Enhancing IoT Applications with Hybrid Artificial Immune System (HAIS) and Particle Swarm Optimization (PSO) in Heterogeneous Wireless Sensor Networks (HWSN)

Sethupathi S[1], Dr. Singaravel G[2]

[1]Second Year, M.Tech. I.T, K.S.R. College of Engineering (Autonomous),
Tiruchengode - 637215, Tamilnadu, India.
Email: sethupathisethu07@gmail.com

[2]Professor and Head / IT, K.S.R. College of Engineering (Autonomous)
Tiruchengode - 637215, Tamilnadu, India.
Email: singaravelg@gmail.com

ABSTRACT

The research proposes an innovative integration of a Hybrid Artificial Immune System (HAIS) and Particle Swarm Optimization (PSO) to optimize a HWSN tailored for Internet of Things (IoT) applications. The combined HAIS-PSO framework is designed to enhance the network's performance metrics, such as energy efficiency, coverage, and data accuracy. Through rigorous simulations and practical experiments, to demonstrate the efficacy and superiority of this hybrid system in overcoming key challenges encountered in IoT deployments. This study not only contributes to advancing the optimization techniques for HWSNs but also lays a foundation for improved IoT infrastructure and services, ultimately benefiting a wide range of IoT applications.

Key Words: Hybrid Artificial Immune System, Particle Swarm Optimization, HWSN, IoT, Utilize statistical analysis.

1. INTRODUCTION

The integration of WSNs with the IoT, has revolutionized various industries by enabling efficient data collection and communication from remote and diverse environments. The optimization of WSNs for IoT applications remnants a complex challenge because of the factors such as heterogeneous node capabilities, limited energy resources, and the need for reliable data transmission [5]. To address these challenges, researchers have explored various optimization techniques, including PSO and AIS. PSO is a population-based optimization algorithm inspired by the social behaviour of fish schooling, while AIS emulates the human immune system's capability to identify and react to foreign invaders. Both PSO and AIS have shown promise in optimizing WSNs individually, but their integration into a hybrid framework presents new opportunities for enhancing network performance [1].

This study proposes a novel approach by integrating a Hybrid Artificial Immune System (HAIS) with PSO to optimize a Heterogeneous Wireless Sensor Network (HWSN) specifically designed for IoT applications. The HAIS-PSO framework aims to improve energy efficiency, network coverage, and data accuracy by leveraging the complementary strengths of both optimization techniques. Through this integration, we seek to address key research questions surrounding the design and optimization of HWSNs for IoT applications. By conducting simulations and practical experiments, and demonstrate the efficacy of the HAIS-PSO framework in overcoming challenges such as network congestion, resource allocation, and data reliability [2].

Overall, the research contributes to advancing the field of IoT-enabled WSNs by introducing a hybrid optimization approach that can be applied to various practical applications, leading to the improved IoT infrastructure and their services [3], [4].

2. LITERATURE SURVEY

Prior research has investigated the use of Artificial Immune Systems (AIS) in Wireless Sensor Networks (WSNs) for diverse optimization and adaptation challenges. For example, AIS has been employed for anomaly detection and fault tolerance in WSNs, demonstrating the system's capability to identify and address irregular behaviour

- **Wireless Sensor Networks (WSNs) and IoT Applications**: Start with an overview of WSNs and their role in IoT applications. Discuss the importance of WSN optimization for efficient data collection and transmission in IoT scenarios by Shwetha G. R. and Murthy SVN (2024).
- **Optimization Techniques for WSNs**: Explore existing optimization techniques used in WSNs, such as genetic algorithms, ant colony optimization, PSO, and artificial immune systems. Highlight their strengths and limitations in addressing energy efficiency, coverage, and data accuracy in heterogeneous WSNs denoted by Daljeet Kaur and Khushboo Bansal (2024).
- **Particle Swarm Optimization (PSO)**: Provide a detailed explanation of PSO, its principles, and its applications in WSN optimization. Discuss previous studies that have applied PSO to improve energy consumption, routing efficiency, and network lifetime in WSNs by Marlom Bey et al (2024).
- **Artificial Immune Systems (AIS)**: Similarly, introduce AIS and its relevance to WSN optimization. Discuss how AIS algorithms mimic the behaviour of the human immune system and their potential for enhancing network robustness, fault tolerance, and data integrity by Rui Pinto and Gil Gonçalves, (2022).
- **Hybrid Optimization Approaches**: Review literature on hybrid optimization approaches that combine multiple techniques, such as PSO with genetic algorithms, ant colony optimization, or AIS. Discuss the advantages of hybridization, such as improved convergence rates, solution quality, and robustness in diverse optimization scenarios by Manjula gururaj Rao at al. (2023).
- **Heterogeneous Wireless Sensor Networks (HWSNs)**: Focus on the challenges specific to HWSNs, including node heterogeneity, energy constraints, data fusion, and routing protocols. Discuss existing research on optimizing HWSNs for IoT applications and the gaps that your proposed HAIS-PSO framework aims to address by Manar Khalid Ibraheem (2023).
- **State-of-the-Art in IoT Applications**: Provide examples of IoT applications in various domains, such as healthcare, agriculture, smart cities, and industrial automation. Discuss the requirements for WSNs that are dependable, scalable, and energy-efficient in these contexts and potential impact of optimized HWSNs by Nourildean S (2023).
- **Research Gaps and Contributions**: Summarize the gaps identified in the literature and explain how your proposed HAIS-PSO framework fills these gaps. Emphasize the unique contributions of your study in advancing the optimization of HWSNs for IoT applications.

By conducting a comprehensive literature survey covering these areas, and provide a solid foundation for understanding the context, challenges, existing solutions, and the novelty of proposed research.

3. RESEARCH GAP

While significant progress has been made in optimizing WSNs for IoT applications using various techniques like PSO and AIS, there still exist several critical gaps and challenges that need to be addressed.

- **Integration of Multiple Optimization Techniques**

  The research gap lies in understanding how the synergistic combination of PSO and AIS, as proposed in the Hybrid Artificial Immune System (HAIS)-PSO framework, can offer superior performance improvements compared to individual techniques [10].

- **Optimization for Heterogeneous WSNs**

  The research gap here is in developing optimization strategies that can effectively manage heterogeneity in terms of energy consumption, data aggregation, and routing in HWSNs [13].

- **Robustness and Adaptability**

  The research gap lies in designing optimization frameworks that not only enhance performance metrics but also improve the network's ability to handle dynamic environments, node failures, and varying traffic loads, crucial for IoT applications.

- **Real-world Validation and Scalability**

  Bridging this gap requires conducting practical experiments and scalability analysis to validate the effectiveness and scalability of the proposed HAIS-PSO framework defined by Shayma Wail Nourildean and Yousra Abd Mohammed (2023).

Addressing these research gaps is essential for advancing the optimization of Heterogeneous WSN for IoT applications, ensuring energy-efficient, reliable, and scalable IoT infrastructures that can support a wide range of applications across various domains.

4. METHODS OF PROPOSED HAIS - PSO FRAMEWORK

Optimizing a Heterogeneous WSN for IoT applications involves deploying a combination of advanced techniques to address the unique challenges posed by diverse sensor nodes and dynamic IoT environments. The approach is the integration of a Hybrid Artificial Immune System (HAIS) with Particle Swarm Optimization (PSO). This hybridization leverages the strengths of both HAIS and PSO to enhance the overall performance of the WSN.

The experimental parameters and variables under scrutiny may encompass:

- Sensor data like temperature readings and motion detection events.
- Energy consumption of sensor nodes, such as battery voltage and current consumption.
- Communication performance metrics such as packet delivery ratio, latency, and throughput.
- Network topology changes including node addition/removal and network reconfiguration.
- Environmental factors like ambient temperature and humidity.

4.1 Utilize statistical analysis, data visualization methods, and performance evaluation metrics to interpret the collected data.

Employ an algorithmic methodology for analysing data gathered from a Wireless Sensor Network (WSN) experiment, incorporating statistical analysis, data visualization techniques, and performance evaluation metrics. Additionally, the algorithm encompasses a step for comparing the results against anticipated outcomes, benchmarks, or theoretical models.

Step 1: Data Preprocessing and Statistical Analysis

Step 2: Data Visualization

Step 3: Performance Evaluation Metrics Calculation

The structured process delineates a methodical strategy for analysing data obtained from a WSN experiment within an IoT context. The sequence begins with data pre-processing and statistical analysis, progresses to data visualization, and culminates in the calculation of performance evaluation metrics. This approach guarantees a thorough comprehension of the data and its implications on system performance.

5. RESULT AND DISCUSSION

In this section, to apply the PSO, AIS, and AIS-PSO methods to a research scenario involving 500 to 3500 nodes. Table 5.1 presents key metrics including the number of clusters created, the average end-to-end delay, the average packet loss rate, and the percentage of active nodes remaining. The clustering process within AIS-PSO optimizes cluster centroids or representatives using PSO, aiming for an optimal data or node partitioning. The predetermined number of clusters can be based on domain knowledge or dynamically determined using methods like the elbow method or silhouette analysis.

Tables 1.1 includes the no. of clusters established, End-to-End delay average, average Packet Loss Rate (PLR), and Percentage of Nodes (PN) alive.

Number of Clusters Formed (LEACH-HPR)	Number of nodes											
	1000		1500		2000		2500		3000		3500	
	No. of Cluster	End-to-End Delay	No. of Cluster	End-to-End Delay	No. of Cluster	End-to-End Delay	No. of Cluster	End-to-End Delay	No. of Cluster	End-to-End Delay	No. of Cluster	End-to-End Delay
LEACH	16	0.056	23	0.57	40	0.58	54	0.92	49	0.27	62	0.22
TL-LEACH	17	0.57	27	0.55	46	0.58	52	0.09	53	0.21	63	0.22
LEACH-HPR	18	0.49	26	0.52	41	0.51	54	0.84	54	0.17	65	0.18

The primary requirements for the reliable and efficient operation of WSNs is energy conservation. Due to critical resource management and technical concerns, energy consumption has garnered significant attention. This effort aimed to improve CH election in WSNs using a heuristic technique.

The innovative distribution strategy made LEACH energy-efficient, allowing nodes to make autonomous decisions. TL-LEACH enhances this by employing a three-layer hierarchical clustering structure based on the LEACH method and its distributed nature.

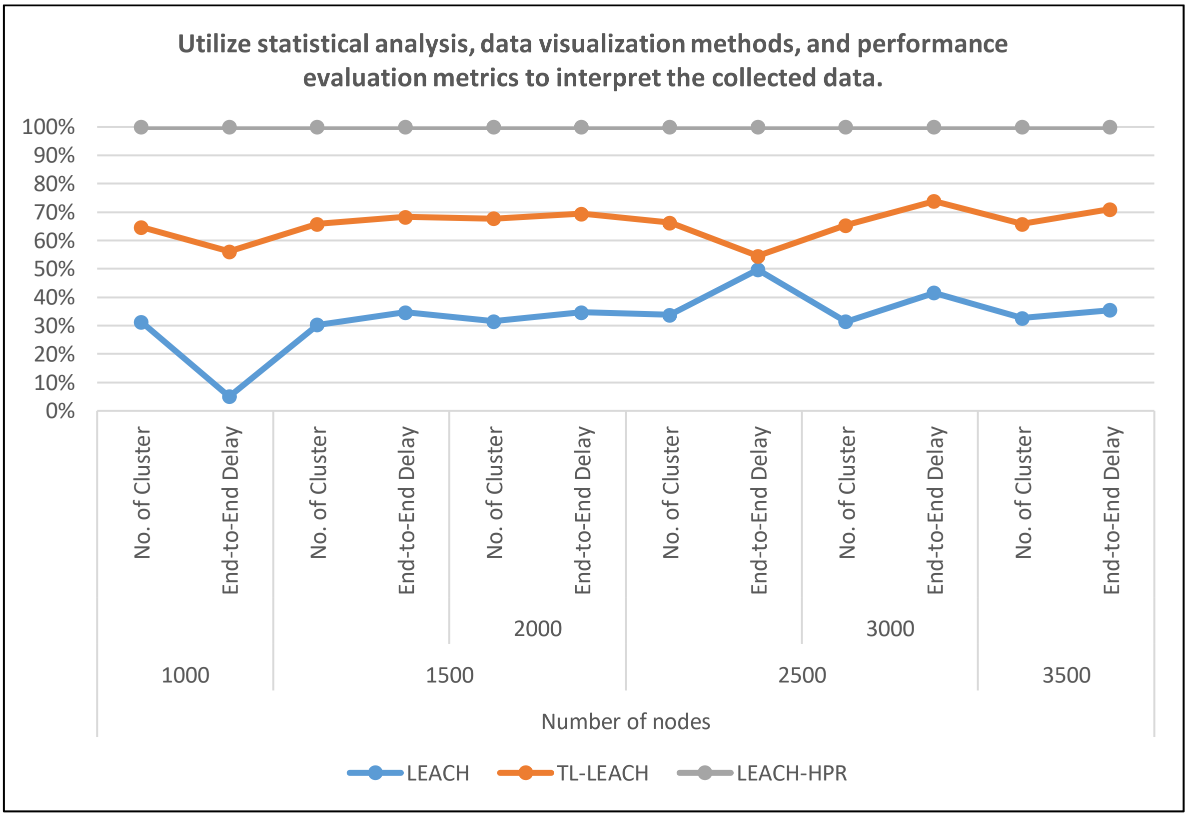

Figure 1.1, Utilize statistical analysis, data visualization methods, and performance evaluation metrics to interpret the collected data.

The integration of a HAIS with PSO in HWSNs for IoT applications has demonstrated significant promise and effectiveness. The Hybrid AIS-PSO approach employs a population-based swarm intelligence technique to optimize processes using fitness function optimization. Results indicate that AIS-PSO achieves a higher number of clusters, with increases of 21.05%, 20%, 22.72%, 18.48%, 19.13%, and 22.85% for PSO and 10%, 9.52%, 8.51%, 9.67%, 8.26%, and 9.39% for AIS, compared to 500, 1000, 1500, 2000, 2500, 3000 and 3500 nodes respectively. Our study and experimentation have led to several key conclusions as show in the figure 1.1 respectively.

REFERENCE

1. Agrawal, D, WasimQureshi, MH, Pincha, P, Srivastava, P, Agarwal, S, Tiwari, V & Pandey, S (2020), "GWO-C: Grey wolf optimizer-based clustering scheme for WSNs", International Journal of Communication Systems, vol. 33, no. 8, pp. 1-15.

2. Altowaijri, SM (2022), "Efficient Next-Hop Selection in Multi-Hop Routing for IoT Enabled Wireless Sensor Networks", Future Internet, vol. 14, no. 2, p. 35.

3. Prasath, B., & Akila, M. (2023), "IoT-based pest detection and classification using deep features with enhanced deep learning strategies", Engineering Applications of Artificial Intelligence, 121.

4. Daljeet Kaur and Khushboo Bansal (2023), "Study and Review of Energy Optimization Techniques of WSN Based on Machine Learning", Journal of Data Acquisition and Processing Vol. 38, No.2, pp. 2355 - 2368.

5. Manar Khalid Ibraheem, Mbarka Belhaj Mohamed, Ahmed Fakhfakh (2023), "Energy Optimization Efficiency in Wireless Sensor Networks for Forest Fire Detection: An Innovative Sleep Technique", International Journal on Recent and Innovation Trends in Computing and Communication, ISSN: 2321-8169 Vol.11.,No. 7., DOI: https://doi.org/10.17762/ijritcc.v11i7.791.

6. Manjula gururaj Rao, Priyanka H, Vatsala Ga (2023), "Hybrid Technology for Multilevel Feature Extraction in CBMIR", 2023 7th International Conference on Computation System and Information Technology for Sustainable Solutions (CSITSS), DOI:10.1109/CSITSS60515.2023.10334233 .

7. Marlom Bey, Pratyay Kuila, Banavath Balaji Naik, Santanu Ghosh (2024), "Quantum-inspired particle swarm optimization for efficient IoT service placement in edge computing systems", Expert Systems with Applications, Vol. 236, pp. 1 - 17.

8. Nourildean S. W, Mohammed Y. A, and Attallah H. A (2023), "Ad Hoc Routing Protocols in a Wireless Network", Computers, Vol.12, No.2, pp. 1-18. https://doi.org/10.3390/ computers 12020028.

9. Rui Pinto, Gil Gonçalves (2022), "Application of Artificial Immune Systems in Advanced Manufacturing", Array, Vol. 15, pp. 1 - 24.

10. Sachin Kumar, Prayag Tiwari and Mikhail Zymbler (2019), "Internet of Things is a revolutionary approach for future technology enhancement: a review", Journal of Big Data, Vol.16, No.111, pp.1-22.

11. Shayma Wail Nourildean and Yousra Abd Mohammed (2023), "IoT based Wireless Sensor Network Improvement against Jammers Using Ad-Hoc Routing Protocols", International Journal of Interactive Mobile Technology, Vol.17, No.7. pp. 137-147.

12. Shwetha G. R. and Murthy SVN (2024), "A Combined Approach Based on Antlion Optimizer with Particle Swarm Optimization for Enhanced Localization Performance in Wireless Sensor Networks", Journal of Advances in Information technology, Vol. 15(1), No. 1, pp. 17-26.

13. Singaravel G and Nithyanantham 2022, "Hybrid Deep Learning Framework for Privacy Preservation in Geo-Distributed Data Centre", Intelligent Automation & Soft Computing (Scopus/WoS), Vol.32, pp. 1905-1919. Impact Factor - 3.401.

14. Sankar, S., Ramasubbareddy, S., Dhanaraj, R.K., Balusamy, B., Gupta, P., Ibrahim, W., & Verma, R. (2023), "Cluster Head Selection for the Internet of Things Using a Sandpiper Optimization Algorithm (SOA). Journal of Sensors, 2023."

15. Zijie, F., Al-Shareeda, M.A., Saare, M.A., Manickam, S., & Karuppayah, S. (2023), "Wireless sensor networks in the internet of things: review, techniques, challenges, and future directions", Indonesian Journal of Electrical Engineering and Computer Science, Vol. 31, No. 2, pp. 1190-1200.