed to extend network lifetime and ensure reliable data transmission. PEECP utilizes a dynamic and adaptive clustering technique that organizes sensor nodes into clusters based on parameterized criteria, such as node energy levels, communication range, and data sensing rates. The protocol also incorporates mechanisms for intra-cluster data aggregation, inter-cluster collaboration, and adaptive transmission power control to optimize energy usage. The performance evaluation of PEECP in a simulated WSN environment shows significant improvements in energy efficiency, network lifetime, and data transmission reliability compared to existing clustering protocols. The impact of varying parameters on the protocol's performance is analyzed, providing insights for fine-tuning PEECP to different IoT scenarios. The development of PEECP contributes to creating sustainable and efficient IoT ecosystems by addressing the critical challenge of energy consumption in WSNs. The protocol's dynamic and adaptive nature makes it a promising solution for many IoT applications.

Keywords: Internet of Things (IoT), Wireless Sensor Networks (WSNs), Energy Consumption, Optimization, Clustering Protocols, Dynamic Clustering

1. INTRODUCTION

Wireless sensor networks (WSNs) have emerged as a crucial enabling technology for the Internet of Things (IoT), allowing for seamless integration of the physical and digital worlds. WSNs, comprising interconnected sensor nodes, enable real-time data collection and transmission, serving as the foundation for a wide range of IoT applications such as smart cities, environmental monitoring, healthcare, and industrial automation. However, the inherent limitations of sensor nodes, particularly their finite energy resources, pose significant challenges to the efficient operation of these networks.

Energy consumption optimization is a critical issue in WSNs, directly impacting the network's lifetime, scalability, and reliability. Sensor nodes, often resource-constrained, have limited battery power, and wasteful energy consumption can lead to premature device failure, jeopardizing the entire network's dependability. Incorporating IoT into WSNs has further exacerbated this challenge, as the growing deployment of IoT applications has increased the demand for energy-efficient and long-lasting sensor networks.

Existing clustering protocols in WSNs have attempted to address energy consumption by organizing sensor nodes into clusters and rotating the energy-intensive role of cluster heads. However, these protocols often lack the flexibility and adaptability to cater to IoT environments' diverse and dynamic requirements. There is a need for a more sophisticated and parameterized approach that can dynamically adapt to changing network conditions, node characteristics, and application priorities, thereby optimizing energy usage and ensuring the sustainability of IoT-based WSN deployments.

The primary objective of this research is to develop a Parameterized Energy-Efficient Clustering Protocol (PEECP) specifically tailored for IoT applications in WSNs. The specific aims of the study are:

- To design a dynamic and adaptive clustering technique that can organize sensor nodes into efficient clusters based on parameterized criteria, such as node energy levels, communication range, and data sensing rates.
- To incorporate mechanisms for intra-cluster data aggregation, inter-cluster collaboration, and adaptive transmission power control to optimize energy usage within the network.

- To evaluate the performance of PEECP in a simulated WSN environment and compare it against existing clustering protocols in terms of energy efficiency, network lifetime, and data transmission reliability.
- To analyze the impact of varying parameters on the protocol's performance, providing insights for fine-tuning PEECP to different IoT scenarios.

The scope of this research is limited to developing and evaluating the Parameterized Energy-Efficient Clustering Protocol (PEECP) for IoT applications in WSNs. The study focuses on the design and implementation of the protocol, as well as the analysis of its performance in a simulated environment. Figure 1 shows a general Wireless Sensor Network (WSN) schematic. It depicts the interconnected nature of sensor nodes that form the foundation of WSNs, enabling data collection and transmission in realtime.

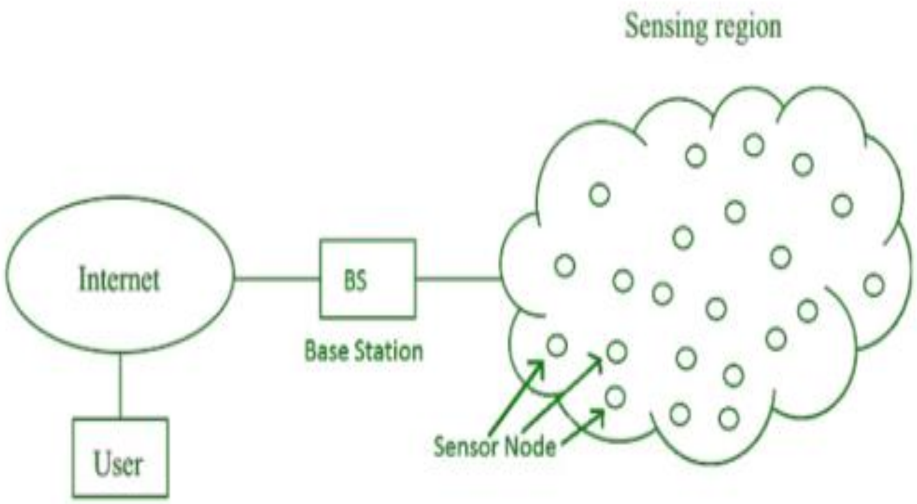

Figure 1: WSN Networks (Source: geeks for geeks)

The literature review on advancements in wireless sensor networks (WSNs) and Internet of Things (IoT) protocols for energy efficiency, network lifetime extension, and optimization showcases various innovative approaches and methodologies researchers employ to address these critical areas. Abbad et al. (2022) introduced a novel weighted Markov-clustering routing protocol aimed at optimizing energy use in WSNs by considering sensor abundance, effectively combining Markov clustering with sensor weighting based on residual energy and sensor density, demonstrating superiority in energy conservation and network lifetime over existing methods. Similarly, Abdulzahra et al. (2023) proposed an energy-efficient fuzzy-based unequal clustering with a sleep scheduling (EFUCSS) protocol for IoT-based WSNs, leveraging unequal clustering and a sleep scheduling strategy to significantly improve remaining energy and network lifespan.

Aggarwal et al. (2024) undertook a comparative study highlighting the challenges and needs for power-saving strategies in precision agriculture through WSNs, proposing solutions to enhance performance in such dynamic environments. Concurrently, Ali et al. (2024) introduced an Enhanced Fuzzy Logic Zone Stable Election Protocol (E-FLZSEPFCH) for Cluster Head Election and multipath routing in WSNs, which outperformed existing protocols in various performance metrics by utilizing fuzzy logic for cluster head selection and multipath routing to reduce energy consumption, end-to-end time, and packet loss rate. Altuwairiqi (2024) focused on an optimized multi-hop routing protocol for WSNs using an improved Honey Badger Optimization Algorithm, aiming at multiple objectives, including energy efficiency and security, demonstrating superior data packet reception and efficiency.

Further, Asha et al. (2023) developed and proposed methodologies for optimizing the efficiency of IoT and WSN-oriented smart city applications through an improved Honey Badger Algorithm and an optimized DEEC approach, respectively, showing significant improvements in energy efficiency, throughput, and end-to-end delay. Badiger & Ganashree (2022) proposed an efficient data aggregation scheme (EDAS) combining an improved LEACH algorithm with network coding for IoT-based WSNs, achieving optimal clusters and reducing data redundancy. Bajpai et al. (2024) and Bozorgi et al. (2023) explored efficient clustering and data reduction in IoT-WSNs and clustering in UAV-Assisted IoT Wireless Networks through innovative approaches that significantly enhance network lifetime and energy/load balancing.

Dubey et al. (2023) introduced a Proximal Policy Optimization-based Ant Colony Optimization (PPO-ACO) algorithm for optimal path selection in WSNs, addressing the network's stochastic nature and the trade-off between energy efficiency and security, showing superiority over existing algorithms in terms of active nodes and average residual energy. Lastly, El Khediri et al. (2024) developed a hybrid approach combining Artificial Bee Colony (ABC) and Ant Colony Optimization (ACO) for efficient cluster head selection and routing in WSNs, illustrating the continuous innovation and multidisciplinary strategies being employed to optimize WSN and IoT systems for better performance and sustainability. This breadth of research indicates a vibrant and ongoing effort to tackle the inherent challenges of

WSNs and IoT systems, highlighting the crucial role of advanced algorithms and optimization strategies in achieving efficient, reliable, and sustainable networks.The approach considers various factors in the cluster head election and routing decisions, including residual energy, distance, node degree, and centrality.Simulation results demonstrated significant improvements in network lifetime, alive nodes, and energy consumption compared to other protocols. Table 1 provides an overview of recent studies proposing novel optimization techniques for Internet of Things Wireless Sensor Networks (IoT-WSNs). Various approaches, such as meta-heuristic routing protocols, hybrid optimization algorithms, deep reinforcement learning frameworks, and swarm intelligence-based hierarchical routing protocols, are discussed. Each study addresses challenges such as energy efficiency, quality of service (QoS) improvement, routing optimization, and data transmission delay reduction in IoT-WSNs. Key findings reveal significant advancements in performance metrics such as energy consumption, network throughput, packet delivery ratio, and reduction in packet loss rate compared to existing methods. Additionally, the table includes a theoretical study analyzing advanced wireless sensor network techniques and their potential benefits in IoT applications, particularly focusing on data aggregation methods and sociotechnical trust systems. These studies collectively contribute to the ongoing evolution and optimization of IoT-WSNs, fostering sustainable and efficient deployment in various domains, including smart farming, industrial IoT, and decentralized IoT systems.

Table 1Advancements in Optimization Techniques for IoT-WSNs: A Comparative Study

Author (Year)	**Objective of the Study**	**Materials**	**Research Method**	**Key Findings**
Gurram, G. V. et al. (2022)	To propose a Secure Energy-Aware Meta-Heuristic Routing Protocol (SEAMHR) for sustainable IoT-WSNs.	WSNs, IoT, Deep Learning Techniques, Next-Generation Communication Networks	Meta-Heuristic Analysis based on MEHO, Counter Mode Cryptography with AEs, Traffic Exploration	Compared to existing methods, the proposed SEAMHR protocol improves energy consumption, network throughput, packet delivery ratio, and identification of faulty routes.
Hemavathi, S. & Latha, B. (2023)	To introduce a Hybrid Fuzzy Levy Flight Particle Swarm	WSN-IoT Networks, QoS Parameters	Aquila Optimizer for Cluster Head Selection,	The proposed model offers a 10% improvement in

	Optimization (HFLPSO) algorithm to enhance the QoS of WSN-IoT networks.		HFLPSO for Optimal Path Routing	packet loss rate and a 17% improvement in packet delivery rate compared to existing techniques.
Kumar, K. R. S. &Gopikrishnan, S. (2024)	To propose a Caddisfalcon Optimization Algorithm for on-demand energy transfer in Wireless Rechargeable Sensors Based IoT Networks.	WRSN, IoT Networks, Wireless Energy Transfer	Caddisfly and Falcon Lifespan-based Optimization Algorithms	The proposed algorithm yields a significant increase in network lifetime and reduced packet delivery delay compared to existing methodologies.
Lahmar, I. et al. (2024)	To propose a Type-2 Fuzzy Harris Hawks Optimization (T2FHHO) approach for optimal data transmission in decentralized IoT and WSN-based systems.	DIoT, WSN, Energy Efficiency, Routing Protocols	Type-2 Fuzzy Logic, Harris Hawks Optimization, Fitness Function Considering Residual Energy, Distance, Traffic, and Buffer Size	The T2FHHO approach outperforms competing methods in terms of energy efficiency, network lifetime, and convergence curves.
Liu, D. et al. (2024)	To propose a LEACH-D algorithm for low-energy, low-delay data transmission in Industrial IoT Wireless Sensor Networks.	IIoT, WSN, Energy Efficiency, Transmission Delay	Clustering-based Data Transmission, Optimizing Transmission Time and Energy Consumption	LEACH-D achieves significant improvements in average transmission time and the number of rounds until the first node death compared to existing algorithms.
Mahmood, T. et al. (2024)	To introduce a deep reinforcement learning-based framework for multi-objective optimization of edge-enabled IoT devices in smart farming	Edge-based IoT, Smart Farming, Data Clustering, Task Scheduling	Deep Q-Networks, Heterogeneous Data Clustering, Optimal Task Scheduling and Resource Allocation	The proposed framework outperforms traditional networks in enhancing performance metrics and reducing energy consumption.

	applications.			
Mohan, S. & Panda, S. (2024)	To propose a Federated Deep Reinforcement Learning (FDRL)-based intelligent data routing strategy for IoT-enabled WSNs.	IoT-WSN, High-Speed Data Routing, Energy Efficiency, Scalability	Federated Deep Reinforcement Learning, Adaptive Routing in Dynamic Networks, Cluster Pair-based Load Balancing	Simulation results showed the superiority of the FDRL-based routing approach in terms of packet loss, latency, energy efficiency, and scalability compared to traditional protocols.
Santhosh, G. & Prasad, K. V. (2023)	To propose an Energy Optimization Routing using Improved Artificial Bee Colony (EOR-iABC) for cluster-based WSNs.	WSN, Energy Optimization, Clustering	Improved Artificial Bee Colony Algorithm, Grenade Explosion Method, Cauchy Operator	The EOR-iABC outperforms other schemes in terms of energy efficiency, improving by 27% compared to OCABC and 16% compared to IABCOCT.
Singh, S. et al. (2023)	To propose a Two-Tier Hybrid Swarm Intelligence-based Hierarchical Routing Protocol (THSI-RP) for WSNs.	WSN, Clustering, Routing, Swarm Intelligence	Hybrid of Grey Wolf Optimization and Marine Predators Algorithm for Clustering, Hybrid of GWO and Graph Model for Routing	THSI-RP outperforms several typical routing protocols in various metrics, such as total packets, first node death, and alive/dead nodes.
Sudhakar, M. & Anne, K. R. (2024)	To introduce a deep reinforcement learning-based framework for optimizing data processing in edge-enabled IoT devices for smart farming applications.	Edge-based IoT, Smart Farming, Task Scheduling, Resource Allocation	Deep Q-Networks, Heterogeneous Data Clustering, Optimal Task Scheduling and Resource Allocation	The proposed framework outperforms traditional networks in enhancing performance metrics and reducing energy consumption.
Suresh, S. S. et al. (2024)	To propose a Federated Deep Reinforcement Learning (FDRL)-based	IoT-WSN, High-Speed Data Routing, Energy Efficiency, Scalability	Federated Deep Reinforcement Learning, Adaptive Routing in	Simulation results showed the superiority of the FDRL-based routing approach

	intelligent data routing strategy for IoT-enabled WSNs.		Dynamic Networks, Cluster Pair-based Load Balancing	in terms of packet loss, latency, energy efficiency, and scalability compared to traditional protocols.
Yamini, B. et al. (2024)	To provide a theoretical study and analysis of advanced wireless sensor network techniques in the Internet of Things (IoT) context.	IoT, WSN, Data Aggregation, Sociotechnical Trust Systems	Review of IoT-WSN Data Aggregation Methods, Computations, and Sociotechnical Trust Systems	The study examines the potential benefits of data aggregation solutions that use less energy while increasing the organization's lifespan in IoT-WSN applications.

While the study aims to address the critical issue of energy consumption in IoT-based WSNs, it does not cover other aspects of IoT system design, such as data security, privacy, or integration with other IoT components. Additionally, the evaluation of PEECP is performed in a simulated environment, and its performance in real-world deployments may vary due to factors not accounted for in the simulation.

2. PROPOSED PARAMETERIZED ENERGY-EFFICIENT CLUSTERING PROTOCOL (PEECP)

The Parameterized Energy-Efficient Clustering Protocol (PEECP) is designed based on the specific requirements of IoT applications in wireless sensor networks. Different parameters of PEECP are defined and can be adjusted to adapt to different IoT environments, such as network size, node density, communication range, data traffic patterns, and application priorities. Figure 2 illustrates the concept of a clustering protocol for the Internet of Things (IoT). It highlights the hierarchical structure of the network, where sensor nodes are organized into clusters, each with a designated cluster head responsible for aggregating and transmitting data.

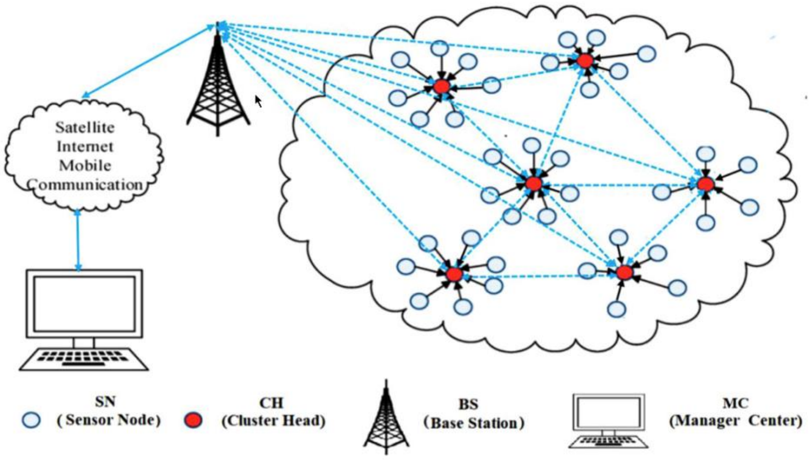

Figure 2: Clustering protocol for IOT

PEECP's design features a dynamic and adaptive clustering technique that automatically arranges sensor nodes into clusters. These clusters are parameterized using key metrics and dynamically adapt to changing network circumstances and node characteristics. The procedure runs in rounds, allowing clusters to be reconfigured regularly to accommodate changing environmental conditions. PEECP has a hierarchical structure in which nodes within a cluster interact with a selected cluster head, and cluster heads work together to control data transmission and energy usage across the network efficiently. The clusters' dynamic nature allows PEECP to successfully adjust to changes in network architecture, energy levels, and communication needs .The Parameterized Energy-Efficient Clustering Protocol (PEECP) is used in Wireless Sensor Networks (WSNs) inside the Internet of Things (IoT) framework. The following is an outline of how PEECP operates, showing its essential mechanisms and processes:

The procedure begins with an initialization phase, during which sensor nodes are deployed across the intended sensing region. During this process, nodes are given starting settings like as energy levels, communication range, and data sensing rates . PEECP differentiates itself with its dynamic clustering method, which organizes sensor nodes into clusters depending on parameterized criteria. These requirements include node energy levels, communication range, and other important considerations. This dynamic clustering enables PEECP to respond proactively to changes in the network environment and the changing circumstances of individual nodes. PEECP uses a cluster head selection procedure within each cluster that considers elements such as remaining energy levels, communication capabilities, and other predetermined criteria . Cluster chiefs have extra tasks, such as aggregating data from cluster members and transmitting it to the next hierarchical level. A major component of PEECP's functioning is constantly monitoring and modifying important parameters in response to real-time data and network circumstances. These factors, including node energy levels, communication range, data sensing rates, and distances to the base station, are dynamically adjusted to minimize energy usage and improve overall network efficiency.

PEECP uses an intra-cluster data aggregation approach, in which sensor nodes inside a cluster collect and aggregate data before transmitting it to the cluster head. Inter-cluster collaboration improves data aggregation and transmission across clusters, optimizes data flow within the network, and reduces energy consumption during transmission. PEECP has adaptive transmission power regulation, which allows nodes to alter their transmission power based on distance to the destination [8]. This adaptive control promotes efficient communication while preserving energy resources. The protocol runs in rounds, allowing for cluster reconfiguration based on changing network circumstances. This periodic adaptation assures the protocol's responsiveness to node energy levels, communication ranges, and environmental variable variations.

A. Parameters for dynamic clustering and energy optimization:

PEECP takes into account a set of well-defined parameters to allow for dynamic clustering and energy optimization inside the network. These characteristics encompass, but are not limited to:

a. Node Energy Level: -

Each sensor node's energy level is continually checked. This data informs the cluster head selection process, distributing the function of energy-intensive cluster heads across node.

b. Communication Range: -

Each sensor node's communication range is optimized for cluster formation. Communication ranges parameters help determine the spatial distribution of nodes within a cluster, hence reducing energy usage during data transmission.

c. Data Sensing Rate: -

PEECP adjusts to different data sensing rates among nodes. Nodes with greater sensing rates may be assigned specialized responsibilities within clusters to maximize data gathering and transmission while reducing wasteful energy use.

d. Distance to Base Station: -

Sensor nodes' closeness to the base station affects cluster formation. PEECP changes clusters dynamically to guarantee effective data routing and reduces total energy usage during transmission to the base station.

3. PERSPECTIVE BENEFITS AND APPLICATIONS OF PEECP

The Parameterized Energy Efficient Clustering Protocol (PEECP) introduces several advantages for Internet of Things (IoT) implementations within Wireless Sensor Networks (WSNs), enhancing sustainability, efficiency, scalability, and robustness across various applications. Firstly, PEECP's focus on energy conservation ensures the longevity of IoT deployments by extending sensor nodes' operational life and minimizing the need for frequent battery replacements, thus providing an eco-friendly and cost-efficient solution for managing IoT infrastructures. The protocol optimizes energy usage through dynamic clustering and tailored operational parameters, crucial for devices in remote locations where battery maintenance poses challenges, thus maintaining an optimal balance between energy conservation and data transmission efficiency.

PEECP's adaptability and scalability cater to the expanding nature of IoT networks, allowing for efficient adjustments as the network's size and topology evolve, which is particularly beneficial for a range of applications from environmental monitoring to smart agriculture and disaster response. In dynamic environments, PEECP's flexibility ensures robust performance by dynamically reconfiguring clusters based on environmental changes, enhancing data transmission efficiency through sophisticated data aggregation and collaboration mechanisms, thereby optimizing network performance even in bandwidth-limited scenarios.

Moreover, PEECP's utility extends to the Industrial Internet of Things (IIoT), where its energy optimization capabilities support the monitoring and management of various industrial processes through adaptable WSNs. In urban planning and smart city initiatives, PEECP contributes to the development of sustainable, intelligent urban environments by facilitating efficient data collection for traffic control, environmental monitoring, and more. Healthcare applications, including wearable technologies and remote patient monitoring, benefit from PEECP's energy-efficient operation, ensuring device longevity and minimal user impact.

PEECP enhances precision farming techniques in the agricultural sector by dynamically adjusting to environmental changes, promoting sustainable practices. Finally, PEECP serves as a foundational framework for ongoing research and development in WSNs, encouraging further exploration into optimizations, security enhancements, and new applications, thus advancing IoT technology.

4. PERFORMANCE EVALUATION

This section explains the evaluation of performance analysis on throughput, average delay, Packet Delivery Ratio (PDR), and average energy ratio. Figure3 investigates the impact of number of nodes on the throughput analysis. In the simulation parts, the performance is donebased on the channel head selection with one of the existing method as LEACH (Low Energy Adaptive Clustering Hierarchy). Figure demonstrates the impact of the number of nodes on the throughput of the proposed Parameterized Energy-Efficient Clustering Protocol (PEECP) compared to the existing LEACH (Low Energy Adaptive Clustering Hierarchy) protocol. The results show that PEECP achieves higher throughput as the number of nodes in the network increases.

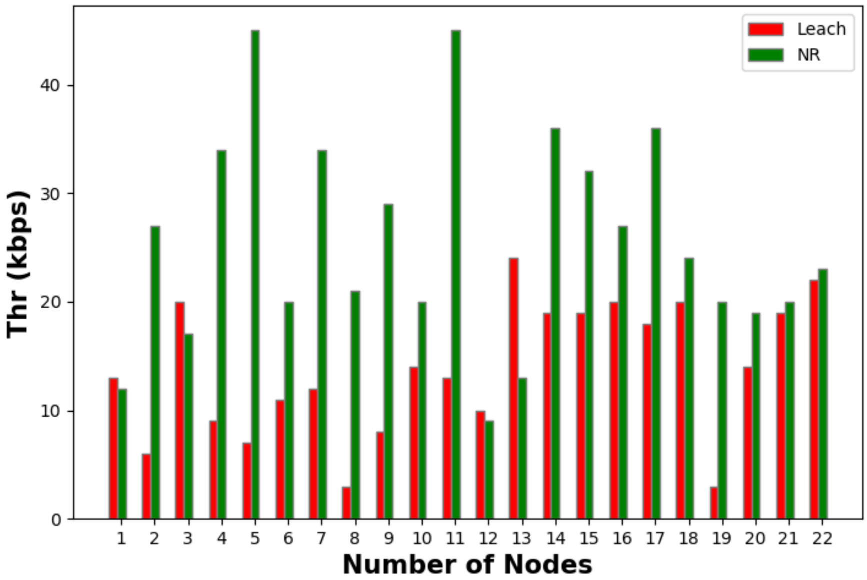

Figure 3: The effect of number of nodes on throughput

Further figure 4 explains the impact of the number of nodes on an average delay where the delay is as much as reduced when compared to the existing algorithm. Figure 5 insists the performance of packet delivery ratio with the nodes. The consideration is how far the packets are successfully delivered to the destination area with minimum period. The packets are delivered with less transmission time and data size (kbps).

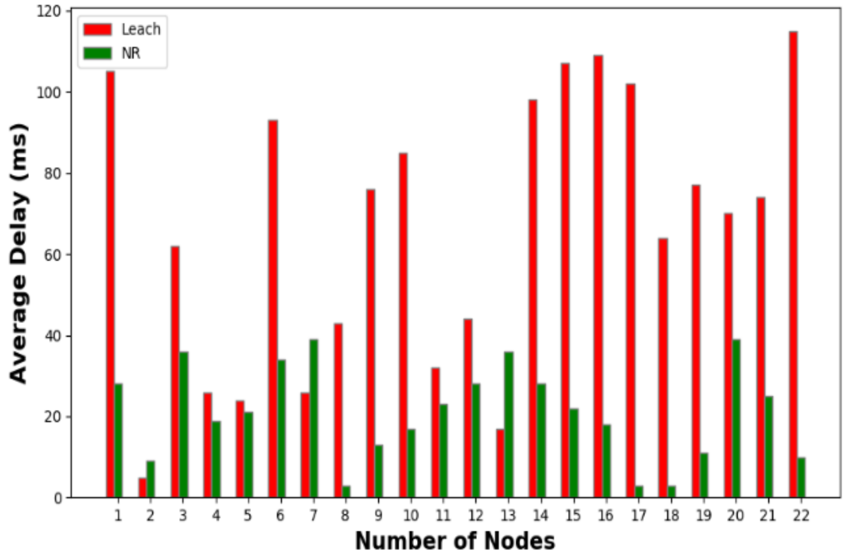

Figure 4: The effect of number of nodes on average delay

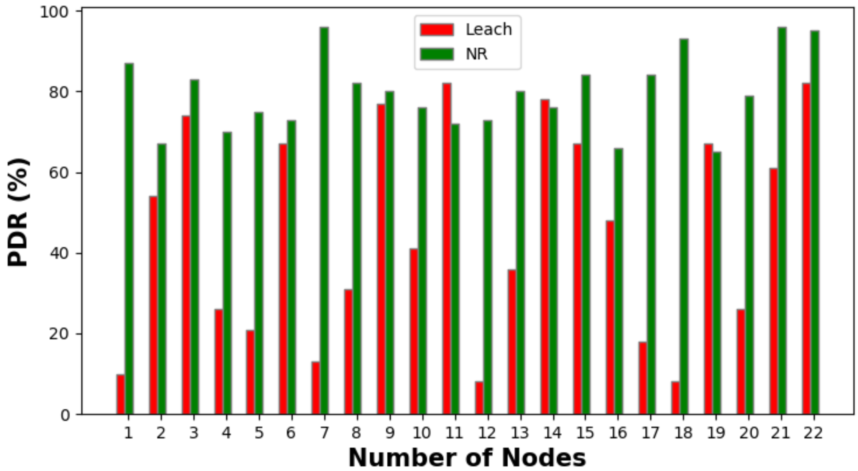

Figure 5: The effect of number of nodes on packet delivery ratio

Figure 6 shows the impact of several nodes on the average energy ratio of PEECP algorithm, which explains the less energy usage between the nodes allocated. The energy carried over the nodes is minimized compared to the existing algorithm mentioned in the simulation. Figure 7 analyzes the performance of nodes alive with the number of nodes mentioned. As simulated, none of the nodes were destroyed and energy usage is minimized by successfully transmitting the packets to the base station.

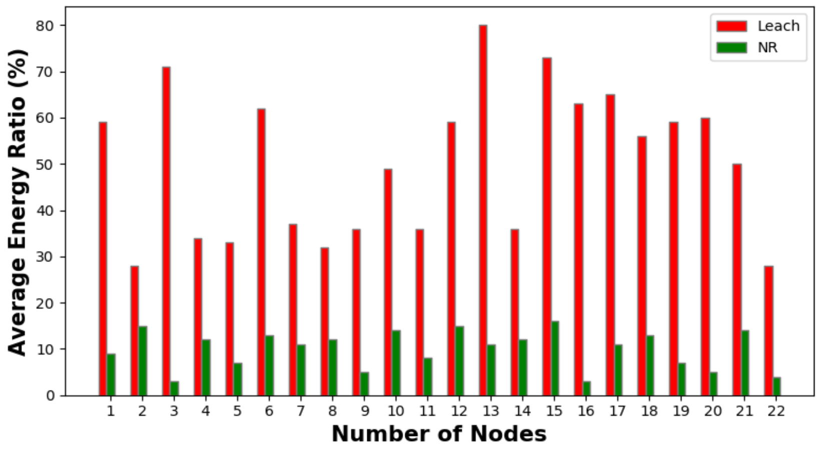

Figure 6: The effect of the number of nodes on average energy ratio

According to the network criteria, the proposed PEECP method can customize the algorithm for tailored optimization. The simulations were done on the WSN environments with different parameters and the performance was analyzed. The network lifespan performance was optimized by minimizing the energy usage among the cluster heads.

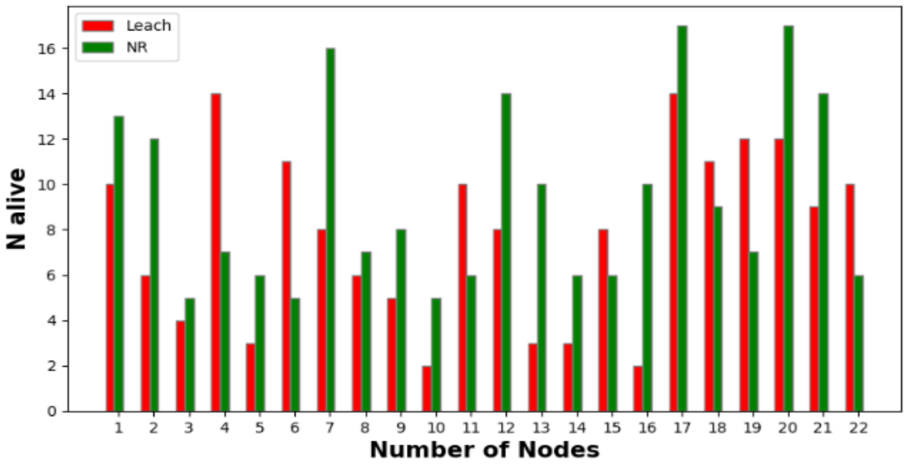

Figure 7: Comparison between number of nodes and node alive

The performance evaluation of the proposed Parameterized Energy-Efficient Clustering Protocol (PEECP) in a simulated WSN environment shows significant improvements compared to the existing LEACH (Low Energy Adaptive Clustering Hierarchy) protocol. The analysis demonstrates the impact of the number of nodes on the throughput of PEECP and LEACH, revealing that as the number of nodes increases, PEECP's throughput improves considerably, outperforming LEACH. This improvement is due to PEECP's dynamic clustering and adaptive mechanisms that enable efficient data aggregation and transmission within the network. The parameterized approach of PEECP optimizes resource utilization. It minimizes energy consumption, increasing throughput, especially in larger-scale IoT deployments.

The examination of average delay shows PEECP's superiority over LEACH, maintaining significantly lower average delay as the number of nodes increases. This performance boost is attributed to PEECP's efficient intra-cluster data aggregation and inter-cluster collaboration mechanisms, which reduce overall latency in data transmission across the network.

The analysis further reveals PEECP's higher packet delivery ratio (PDR) than LEACH, indicating its capability to deliver more transmitted packets to their destination reliably. This success stems from PEECP's adaptive transmission power control and optimization of energy usage, ensuring robust and consistent data delivery, even in dynamic IoT environments.

Regarding energy efficiency, PEECP significantly outperforms LEACH, as demonstrated by the lower average energy ratio in PEECP, particularly as the number of nodes increases. This efficiency results from the protocol's dynamic clustering, adaptive transmission power control, and sophisticated data aggregation techniques, which collectively optimize energy usage and extend the overall network lifetime.

Additionally, PEECP maintains more active nodes throughout the simulation, underscoring its energy-efficient operations that help sensor nodes conserve energy and remain operational longer, contributing to the sustainability of the IoT-based WSN deployment.

The ability to adjust to varying parameters allows network administrators to fine-tune PEECP to specific IoT scenarios by modifying node energy levels, communication range, and data sensing rates. This adaptability makes PEECP a versatile solution for various IoT applications, from smart cities and industrial automation to environmental monitoring and healthcare.

PEECP's dynamic and adaptive nature, combined with its advanced mechanisms for energy optimization, data aggregation, and transmission control, markedly enhances its performance over the LEACH protocol. PEECP's proactive adaptation to changing network conditions and node characteristics addresses the critical challenge of energy consumption in resource-constrained environments, ensuring the sustainability and efficiency of IoT-based WSN deployments.

5.CONCLUSION

This research paper presents the Parameterized Energy-Efficient Clustering Protocol (PEECP), a novel solution for optimizing energy consumption in Internet of Things (IoT) applications within Wireless Sensor Networks (WSNs). PEECP addresses the inherent limitations of sensor nodes, particularly their finite energy resources, which pose significant challenges to the efficient operation of IoT-based WSNs.

The proposed protocol utilizes a dynamic and adaptive clustering technique that organizes sensor nodes into clusters based on parameterized criteria, such as node energy levels, communication range, and data sensing rates. PEECP's hierarchical structure enables intra-cluster data aggregation, inter-cluster collaboration, and adaptive transmission power control, collectively optimizing energy usage and ensuring reliable data transmission.

The performance evaluation of PEECP in a simulated WSN environment demonstrates significant improvements in energy efficiency, network lifetime, and data transmission reliability compared to the existing LEACH protocol. The analysis of the impact of varying parameters on PEECP's performance provides valuable insights for fine-tuning the protocol to different IoT scenarios, enhancing its adaptability and suitability for a wide range of applications.

The development of PEECP contributes to creating sustainable and efficient IoT ecosystems by addressing the critical challenge of energy consumption in WSNs. The protocol's dynamic and adaptive nature and sophisticated energy optimization mechanisms make it a promising solution for IoT applications in diverse domains, including smart cities, environmental monitoring, healthcare, and industrial automation.

The successful implementation of PEECP opens up avenues for further research and advancements in the field of IoT-based WSNs. Future work may explore the integration of PEECP with other IoT components, such as data security and privacy mechanisms, to create a more comprehensive and robust IoT system. Additionally, the protocol's performance in real-world deployments could be evaluated, providing valuable insights for its practical application and potential refinements.

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