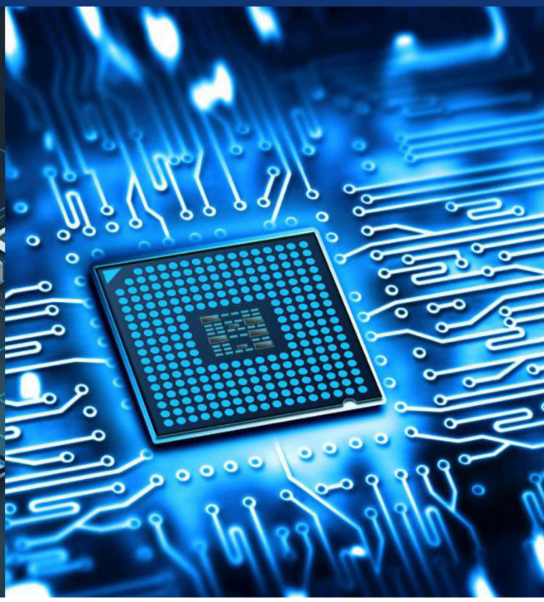
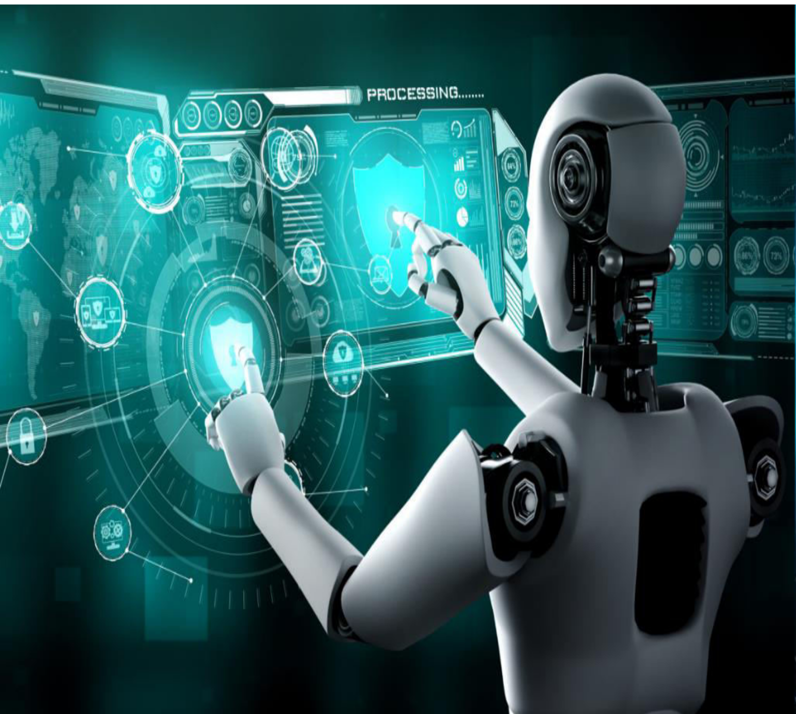
ISSN(O): 2320-9801
ISSN(P): 2320-9798


International Journal of Innovative Research in Computer and Communication Engineering

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.771

Volume 13, Issue 5, May 2025

www.ijircce.com ijircce@gmail.com +91-9940572462 +91 63819 07438

International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE)
(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

ACO-Based Cluster Head Selection: Enhancing Performance and Network Lifetime in WSNS

Manimuthu R[1] Nagaraj A[2]

PG Student, Department of ECE, Sethu Institute of Technology, Virudhunagar (Dt), Tamil Nadu, India[1]

Assistant Professor, Department of ECE, Sethu Institute of Technology, Virudhunagar (Dt), Tamil Nadu, India[2]

ABSTRACT: In Wireless Sensor Networks (WSNs), an effective clustering and Cluster Head (CH) selection is required to optimize the longevity of the network and energy consumption with maintaining the integrity of data communication. Our conventional approach of dual CH selection method in which utilizes primary and secondary CHs,offering duplication. But it mostly leads to cluster overheads and mitigated performance in dynamic systems. To address these challenges, we developed a clustering and CH selection approach using Ant Colony Optimization (ACO). The proposed ACO method leverages pheromone-based heuristics to dynamically identify optimal CHs by considering critical node attributes such as residual energy, distance from the base station, and communication cost. Comparative analysis demonstrates that the ACO-based approach outperforms traditional dual CH models in terms of energy efficiency, network lifespan, and throughput while maintaining strong fault tolerance. As a result of the simulation process, it shows that the ACO model's efficiency and ensuring its scalability and energy effective method for WSNs.

KEYWORDS: WSN, ACO, CH, Fuzzy.

I. INTRODUCTION

In the context of Information and communication Technology, the data transmission act as the basic process and plays a vital part in the communication network. Regarding wireless sensor networks (WSNs), it is crucial to develop an effective methodology for data acquisition and communication routing process which offering both theoretical data and real time merits [1,2]. These techniques can significantly reduce energy consumption, thereby achieving the prolonged existence of the network and optimizing its applicability in real time. The dispersed sensor nodes among the vast geographic locations, are capable of collecting data anytime, anywhere, and under any conditions. Eventually, WSNs emerged as the essential technique in the development of Internet of Things (IoT) and found extensive applications in various sectors, including space exploration, transportation, healthcare, manufacturing, and so on [6-8]. However, majority of the sensor nodes face significant constraints, such as limited energy, computational power, storage, and communication capabilities. Actually,these restrictions make the model aggravating where the batteries are more complex or incapable of recharge or replace it constantly [9]

The persistent and distinct transfer of data among the sensor nodes and the base station leads to rapid depletion of energy, results in minimizing the lifespan of the nodes. To tackle this issue, researchers have concentrated on strategies to optimize the sensor node's effective utilization of energy for performing tasks such as data acquisition, transmission, analysis, and processing, often through advanced applications and user interfaces. Among the many approaches proposed to address these challenges, clustering and routing protocols have proven to be some of the most effective solutions [10]. These techniques paves the way for increasing life time of the network, optimized energy efficiency with ensuring reliable data transfer[11].

A Meta-heuristic framework can manage the complex nonlinear concerns due to their great potential and dispersed characteristics.In general,improvization ability of this approach is also more effective which can handle and address the major challenges faced in NP in the wireless sensor network with less number of factors.A meta-heuristic approach is choosing the CHs and a routing pathway which develops an optimization concern with a particular objective function. The process continues regularly as long as achieved the optimal solution for the function.

A diverse algorithms which involves the cat swarm algorithm, fish migration optimization algorithm [19], ant colony optimization algorithm , and genetic algorithm, have been utilized for selecting cluster heads (CHs) and evaluating routing pathways in clustering and routing algorithms. However, many meta-heuristic frameworks frequently producing random outcomes because of their dependence on initial parameter settings. Additionally, they frequently risk getting stuck in local optima when tackling complex problems.

To overcome these challenges, combinations of different meta-heuristic approaches have been developed to tackle multi-objective problems. Examples include clustering methods based on the butterfly algorithm integrated with ant colony optimization method for routing process, enhanced duck and traveler optimization for clustering along with artificial gorilla troop optimization for routing [23], and a hybrid method using gray wolf optimization paired with the marine predator algorithm for clustering process, incorporated with hybrid gray wolf optimization and a model based on graph for routing process [12].

But, these protocols often become significantly more complex to implement. Hybrid approaches combining meta-heuristic and conventional frameworks are employed in order to achieve a balanced network performance. For example, the BAT algorithm has been integrated with fuzzy logic-based routing models, in which the fuzzy control attributes are adjusted by using the shuffled frog-leaping algorithm . Similarly, clustering based on a fuzzy logic model has been paired with particle swarm optimization for routing [13].

II. RELATED WORK

In Wireless Sensor Network (WSN) system, the sensor nodes are dispersed among the particular physical location in order to evaluate the environmental conditions like temperature, pressure, humidity ,light, seismic and vibration tasks. With this gathered physical parameters, the sensor nodes transmit it to the sink node or gateway among the collaborative (multi-hop) trend in a long period of time.
In order to enhance the cluster heads (CHs) selection process,the Butterfly Optimization Algorithm (BOA) is introduced in research [14] which establishes the objective functions by considering diverse attributes like remaining energy, proximity to adjacent nodes, distance from the base station (BS), node centrality, and node connectivity. Following this, the Ant Colony Optimization (ACO) method is used to identify the most effective transmission route from the source node to the base station through the CHs, considering factors such as BS distance, remaining energy, and node connectivity. As a result of comparison analysis of current technologies with traditional algorithms,this model shows that there is remarkable enhancement in the prolonged network life time.

A THSI-RP model is proposed in the research [12] which is a dual-layer protocol designed to perform clustering and routing operation for optimizing efficiency of the network.In the first layer,the specific function is developed to predict the most appropriate cluster heads (CHs) by taking into account the various attributes such as energy consumption, distance within clusters, CH to base station (BS) separation, and node centrality.The model incorporates the Grey Wolf Optimization (GWO) with the Marine Predator Algorithm (MPA) in order to enhance the potential of clustering identification. A THSI-RP creating a routing tree method in the subsequent layer for transmitting the data between CHs and the BS which aims to mitigate the data transmission range.

As a result of the experiment, it shows that THSI-RP optimizes the prolonged life time of the network eventhough the dual-tier framework design further enhances the complexities of the network. Concurrently, the two-level genetic algorithm [15] presented an innovative approach to tackle two issues simultaneously: cluster head selection and optimal multi-hop routing. This method incorporates the energy consumption of multi-hop routing, as determined by the second-level algorithm, as a attribute in estimating chromosomes in the first-level algorithm.

In the research [16], a new clustering and routing technique was presented by S. Jagadeesh et al.[17] To improve CH selection, OAFS-IMFO deployed the Oppositional Artificial Fish Swarm (OAFS) method, which built a desired function using, distance between CHs, residual energy and distance between CHs and cluster members (CMs). The IMFO (enhanced moth flame optimization) method was then used to determine the shortest communication channel between CHs and the BS, taking into account variables like the distance between relay CH,CH, and BS and the residual energy of CHs. Compared to other algorithms, OAFS-IMFO achieves much higher packet throughput with more energy consumption.

www.ijircce.com | e-ISSN: 2320-9801, p-ISSN: 2320-9798| Impact Factor: 8.771| ESTD Year: 2013|

International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

In the research [18], it proposed the clustering objective function was redefined as a Quadratic Unconstrained Binary Optimization (QUBO) problem, and two encoding techniques. The initial, one-hot encoding, assigns every data directs to a k-bit string. However, this approach has inherent limitations and does not fully leverage the capabilities of quantum bits. The second method, binary encoding, represents the classification of each data point by using a binary string as well as operates hierarchically. The proposed method implementation requires using commercially accessible quantum annealing hardware and "qbsolv," a traditional solver developed by D-Wave.

In research [19], the portable sink node gathers data from each node within its transmission limit along the designated route. Subsequently, it returns to its starting point upon completing an entire circuit. The challenge of determining the most effective route for a mobile sink node can be fundamentally likened to the traveling salesman problem (TSP). In order to solve the entire energy problem, Zhijie Huang et al. utilized quantum encoding methods to encode the mobile path and the Hamiltonian of the QA technique to direct the quantum revolving gate's functions.

III. METHODOLOGY

1. Sensor Nodes Deployment

The initial phase of this proposed framework involves distributing the sensor nodes as per the application among the entire relevant region in a random manner or structured patten.The sensors configured in each node are the communication system and a energy constrained source like battery.The prime concern is to make sure the nodes are implemented throughout the area of interest in order to gather the precise insights.Hence the nodes are employed in diverse settings like forests,underwater area or urban regions.

2. Calculate the Node's Properties

Following deployment, the characteristics of each node are assessed to support subsequent decision-making within the network. The primary attributes analyzed include:

•Distance: By utilizing the signal effectiveness or relevance-based measures among the physical route, each node's range from the base station or another node in the network system is estimated.

•Energy: As the sensor nodes are operating by batteries, the availability of energy is crucial for controlling the functionalities over a long period of time. It is important to estimate the sustaining energy of all sensor node.

•Location: The physical mapping of every node is evaluated oftenly by utilizing the localization protocol or GPS.An accurate location insight facilitates the cluster identification and an effective way of directing the routes.

3. Cooperative Node List

The cooperative nodes are identified from the evaluation metrics in which the node has the specific factors like adequate energy, persistent location and an appropriate distance.These nodes are then included in the cooperative node list which is an effective subset of each deployed nodes.In this stage,the nodes which satisfied the specific scenarios can be utilized for further clustering process and communication activities to optimize the energy efficacy and computational performance.

4. Cluster Formation

Based on the intimacy of the nodes and network range,the cooperative list nodes are compiled into clusters.This cluster formation classifies the the node into smaller and accessible communities which streamline the network.In this cluster process,one node in every cluster is selected as the cluster head which serves as the central network hub for all other nodes.This clustering process mitigates the power consumption by reducing the direct connection between each node and the base station.

5. Cluster Head Election utilizing Ant Colony Optimization (ACO)

This module utilizes the Ant Colony Optimization (ACO) algorithm in order to evaluate an appropriate Cluster Head (CH) for each cluster.The ANT's capacity to evaluate the quickest pathways to food resources which motivates the ACO system.The attributes involved in this framework are

•Residual Energy: The nodes with higher energy levels are chosen in order to provide the prolonged operational existence of the cluster

•Proximity to Nodes: A centralized positioning node is selected among the cluster since it reduces the transmission distance for the remaining member nodes in the network.

www.ijircce.com | e-ISSN: 2320-9801, p-ISSN: 2320-9798| Impact Factor: 8.771| ESTD Year: 2013|

International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

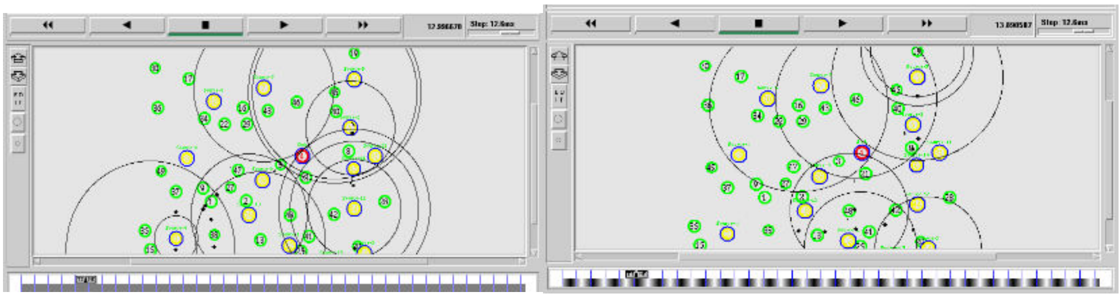
•Communication Quality: The robust network and reliable nodes are significantly the major target. The ACO algorithm is always utilized to optimize the CH selection process in order to make sure that great potential node is elected as CH.

6. Calculate the Communication Performance

Based on the cluster and cluster head formation, the transmission performance of the network is analyzed. An efficacy of the network is interpreted based on the following attributes like latency, packet delivery ratio, energy consumption and Throughput. In this process,it offers an extensive data regarding the potential of the clustering process and CH selection through ACO algorithm.Moreover,it intimates the sectors to be developed more to achieve the optimized network performance.

IV. EXPERIMENTAL RESULTS

In the simulation representation, the Wireless Sensor Network (WSN) along with clusters altering over time.The Cluster Heads (CH) are represented as yellow nodes whereas the green nodes illustrates the member nodes in the cluster. CHs are collecting the insights from member nodes and transmit to the base station.The selection of Cluster Heads (CHs) in Figures 2(a) and 2(b) is performed dynamically through an Ant Colony Optimization (ACO) algorithm, which takes into account various factors, including energy levels, distance, and load.This model offers an effective energy consumption and enhances the prolonged lifespan of the network. In order to attain an optimized network performance, the CHs facilitates an efficient communication in dynamic environment during the packet transmission process.



2 (a) 2 (b)

In figure 3(a),it clearly shows the graphical representation of the energy consumption in the network by employing two various cluster models which are Ant Colony Optimization-based Cluster Head (ACO-CH) and Fuzzy Inference System-based Dynamic Cluster Head (FIS-DCH).The ACO-CH method is represented in red line whereas the FIS-DCH in green line.The FIS-DCH consumes more energy as the number of node increases.In contrast,the ACO-CH model utilized less energy which demonstrates its efficiency.Hence,the ACO-CH algorithm seems to be the energy effective model in the wider application network.

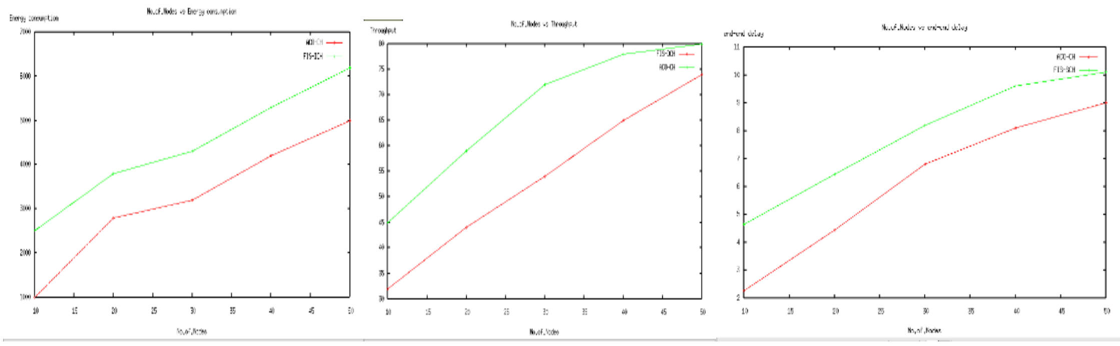
Figure 3(b) graph illustrates the Throughput of nodes within a network, employing two distinct clustering methodologies: Ant Colony Optimization-based Cluster Head (ACO-CH) and Fuzzy Inference System-based Dynamic Cluster Head (FIS-DCH). The red line illustrates the FIS-DCH minimum throughput compared to the green line of ACO-CH. Thereby establishing ACO-CH as a more energy-efficient throughput for more extensive networks.

Figure 3(c) illustrates the end-to-end delay obtained by two distinct clustering methodologies: Ant Colony Optimization-based Cluster Head (ACO-CH) and Fuzzy Inference System-based Dynamic Cluster Head (FIS-DCH). The red lines state the delay obtained by ACO-CH, whereas the green line indicates the delay attained by FIS-DCH. Hence, it proved that ACO-CH has minimum delay compared to FIS-DCH.

www.ijircce.com | e-ISSN: 2320-9801, p-ISSN: 2320-9798| Impact Factor: 8.771| ESTD Year: 2013|

International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



3 (a) 3(b) 3(c)

V. CONCLUSION

The proposed ACO-based algorithm for clustering and cluster head (CH) selection offers significant improvements in the performance of wireless sensor networks (WSNs) compared to traditional dual CH models. By dynamically choosing CHs based on energy levels, distance, and communication cost, the ACO approach reduces energy consumption, prolongs network lifespan, and ensures reliable data transmission. Simulation results show a substantial increase in throughput and fault tolerance, confirming the effectiveness of the ACO model. This study highlights that ACO-based clustering is a scalable, energy-efficient, and dependable solution for modern WSNs, overcoming the limitations of dual CH methods and meeting the needs of large-scale, dynamic deployments.

REFERENCES

1. Pandey, O.J.; Hegde, R.M. Low-latency and energy-balanced data transmission over cognitive small world WSN. IEEE Trans. Veh. Technol. 2018, 67, 7719–7733. [CrossRef]
2. Zhang, G.; Li, R. Fog computing architecture-based data acquisition for WSN applications. China Commun. 2017, 14, 69–81. [CrossRef]
3. Flammini, A.; Ferrari, P.; Marioli, D.; Sisinni, E.; Taroni, A. Wired and wireless sensor networks for industrial applications. Microelectron. J. 2009, 40, 1322–1336. [CrossRef]
4. Kafi, M.A.; Challal, Y.; Djenouri, D.; Doudou, M.; Bouabdallah, A.; Badache, N. A study of wireless sensor networks for urban traffic monitoring: Applications and architectures. Procedia Comput. Sci. 2013, 19, 617–626. [CrossRef]
5. Wu, F.; Li, X.; Sangaiah, A.K.; Xu, L.L.; Kumari, S.; Wu, L.X.; Shen, J. A lightweight and robust two-factor authentication scheme for personalized healthcare systems using wireless medical sensor networks. Futur. Gener. Comp. Syst. 2018, 82, 727–737. [CrossRef]
6. Dubois, P.; Botteron, C.; Mitev, V.; Menon, C.; Farine, P.A.; Dainesi, P.; Ionescu, A.; Shea, H. Ad hoc wireless sensor networks for exploration of Solar-system bodies. Acta Astronaut. 2009, 64, 626–643. [CrossRef]
7. Gulec, O. Extending lifetime of Wireless Nano-Sensor Networks: An energy efficient distributed routing algorithm for Internet of Nano-Things. Futur. Gener. Comp. Syst. 2022, 135, 382–393. [CrossRef]
8. Amer, A.; Abd El-Samie, F.E.; Salem, A.A.; Shokair, M.; Benaya, A.M. Secure Transmission in Wireless Sensor Networks via Reconfigurable Intelligent Surface. Digit. Signal Prog. 2023, 140, 8. [CrossRef]
9. Nguyen, L.; Nguyen, H.T. Mobility based network lifetime in wireless sensor networks: A review. Comput. Netw. 2020, 174, 24. [CrossRef]
10. Nassra, I.; Capella, J.V. Data compression techniques in IoT-enabled wireless body sensor networks: A systematic literature review and research trends for QoS improvement. Internet Things 2023, 23, 19. [CrossRef]
11. Fanian, F.; Rafsanjani, M.K. Cluster-based routing protocols in wireless sensor networks: A survey based on methodology. J. Netw. Comput. Appl. 2019, 142, 111–142.
12. Yang, X.; Yan, J.Q.; Wang, D.S.; Xu, Y.G.; Hua, G. THSI-RP: A two-tier hybrid swarm intelligence based node clustering and multi-hop routing protocol optimization for wireless sensor networks. Ad Hoc Netw. 2023, 149, 22. [CrossRef]

13. Rawat, P.; Kumar, P.; Chauhan, S. Fuzzy logic and particle swarm optimization-based clustering protocol in wireless sensor network. Soft Comput. 2023, 27, 5177–5193.
14. Maheshwari, P.; Sharma, A.K.; Verma, K. Energy efficient cluster based routing protocol for WSN using butterfly optimization algorithm and ant colony optimization. Ad Hoc Netw. 2021, 110, 15.
15. Kaedi, M.; Bohlooli, A.; Pakrooh, R. Simultaneous optimization of cluster head selection and inter-cluster routing in wireless sensor networks using a 2-level genetic algorithm. Appl. Soft. Comput. 2022, 128, 11. [CrossRef]
16. Jagadeesh, S.; Muthulakshmi, I. A novel oppositional artificial fish swarm based clustering with improved moth flame optimization based routing protocol for wireless sensor networks. Energy Syst. 2022, 1–21. [CrossRef]
17. Potthuri, S.; Shankar, T.; Rajesh, A. Lifetime Improvement in Wireless Sensor Networks using Hybrid Differential Evolution and Simulated Annealing (DESA). Ain Shams Eng. J. 2018, 9, 655–663. [CrossRef]
18. Kumar, V.; Bass, G.; Tomlin, C.; Dulny, J. Quantum annealing for combinatorial clustering. Quantum Inf. Process. 2018, 17, 14. [CrossRef]
19. Huang, Z.J.; Zhang, J.L.; Wu, M.Q.; Li, X.; Dong, Y.M. Evolutionary Method of Sink Node Path Planning Guided by the Hamiltonian of Quantum Annealing Algorithm. IEEE Access 2021, 9, 53466–53479

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN COMPUTER & COMMUNICATION ENGINEERING

9940 572 462 6381 907 438 ijircce@gmail.com

www.ijircce.com

Scan to save the contact details