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Original Article

Modified Leach Ant Colony Optimization Hybrid Algorithm for Energy-Harvesting Wireless Sensor Network

Angeeta Hirwe Chouhan[1], Nitin Kumar Jain[2], Ravi Sindal[3]

[1,2]*Department of ECE, IPS Academy, Institute of Engineering & Science, Madhya Pradesh, India.*
[1,3]*Department of ECE, DAVV, Institute of Engineering & Technology, Madhya Pradesh, India.*

[2]*Corresponding Author : nitinkumarjain@ipsacademy.org*

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Abstract - *Wireless Sensor Networks (WSNs) comprise a multitude of sensor nodes distributed in a random fashion across the designated area. These nodes are responsible for monitoring and recording physical data from their surroundings. Subsequently, they transmit this collected information to a central base station using wireless communication. Two critical applications of WSNs include biomedical and environmental monitoring. However, in challenging environments, replacing the sensor node's battery is nearly impractical once the sensor node's battery is fully depleted. Consequently, maintaining the network's lifespan and ensuring reliable communication between nodes in such harsh conditions pose significant challenges for researchers. This research aims to enhance both the survivability of the network and its Network Throughput (N_{Th}). To achieve this, a simplified energy harvesting model is employed to enhance the network's ability to survive in challenging conditions. This paper introduces a novel hybrid scheme for selecting Cluster Heads (CH) in energy harvesting WSNs, which is termed Modified Leach Ant Colony Optimization (MLACO). This scheme not only enhances the Network Throughput but also improves the network's overall survivability. Comparative analysis against existing clustering methods like MLEACH and FEEDC reveals that the proposed MLACO scheme outperforms both of them. On average, MLACO exhibits a 31.5% higher network throughput compared to MLEACH and a 26.6% improvement over the FEEDC CH selection strategy. Moreover, the network survivability demonstrated by the proposed scheme is consistent with that of established methods and surpasses them, particularly between 900 and 1300 rounds.*

Keywords - *Solar Harvested Energy Wireless Sensor Network (SHE-WSN), Network's lifespan, Network survivability, Cluster Heads (CHs), Network throughput.*

1. Introduction

A Wireless Sensor Network (WSN) comprises a multitude of minuscule electronic devices referred to as Sensor Nodes (SNs). These SNs assume a crucial role across various domains, such as real-time environmental monitoring, Bio-Medical engineering [1], bridge surveillance [2], agriculture [3], military applications, and more. Typically powered by external batteries, these SNs face a significant challenge when these batteries are completely depleted, rendering battery replacement nearly infeasible.

To tackle this issue, several solutions have been considered to employ energy harvesting systems, thereby enhancing the battery efficiency of SNs and extending the overall WSN lifespan [4]. Among the available options, solar cells emerge as one of the most promising energy harvesting solutions [5]. Energy efficiency holds paramount importance in the deployment of expansive WSNs [1]. Yet, the network's lifespan and survival duration also pose substantial concerns, particularly when nodes are positioned in hostile environments. Consequently, in such scenarios, both energy efficiency and network lifespan become pivotal considerations. Clustering has proven to be an effective strategy for curtailing energy consumption and enhancing the WSN's survival duration [2].

The approach outlined in this study encapsulates a pragmatic WSN setup featuring sensor nodes equipped with solar energy-harvesting capabilities. This setup also accounts for the inherent variability in the initial energy levels of SNs and the decision-making process for routing. A solar model is constructed by taking into account various solar conditions in Figure 1. In this paper, a novel hybrid scheme, referred to as Modified Leach Ant Colony Optimization (MLACO), is introduced. This scheme amalgamates the principles of modified LEACH and ant colony optimization. MLACO not only facilitates the selection of cluster heads but also offers guidance for optimal routing decisions within the scenario. Through simulation results, it becomes evident that the proposed MLACO strategy significantly enhances the WSN's throughput and network survivability in comparison to existing methodologies. The foremost part of the work is as follows:

1. The employment of Modified Leach (ML) takes centre stage in Cluster Head (CH) selection due to its computational efficiency. In this study, ML is harnessed to opt for CHs based on their remaining energy levels.
2. Ant Colony Optimization (ACO) finds its application in establishing the shortest route between CHs and the Base Station (BS) due to its adeptness in rapidly deriving solutions in WSNs. To address the challenge of unpredictable convergence times, this research enhances ACO by integrating considerations of node degree, distance, and residual energy.
3. The advancement in choosing efficient CH and optimal path determination for data transmission via ACO enhances both network survivability and throughput. Moreover, by choosing a better route in terms of distance, the BS achieves a higher overall packet reception rate.
4. Creating a solar-powered battery recharging framework to enhance network resilience. This form contributes to an extended lifespan for WSNs by appropriate selection of CH and better selection of route between CH and BS.

The remaining part of this paper is structured as follows: Section 2 outlines the problem description. Section 3 delves into an exploration of prior research concerning the selection of CHs. Section 4 outlines the discourse on energy dissipation and the energy harvesting model. Moving on to Section 5, the system model is expounded upon, followed by the introduction of the proposed MLACO scheme. Section 6 entails a comprehensive discussion of simulation parameters and the resultant findings. Lastly, Section 7 encapsulates the conclusion of the paper.

2. Literature Review

When faced with scenarios where direct transmission of data is either unfeasible or demands excessive energy consumption, clustering techniques become essential tools for managing large systems [6]. Consequently, a considerable body of research has focused on clustering within WSNs, with a primary emphasis on optimizing energy efficiency [7]. The Low-Energy Adaptive Clustering Hierarchy (LEACH) [8] emerges as a pivotal mechanism for CH selection, strategically employing random selection to achieve a balanced distribution of the energy load among the nodes that are available. In LEACH, each individual sensor node produces a randomly generated number within the range of 0 to 1. This Random Number (RN) is subsequently compared to a Threshold Value (TV), denoted as T(Z), which is computed using a specific formula.

$$T(Z) = \begin{cases} \dfrac{q}{1 - q * (n \, mod \dfrac{1}{q})} & if\ Z \in G \\ 0 & else \end{cases}$$

In this context, the parameter q signifies the percentage of Cluster Heads (CHs), n denotes the present round, and Z represents the count of nodes that refrained from CH selection in the preceding 1/q rounds. Nodes with an RN below the TV are designated as new CHs.

Furthermore, each CH sends a piece of singular text information to its cluster neighbors, encouraging participation and cluster membership based on signal strength. Subsequently, within the established clusters, member nodes send data to their designated CHs according to the time slot of the node as per the schedule of TDMA. After that, CH forwards the received data to BS for further processing. LEACH aims to distribute energy loads equitably among Sensor Nodes (SNs) using the round-robin technique to rotate CHs.

Nevertheless, energy consumption between rounds remains unaccounted for, leading to suboptimal energy management and efficiency. Barranidharavi et al. introduced a Fuzzy-based Distributed Unequal Clustering (DUCF) algorithm, where the design of fuzzy rules relies on metrics such as distance from the Base Station (BS), residual energy of nodes, and nodal degree. The outcomes demonstrate the superiority of DUCF over LEACH in terms of network longevity and utilization of energy. Another fuzzy clustering algorithm is introduced in [10], incorporating fuzzy input variables like node-to-BS distance, node centrality, hop count, residual energy, and node density.

Additionally, previous research papers discusses various cooperative Wireless Sensor Network (WSN) relay selection schemes, aiming to mitigate multi-path fading effects and enhance network throughput and survivability. In [11], the Clustering with Robust Routing (CRR) protocol was presented. The routing determinations are guided by factors such as traffic density and residual energy.

Additionally, CRR enhances route maintenance and optimizes load distribution, initiating maintenance routines to mitigate unnecessary energy expenditure. Energy equilibrium among nodes is achieved through CRR; however, emphasis is placed on the residual energy of nodes over the distance between nodes and the BS.

In [12], it introduces a novel clustering approach for the Internet of Things, focusing on message reduction and cluster lifespan improvement. Various clustering algorithms are extensively reviewed and discussed in [13-16]. By incorporating CHs throughout the network, LEACH can enhance cluster management, reduce routing packet count, and conserve network power [17]. However, its dynamic and random CH selection results in uneven cluster distribution and energy load [17]. To address this, Liang Zhao et al. propose a Modified LEACH (MLEACH) that considers residual energy for CH selection. Nevertheless, the distance between CH and BS isn't accounted for during data routing, leading to inefficient communication in large sensor networks.

3. Problem Description

Present WSN dilemmas include the imperative consideration of objective function selection to foster energy efficiency within the network. Notably, approaches presented in [11] and [19] prioritize the residual energy of nodes in clustering to enhance energy efficiency. However, a true reduction in network energy consumption is achieved when techniques consider energy and distance between the nodes, both parameters simultaneously. Effective energy-efficient WSN solutions must be adaptable for all types of applications. Additionally, direct transmission of information from CH to the base station in WSN [17] escalates energy consumption and also leads to issues of packet loss.

Furthermore, fuzzy-based routing [10, 18] exacerbates packet loss across networks as a result of a combination of proactive and reactive algorithms. Moreover, node deployment in harsh environments renders sensor nodes unreliable and prone to faults, amplifying energy consumption concerns during data transmission. Inadequate node energy levels contribute to packet drops during transmission, underscoring the criticality of energy management in sustaining WSN functionality.

To address these concerns, a novel hybrid algorithm named MLACO, is proposed for CH selection and routing decisions in WSNs. The proposed algorithm prioritizes factors like the degree of a Node (ND), Residual Energy (E_{res}), and distance between cluster head and Base Station ($D_{CH,BS}$) to determine the optimal path between CHs and the BS.

4. Energy Model

4.1. Energy Harvesting Model

The principal objective of integrating solar energy harvesting into Wireless Sensor Networks is to enhance the operational lifespan of the network, quantified by the duration until the depletion of the first node's battery. In SHE-WSN, nodes with depleted batteries can resume operation during the subsequent energy collection cycle.

This establishes a scenario in which energy-neutral operation becomes feasible when a node's harvested energy exceeds the energy dissipated from the system [19]. Examine diverse energy source models in reference [20], classifying them into controlled, uncontrolled, fully controlled, and partially controlled categories. Solar energy is classified as uncontrolled but predictable, especially when understanding diurnal cycles. In such cases, the accuracy of prediction models can be improved by using precise forecasting models tailored to the specific WSN deployment location. Solar energy offers a significant advantage over other forms of energy due to its relatively predictable nature [21]. Various energy harvesting models are proposed in [21] that consider weather conditions, variations in sun position, and weighted averages. The simplified harvested energy model is depicted in Figure 1.

Considering each round in the SHE-WSN as an hour and denoting Eh_{max} as the highest limit of harvestable energy, the energy harvested by node *j* in round m within the SHE-WSN can be formulated as follows [20]:

$$Eh_j(m) = \begin{cases} 0, & m \bmod 24 \le 7 \\ \dfrac{Eh_{\max}((m \bmod 24) - 7)}{3}, & 7 < m \bmod 24 \le 10 \\ Eh_{\max}(1.2 - 0.2(m \bmod 24)), & 10 < m \bmod 24 \le 15 \\ \dfrac{Eh_{\max}(18 - (m \bmod 24))}{3}, & 15 < m \bmod 24 \le 18 \\ 0, & 18 < m \bmod 24 \end{cases} \quad (1)$$

For every round (hour), the mean energy gathered by node j is expressed as:

$$Eh_{avg} = \frac{Eh_{\max}}{24} \sum_{m=1}^{24} Ehj(m) \quad (2)$$

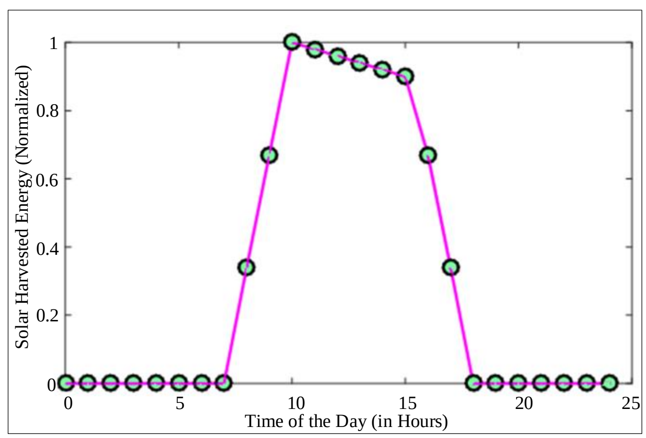

Fig. 1 Energy harvested model

4.2. Energy Dissipation Model

The energy level of the node undergoes alterations when transmitting and receiving signals. Several factors affect the energy consumption during transmission (E_{tx}), including (i) The energy consumption of electrical components (Eel), (ii) The energy expended on amplification, and (iii) The separation distance between the relay and the final destination node (D). The formula for E_{tx}, which quantifies the energy required to transmit b bits of data between SNs, is defined as follows:

$$E_{j,Etx} = \begin{cases} b * E_{el} + b * \varepsilon_{fs} * D^2, & \text{if } D < D_0 \\ b * E_{el} + b * \varepsilon_{ap} * D^4, & \text{if } D \ge D_0 \end{cases} \quad (3)$$

$$D_0 = \sqrt{(\varepsilon_{fs} / \varepsilon_{ap})} \quad (4)$$

Equation 4 defines the threshold distance, denoted as D0. However, If the distance between SNs is below the threshold distance, the required energy for transmission increases proportionally to the square of the distance. In contrast, when the distance surpasses this threshold, the energy needed scales with the fourth power of the distance. Next, let's consider the energy consumption for receiving data:

$$E_{rx} = b * E_{el} \quad (5)$$

The energy consumption associated with electrical components is solely necessary for receiving b bits, as described in Equation 5. Consequently, the overall energy expenditure for the communication of 'b' bits is the addition of the required energy for both transmitting and receiving bits. By employing the mathematical expressions 3 and 5, we can calculate the total (overall) energy consumption, denoted as $E_{j,\ total}$, for 'b' bit communication in the following manner:

$$E_{j,total} = \begin{cases} 2 * b * E_{el} + b * \varepsilon_{fs} * D^2, & \text{if } D < D_0 \\ 2 * b * E_{el} + b * \varepsilon_{ap} * D^4, & \text{if } D \ge D_0 \end{cases} \quad (6)$$

The remaining energy (E_{res}) of node j is represented as the energy that remains after the transmission and reception of a packet, and it can be expressed as follows:

$$E_{j,res} = E_0 - E_{j,total} \quad (7)$$

5. System Model and Proposed MLACO Scheme

The simulation setup for the proposed scheme involves a stationary node within a Wireless Sensor Network (WSN) powered by solar energy. The study takes into account WSNs that utilize clustering, involving the rotation and selection of CHs. Communication in Wireless Sensor Networks (WSN) occurs in two stages: (I) the building of clusters and the identification of each Cluster Head (CH) node, and (II) the reception and transmission of data between Child nodes and the Base station.

As depicted in Figure 2, the research scenario involves 100 energy-harvested SNs distributed randomly within a 100*100 square meter area. The central point of this region houses the sink node or BS. Within this context, the proposed MLACO algorithm is utilized to establish the optimal route between the CH and the BS. The structure of clustering and multihop communication within the WSN is illustrated in Figure 3. Through the utilization of the proposed MLACO scheme, the most favorable route between the CH and BS is determined.

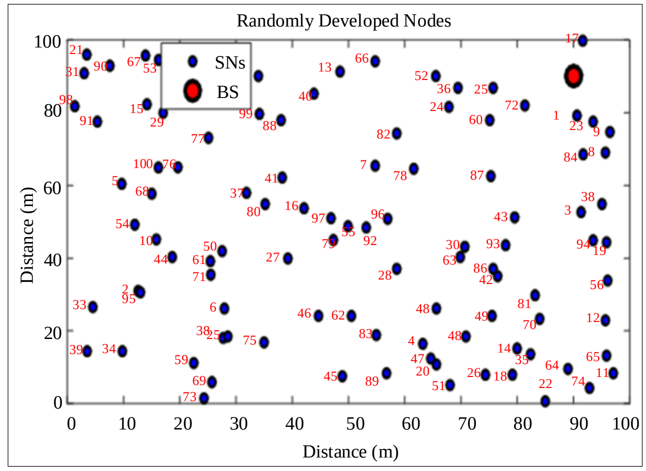

Fig. 2 The deployment of SNs occurs in a randomized manner across the dseignated area

5.1. Proposed MLACO Scheme

MLACO undergoes a dual-phase structure. In the initial phase, the determination of the cluster head unfolds through the utilization of the MLEACH method. Subsequently, in the ensuing phase, the Ant Colony Optimization (ACO) algorithm comes into play for the channel selection process during the transmission of packets. Ant Colony Optimization, falling under the classification of a metaheuristic algorithm, draws inspiration from the foraging tendencies of ants as they navigate the shortest path to their nest and locate sources of sustenance. At the algorithm's inception, individual nodes are analogously treated as ants, and each connection is endowed with an associated weight.

The determination of the route connecting the Base Station (BS) and Cluster Head (CH) is orchestrated by placing an ant in each CH. The CH sources are responsible for generating and forwarding the packet for the establishment of the route, referred to as the Forward Ant Data Packet (FADP). The creation of a route between the Base Station (BS) and Cluster Head (CH) is accomplished by placing an ant at each CH. These source CHs initiate the generation and forwarding of packets for route establishment, known as Forward Ant Data Packets (FADP).

- These FADPs are sent to the subsequent CH node based on a probability matrix, with this process continuing until the FADPs reach the BS.
- Each FADP packet carries vital information, including the Residual Energy (E_{res}), the distance between the CH and BS ($D_{CH,\ BS}$), and the degree of Node (N_D).
- The generation of backward packets is facilitated using the FADP database and follows the same path utilized by the FADPs.

- The ant's selection of the next hop is governed by the probability associated with selecting node i as the subsequent node j, guided by the ant q's behavior.

$$P_{ij}(q) = \frac{[\chi_{ij}(q)]^{\alpha}[\eta_{ij}(q)]^{\beta}}{\sum_{i\epsilon N_k}[\chi_{ij}(q)]^{\alpha}[\eta_{ij}(q)]^{\beta}} \text{ if } j\in N_k \quad (8)$$

Let and symbolize the pheromone and heuristic values χ_{ij} and η_{ij}, respectively. Additionally, α and β serve as control parameters for χ_{ij} and η_{ij}. N_k denotes a set of nodes that the k_{th} ant has not traversed yet. The χ_{ij} and η_{ij} are continuously updated as the intelligence of CH changes. η_{ij} depends upon the $D_{CH,BS}$ is expressed as:

$$\eta_{ij} = \frac{1}{D_{CH,BS}} \quad (9)$$

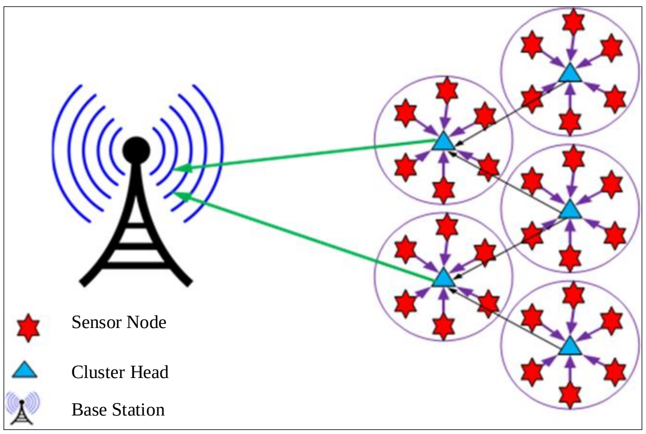

Fig. 3 Multihop communication within the WSN across the designated 100∗ 100m²

And χ_{ij} is updated by following the equation,

$$\chi_{ij} = (1-\rho)\chi_{ij}^{old} + \sum_{k=1}^{M} A\chi_{ij}^{k} \quad (10)$$

Where ρ∈[0,1] is the decay parameter. The pheromone parameter is denoted as $\nabla\chi_{ij}^{k}$ is expressed as follows:

$$\nabla\chi_{ij}^{k} = \begin{cases} Q/C_k & \text{if the k}^{\text{th}}\text{ant traversed line (i,j)} \\ 0 & \text{otherwise} \end{cases} \quad (11)$$

Q is the constant value, and C_k is the route cost computed by Equation 12,

$$C_k = X_1 E_{res} + X_2 D_{CH,BS} + X_3 N_D \quad (12)$$

Where X_1=0.5, X_2=0.3, X_3=0.2. In order to improve survivability and minimizing energy-draining, the residual energy of the child nodes is the prime concern. Subsequently, the distance between the CH and BS node and the degree of the CH node is prioritized in the second and third, respectively. The flowchart of MLACO is shown in Figure 4.

Table 1. Simulation parameters

Total Nodes Deployed	100
WSN Designated Area	100 *100 m^2
The Initial Energy of SNs	0.5J
Average Energy Obtained from SNs Harvest	0.00010 J
Size of Packet	50 bits
Energy Utilization in Transceiver Idle State	50 nJ/bit
Energy Consumption in Data Aggregation/Fusion	5nJ/bit/report
Energy Associated with Amplification $E_{fs}(D<D_o)$	10pJ/bit/m^2
Energy Associated with Amplification E_{ap} $(D \geq D_o)$	0.0013pJ/bit/m^4

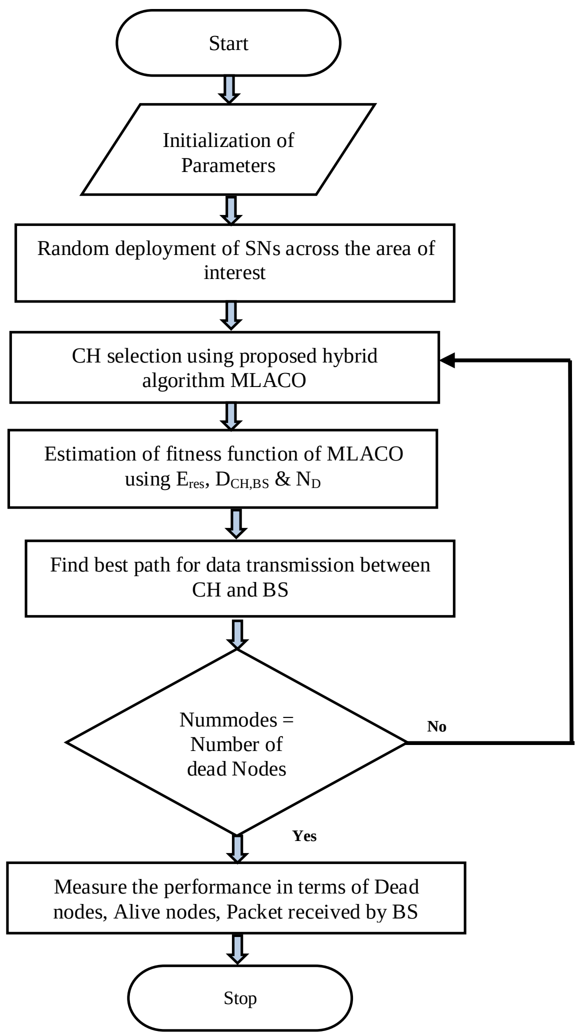

Fig. 4 Flowchart of the proposed algorithm

6. Result and Discussion

The performance of the proposed MLACO algorithm and existing MLEACH and ACO algorithms is evaluated using a network simulator developed with MATLAB programming. During the simulation program design, the following parameters for Wireless Sensor Network (WSN) design are considered:

1. Sensor node deployment is entirely random within the region.
2. Once deployed, sensor node positions remain fixed and cannot be changed.
3. The position of the Base Station (BS) is also fixed.
4. Initially, all nodes have the same residual energy, set to 0.5J.
5. The energy harvesting rate for nodes is set to 0.0001J. Further simulation parameters are presented in Table 1.

Figure 5 portrays the relationship between the number of selected Cluster Head (CH) nodes and the number of rounds. It is evident that an increase in the number of rounds corresponds to a decrease in the number of selected CHs. This phenomenon can be attributed to the rise in the total count of depleted nodes as the number of rounds escalates. Remarkably, the proposed MLACO scheme exhibits a higher number of selected CHs compared to the other two techniques within the range of 900 to 1300 rounds.

This observation aligns with the notion that the proposed scheme experiences a relatively lower node depletion rate during this specific interval. Figures 6 and 7 depict the evolution of dead and alive SNs as the iteration increases. It becomes evident that the network's lifespan is contingent on the quantity of nodes that remain operational as the number of rounds advances. In the context of SHE-WSN, the proposed MLACO scheme demonstrates a network lifespan that closely aligns with the MLEACH and FEEDC strategies for cluster head selection. Notably, during rounds 900 to 1300, the proposed scheme exhibits superior performance compared to the other two approaches.

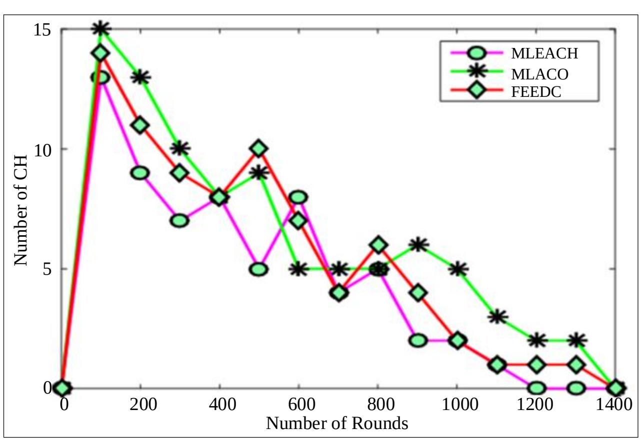

Fig. 5 The count of chosen cluster heads varies across distinct strategies as the number of rounds increases

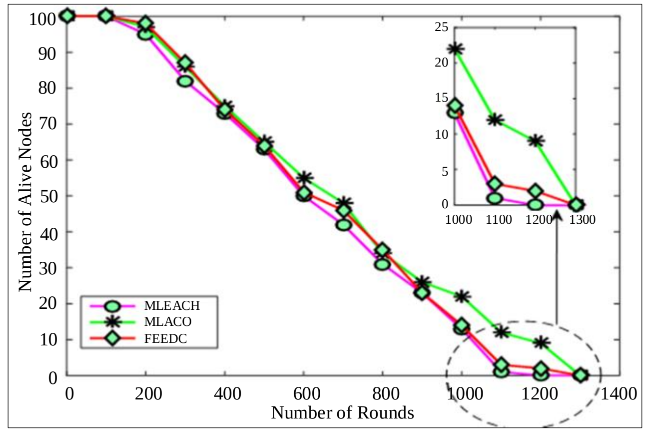

Fig. 6 An assessment of the quantity of active nodes as the number of rounds increases

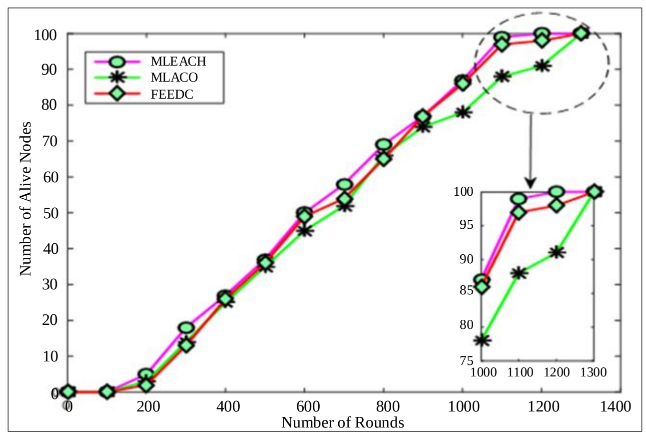

Fig. 7 An evaluation of the quantity of dead nodes as the number of rounds progresses

Throughput stands as a pivotal metric for assessing network reliability. It quantifies the total packets received by the BS in tandem with the increasing number of rounds. Figure 8 distinctly portrays the superior performance of the MLACO over MLEACH and FEEDC strategies. The mean packets gathered by the BS in the MLACO, MLEACH, and FEEDC cluster head selection schemes stand at 6.1579×10^3, 4.6815×10^3, and 4.8621×10^3 respectively. Moreover, the average network throughput of MLACO surpasses that of the existing MLEACH and FEEDC cluster head selection strategies by 31.5% and 26.6%, respectively.

Network survivability ranks as a prominent concern among researchers. The concept of the Network Survivability Index (NSI) offers insight into WSN's robustness. NSI denotes the ratio of operational nodes to the total node count. As depicted in Figure 9, NSI's performance progression aligns with the increase in rounds. The utmost NSI value of 1 signifies all nodes are operational, while the minimum of 0 reflects total node failure. Evidently, the proposed MLACO scheme's performance notably improves with increased rounds, and particularly within the rounds of 900 to 1300, it surpasses both existing schemes.

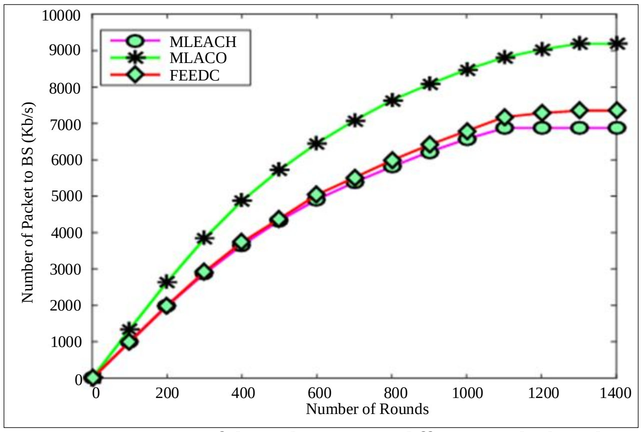

Fig. 8 An assessment of throughput across different methods with an increasing number of iterations

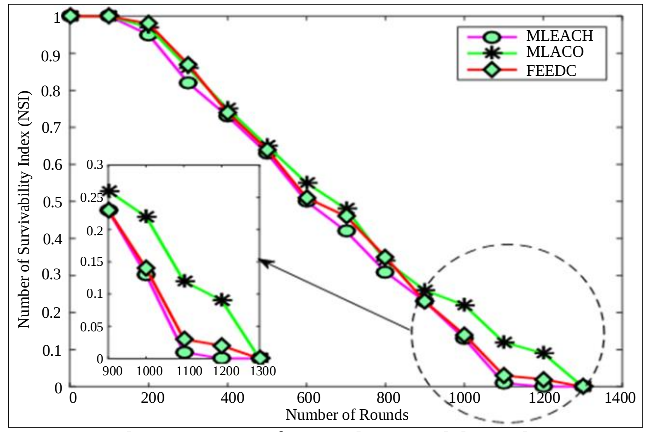

Fig. 9 The progression of Network Survivability Index (NSI) performance as the number of rounds increases

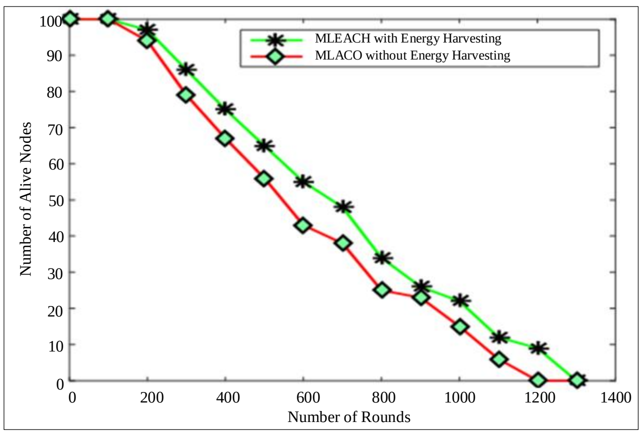

Fig. 10 Performance development concerning active nodes in Wireless Sensor Networks (WSN) with and without energy harvesting

The WSN's survival within hostile environments remains a paramount concern. Energy harvesting models present a viable strategy for enhancing network survivability. Figure 10 provide an evaluation of WSN performance, contrasting energy harvesting and non-energy harvesting scenarios in terms of alive nodes. The outcomes underscore that energy harvesting significantly bolsters WSN survivability compared to scenarios without energy harvesting.

7. Conclusion

Within the realm of WSN, the dual metrics of network survivability and network throughput stand as pivotal considerations. It proves to be an intricate challenge to simultaneously address and optimize both these parameters. However, this study undertakes the task of concurrently enhancing these metrics. The outcomes unequivocally underscore the superiority of the proposed MLACO scheme over the MLEACH and FEEDC cluster head selection approaches, particularly concerning network throughput.

Specifically, the average network throughput achieved by MLACO surpasses that of the existing MLEACH and FEEDC strategies by 31.5% and 26.6%, respectively.

Concomitantly, the network survivability of the proposed scheme nearly aligns with that of the existing approaches while also displaying enhanced performance within rounds 900 to 1300. Furthermore, the incorporation of the simplified solar energy harvesting model significantly enhances the overall survivability of the WSN.

References

[1] Hoi Ching Tung et al., "A Mobility Enabled Inpatient Monitoring System Using A ZigBee Medical Sensor Network," *Sensors*, vol. 14, no. 2, pp. 2397-2416, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[2] J.J. McCullagh et al., "Long-Term Testing of a Vibration Harvesting System for the Structural Health Monitoring of Bridges," *Sensors and Actuators A: Physical*, vol. 217, pp. 139-150, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[3] Stefanos A. Nikolidakis et al., "Energy Efficient Automated Control of Irrigation in Agriculture by Using Wireless Sensor Networks," *Computers and Electronics in Agriculture*, vol. 113, pp. 154-163, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[4] Michele Magno et al., "Extended Wireless Monitoring through Intelligent Hybrid Energy Supply," *IEEE Transactions on Industrial Electronics*, vol. 61, no. 4, pp. 1871-1881, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[5] Gwo-Jiun Horng, and Hsin-Te Wu, "The Adaptive Path Selection Mechanism for Solar-Powered Wireless Sensor Networks," *Wireless Personal Communications*, vol. 81, pp. 1289-1301, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[6] Feng Yu, Wei Liu, and Gang Li, "An Improved Cluster Head Algorithm for Wireless Sensor Network," *Computer Engineering and Networking*, pp. 65-71, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[7] Norah Tuah, Mahamod Ismail, and Kasmiran Jumari, "Cluster-Head Selection by Remaining Energy Consideration in a Wireless Sensor Network," *International Conference on Informatics Engineering and Information Science*, pp. 498-507, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[8] W.R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-Efficient Communication Protocol for Wireless Microsensor Networks," *Proceedings of the 33rd Annual Hawaii International Conference on System Sciences*, Maui, USA, vol. 2, 2000. [CrossRef] [Google Scholar] [Publisher Link]

[9] B. Baranidharan, and B. Santhi, "DUCF: Distributed Load Balancing Unequal Clustering in Wireless Sensor Networks Using Fuzzy Approach," *Applied Soft Computing*, vol. 40, pp. 495-506, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[10] Aysegul Alaybeyoglu, "A Distributed Fuzzy Logic-Based Root Selection Algorithm for Wireless Sensor Networks," *Computers and Electrical Engineering*, vol. 41, pp. 216-225, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[11] Khalid Haseeb et al., "WECRR: Weighted Energy-Efficient Clustering with Robust Routing for Wireless Sensor Networks," *Wireless Personal Communications*, vol. 97, pp. 695-721, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[12] Adnan Ismail Al-Sulaifanie, Bayez Khorsheed Al-Sulaifanie, and Subir Biswas, "Recent Trends in Clustering Algorithms for Wireless Sensor Networks: A Comprehensive Review," *Computer Communications*, vol. 91, pp. 395-424, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[13] Masood Ahmad et al., "Optimal Clustering in Wireless Sensor Networks for the Internet of Things Based on Memetic Algorithm: memeWSN," *Wireless Communications and Mobile Computing*, vol. 2021, pp. 1-14, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[14] Indra Kumar Shah et al., "ICIC: A Dual Mode Intra-Cluster and Inter-Cluster Energy Minimization Approach for Multihop WSN," *IEEE Access*, vol. 10, pp. 70581-70594, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[15] Indra Kumar Shah, Tanmoy Maity, and Yogendra Singh Dohare, "Algorithm for Energy Consumption Minimisation in Wireless Sensor Network," *IET Communications*, vol. 14, no. 8, pp. 1301-1310, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[16] Indra Kumar Shah, Tanmoy Maity, and Yogendra Singh Dohare, "Weight Based Approach for Optimal Position of Base Station in Wireless Sensor Network," *2020 International Conference on Inventive Computation Technologies (ICICT)*, Coimbatore, India, pp. 734-738 2020. [CrossRef] [Google Scholar] [Publisher Link]

[17] Liang Zhao, Shaocheng Qu, and Yufan Yi, "A Modified Cluster-Head Selection Algorithm in Wireless Sensor Networks Based on LEACH," *EURASIP Journal on Wireless Communications and Networking*, vol. 2018, pp. 1-8, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[18] Ying Zhang et al., "Fuzzy-Logic Based Distributed Energy-Efficient Clustering Algorithm for Wireless Sensor Networks," *Sensors*, vol. 17, no. 7, pp. 1-21, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[19] Deepak Sharma, and Amol P. Bhondekar, "An Improved Cluster Head Selection in Routing for Solar Energy-Harvesting Multi-Heterogeneous Wireless Sensor Networks," *Wireless Personal Communications*, vol. 108, pp. 2213-2228, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[20] Aman Kansal et al., "Power Management in Energy Harvesting Sensor Networks," *ACM Transactions on Embedded Computing Systems (TECS)*, vol. 6, no. 4, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[21] Carlo Bergonzini, Davide Brunelli, and Luca Benini, "Algorithms for Harvested Energy Prediction in Batteryless Wireless Sensor Networks," *2009 3rd International Workshop on Advances in Sensors and Interfaces*, Trani, Italy, pp. 144-149, 2009. [CrossRef] [Google Scholar] [Publisher Link]