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RESEARCH ARTICLE

HYBRID OPTIMIZATION USING ENERGY EFFICIENT CLUSTER FORMATION AND ROUTING IN WIRELESS SENSOR NETWORKS

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Abstract –Wireless Sensor Network (WSN) is an interconnected sensor node that can connect and communicate with one another to collect and transmit data from their surroundings. However, the existing technique has high delay, low network lifetime and energy consumption. To address these issues, a novel Hybrid Optimization using Energy Efficient Cluster Formation and Routing in Wireless Sensor Networks (HOER). Initially, C Means clustering is employed in the proposed framework to improve cluster formation. The Artificial Bee Colony Optimization (ABCO) provides an effective way for cluster head selection (CHS) based on node degree, energy consumption and normalization. Consequently, the Ant Colony Optimization (ACO) is utilized to find a routing path between the source and the destination over the cluster head. The proposed model was compared to existing techniques on energy consumption, throughput, Alive Node, delay and network lifetime are used. The proposed HOER achieves the higher network lifetime by 95.8% for proposed and 48.17 %, 39.17 % and 20.25% than the RK-EFCRP, DOS-RL and EPFMR approaches.

Keywords *– Wireless Sensor Network, C-means Clustering, Artificial Bee Colony Optimization, Ant Colony Optimization, cluster head selection, Energy-Efficiency and routing.*

1. INTRODUCTION

The WSN comprises of tiny low-power sensor nodes that monitor and gather data from their surroundings before sending it to a central base station for processing and analysis. Each node consists of a sensing unit, a processing unit, a transmission unit, and a power unit, and it is in charge of data collecting, processing, and communication with other nodes. WSNs organize themselves and form multi-hop networks to transfer data efficiently over long distances. Sensor nodes operate on limited battery power, so conserving energy is very important. The application of various methods like clustering, data aggregation, load balancing, and scheduling results in less energy consumption, better workload management, and longer network lifetime. Through the process of clustering, nodes are classified with a Cluster Head that gathers information from other nodes, processes it, and transmits it to the base station, thereby minimizing the consumption of energy and communication throughput. WSNs operate in harsh and remote areas. Replacing or recharging batteries is quite challenging while continuous monitoring and data delivery are maintained.

Routing in WSN is the process of finding the path of sensing data from sensor nodes to the base station. In small networks, single-hop communication is possible between nodes and a base station. Large-scale networks desire for multi-hop communications, in which all nodes send and forward data from other nodes. Routing should take into account the restricted energy supply, processing capacity, and memory of the sensor nodes, and it should prioritize energy conservation, delay reduction, and prolongation of the network's lifetime. Routing protocols should be designed in such a way that they can achieve load balancing, hence, preventing the over-use of a single node which might lead to the node being drained of energy rapidly. They will also adapt to network topology changes, such as node failures or the addition of additional nodes. The routing function must be non-scalable in the sense that it cannot handle networks with thousands of nodes while also providing reliable data delivery in both dense and wide areas.

WSNs depend on batteries, which makes energy management very important to prolong the network life and also to guarantee the receipt of reliable data. Power shortage remains a very serious issue, more particularly in demanding environments like battle zones or isolated observation locales. Sensor nodes' performance degrades at the low battery power levels, which can potentially lead to network failure or data loss. The energy issue is extremely vital to be tackled, as the power sources of nodes are limited and battery changing or recharging is not always easy. A WSN may consist of millions of energy-limited nodes therefore energy management must be done very meticulously in order for the network to function properly and efficiently.

- The primary objective of the work is developed a novel Hybrid Optimization using Energy Efficient Cluster Formation and Routing in Wireless Sensor Networks.
- C means clustering is used to improve cluster formation.
- Artificial Bee Colony Optimization gives an effective approach for CHS based on node degree, energy consumption, and normalization.
- The Ant Colony optimization method is used for routing between source and destination.
- The proposed model was compared to existing techniques on energy consumption, throughput, Alive Node, delay and network lifetime are used.

The content of the paper is organized as: Section 2) explains the literature survey, Section 3) discusses the proposed methodology and its working process, and Section 4) Results & discussion Finally, section 5 concludes the paper.

2. LITERATURE REVIEW

Recent advancements in WSN have significantly improved the ML and DL models for improving energy efficiency and network life time. This literature review explores current approaches in clustering in WSN. Some of the most recent approaches are discussed in this section.

In 2023, Pedditi, R.B., and Debasis, K. [14] suggested an energy-aware Internet of Things (IoT)-based WSN model for forest fire monitoring that uses an efficient clustering and routing approach. Traditional forest fire detection technologies and current WSN-based systems are inefficient for real-time monitoring of huge forest regions. The proposed EERP protocol minimizes overall energy usage while improving the routing of forest fire detection devices. Simulation results suggest that current MAC protocols can reduce sensor node energy usage while boosting overall network performance.

In 2025, Hussain, M., et al. [15] suggested an improved Rank-Based Key Management for Energy-Efficient Cluster-Based Routing Protocol (RK-EFCRP). Existing WSN routing techniques fail to combine energy economy, security, and dependable data transfer. The proposed RK-EFCRP method utilizes an adaptive clustering approach, which leads to energy consumption reduction and at the same time, security, data dependability, and latency enhancements. Experimental outcomes indicate that RK-EFCRP is superior to the current protocols, including Safety-RPL, HBEER, SEHR, and SEAMHR in terms of various important performance indicators.

In 2023, Godfrey, D. et al. [16] introduced an energy-efficient multi-objective routing strategy in light of the Reinforcement Learning with Dynamic Objective Selection(DOS-RL) strategies. Traditional routing techniques are unable to cope with the network changes occurring dynamically in an efficient manner, leading to high latency and poor performance of the network. The suggested DOS-RL routing ability offers a well-balanced performance continuum consisting of energy saving, reliability, and adjustability, thus making it appropriate for changing and enormous IoT scenarios. Simulation findings show that the DOS-RL protocol performs much better than classic routing protocols like OSPF and SDN-Q.

In 2022, Mehbodniya, A., et al. [17] suggested an Energy-aware Proportional Fairness Multi-user Routing (EPFMR) framework for WSNs. Existing method doesnot provide effective routing procedures that conserve energy during route finding and data transfer. The EPFMR framework substantially decreases energy usage during routing, shortens route search time, and increases throughput. The simulation results show EPFMR outperforms current state-of-the-art approaches.

In 2022, Jaffri, Z.U.A., et al. [18] developed a Threshold-based Energy-aware Zonal Efficiency Measuring (TEZEM) hierarchical routing system for next-generation WSN. Hierarchical routing techniques fail to increase network lifetime, resulting in wasteful energy use, decreased stability, and poorer throughput. The proposed TEZEM protocol increases energy efficiency by efficiently controlling network traffic using zonal divisions and threshold-based data transfer. The simulation results show that the TEZEM protocol with 9 zonal divisions has the maximum stability and throughput.

In 2022, Dogra, R., et al. [19] introduced a new routing protocol called Enhanced Smart Energy-Efficient Routing Protocol (ESEERP) intended to make WSN-IoT scenarios more energy-efficient and to extend their lifetime. The integration quality of WSNs into IoT fails due to high consumption of energy and limited network lifespan. ESEERP deduces the number of sensor nodes needed to sleep for better energy preservation, efficient route mechanism, and higher bandwidth utilization. Simulation result show that ESEERP outperforms other approaches, including Genetic Algorithm, Ant Lion Optimization, and Particle Swarm Optimization.

In 2024, Kumar, N., et al. [20] developed a Hybrid Whale-Ant Optimization Algorithm (WAOA) for energy-efficient routing in WSNs. Existing approaches do not maximize CHS and data routing at the same time, resulting in inferior network efficiency and shorter lifetime. The WAOA algorithm successfully balances energy consumption and routing efficiency by optimizing both CHS and data pathways. According to the performance analysis, WAOA beats existing approaches such as MOORP, MMABC, and AZEBR in terms of network lifespan by 5.78%, 16.11%, and 18.52%, respectively.

3. PROPOSED METHODOLOGY

In this section, a novel Hybrid Optimization using Energy Efficient Cluster Formation and Routing in Wireless Sensor Networks (HOER) has been proposed. Initially, sensor nodes are first grouped into clusters. C Means clustering is used to improve cluster formation. then, the ABCO algorithm is introduced as an effective method for selecting cluster heads based on node degree, energy consumption and normalization. Then ACO algorithm is utilized to routing path between the source and the destination across the CHS. Figure 1 shows the proposed methodology.

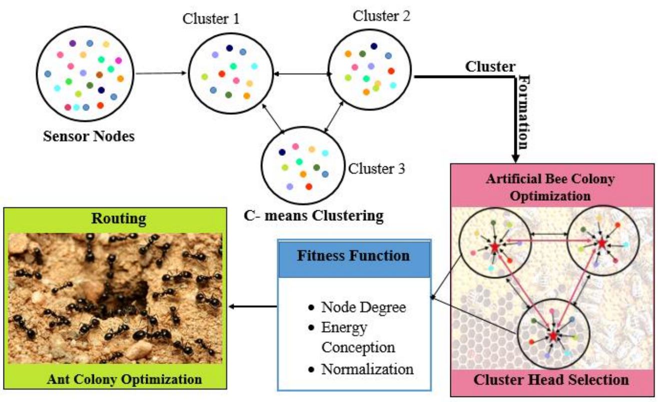

Figure 1: Proposed Methodology

3.1 Cluster Formation via C-means Clustering

In this section, C-means clustering is used for cluster formation. C-means is an unsupervised clustering technique that partitions data samples into *C* distinct clusters based on feature similarity. It is widely adopted due to its simplicity and effectiveness. However, one major drawback of this method is that the number of clusters must be predefined, which may not be optimal for datasets with unknown or varying structures. Hence, there is a need for clustering approaches that can adaptively determine suitable cluster configurations.

The objective function of the C-means clustering algorithm is given by:

$$M_{FCJ}(V,U) = \sum_{i=1}^{n} \sum_{i=1}^{C} V_{JI}^{A} \; \|Y_J - U_I\| \tag{1}$$

$$T.s \; \sum_{i=1}^{n} v_{ji} \; =1, i=1,\ldots,N \tag{2}$$

FCM can only assign one sample to an imprecise cluster, it is difficult to produce appropriate results for some samples that overlap between several clusters.

$$J_{MCN^{T,I,K,U)}} = \sum_{J=1}^{N} \sum_{I=1}^{C} \{\varpi_1 T_{ij}\} \|Y_J - U_I\| \, 2 \tag{3}$$

$$T.s \; \sum_{i=1}^{n} T_{ij+y_{j+k_j}} =1, 0 < T_{ji}, Y_J K_I \; <1 \tag{4}$$

J_{MCN} is the inaccurate cluster center for y_j,and δ is a parameter to detect outliers. The weight factors are $\varpi 1$, $\varpi 1$, and $\varpi 3$; $\beta$is the same as MCN.N

$$u_i = \frac{\sum_{J=1}^{n} (\varpi_1 K_{ji}) \; y_j}{\sum_{J=0}^{n} (\varpi_1 K_{ji})} \tag{5}$$

The support degree of Y_i to the accurate cluster is represented by y_j, Whereas the support degree of y_j . the support degree of y_i to outliers is shown by k_{ji} .

3.2 Artificial Bee Colony Optimization

In this part, Artificial Bee Colony Optimization (ABCO) is utilized to choose cluster heads. Bees that were waiting for the food source (FS) selection in the dance area were regarded as observers; bees that foraged at random were called scout bees; The hired bees returned to a FS they had just visited.

Initialization: Let us assume that SN is the population size required when we want to find the population variance. $X_i = \{X_{i1} X_{i2,\ldots} X_{id}\}$ $(i = 1,2,\ldots,n)$, The problem is to optimize the dimension vector d. Thus, the first population is formed at random.

$$X_i = X_U + rand(0,1).(X_U - X_L) \tag{6}$$

Population Updating: The FS location is initialized randomly and each forager bee is associated randomly with a FS. Every worker bee recognizes and examines another adjacent FS near the one it worked on previously.

(i) $$V_{ij} = X_{ij} + rand(-1,1).(X_{ij} - X_{kj}) \tag{7}$$

where V_{ij} is the candidate food position, k∈{1, 2, 3... SN}, j∈{1, 2, 3,..., d}, and rand (−1,1) is the numerical value around randomly generated (−1, 1).

Bee Source Selection: In this phase, the spending level of the source determines how bees are there to fly. which are determined by their fitness values. With the equation, they will be pushed toward FS that generate significant profits:

(ii) $$p_i = \frac{fit(X_i)}{\sum_{n=1}^{SN} fit\,(X_i)} \tag{8}$$

where f (X_i) represents the fitness function of the n-th solution, which is proportional to the amount of nectar available to the FS $n \in \{1,2,3,\ldots,SN\}$.

$$fit_{(X_n)} \begin{cases} f\frac{1}{(X_n)}, f(X_n) \geq 0 \\ 1 + abs\left(f(X_n)\right), f(X_n) < 0 \end{cases} \tag{9}$$

Where $f(X_n)$ is the objective function value corresponding to the bee source X_n following bees are roaming the area around the source, thus augmenting the local availability of the algorithm.

3.3 ANT Colony Optimization Via Routing

In this part, the selected cluster head is used to find the shortest path using Ant Colony Optimization (ACO). ACO is a nature-inspired algorithm based on the communication methods used by ant colonies. Individual ants communicate through the use of pheromone trails in a form of indirect communication.

$$\eta ij = \begin{cases} -\log CFP(\{e_{i,j}\}) \\ 0, \qquad else. \end{cases} \tag{10}$$

The pheromone setting is mostly governed by the rules of the Max-Min Ant System. In order to reduce the chance of getting stuck in local maxima, after the first iteration the pheromone levels will be limited to be between two values calculated from the best solution that we have encountered.

$$\tau_{max} = \frac{f_{gb}}{b}(1-\rho) \tag{11}$$

$$\tau_{min} = \in . \tau_{max} \tag{12}$$

We only distribute pheromones on the best path taken within the given iteration.

$$\tau_{ij} = \rho . \tau_{ij}^{(t-1)} \tag{13}$$

On the best route found, the pheromone update is described with Eq. (), the negative logarithm of the probability of the given path failing is considered:

$$\tau_{ij}^{(t)} = \rho.\tau_{ij}^{(t-1)} - \log(A(P)) \quad (14)$$

$$p(i,j) = \frac{(\tau ij)^{\alpha}(\eta ij)^{\beta}}{\sum_{u_q} \epsilon n_i ((\tau ij)^{\alpha}(\eta ij)^{\beta}}, \text{if } u_j \in n_i \quad (15)$$

All ants are put at the beginning position s. They select the next node based on heuristics and pheromone levels. Nodes can only be visited once, and the last visited node must be t. If an ant fails to reach the destination, no path will be returned.

4. RESULT AND CONCLUSION

In this section, the efficacy of the suggested technique is assessed using matlab-2022b, performance analysis is discussed regarding various calculation metrics such as Residual Energy, Alive Node, Cluster Stability, throughput, and end to end delay. The PC requirements for this experiment comprised an i9-9820X 3.30 GHz CPU, 2 TB of RAM, and Ubuntu 20.04.1 LTS. The proposed model efficacy is contrasted with RK-EFCRP [15], DOS-RL [16], EPFMR [17] respectively.

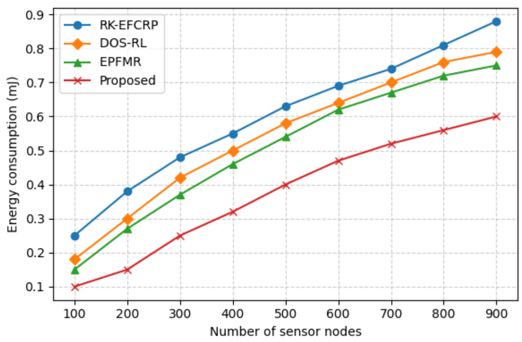

Figure 2: Energy consumption

Figure 2 shows comparison of Energy consumption via number of sensor nodes. The proposed model has lower energy consumption compared to existing techniques such as RK-EFCRP, DOS-RL and EPFMR. When a node is 300, the energy consumption of the proposed model is 0.25 mJ and the existing RK-EFCRP, DOS-RL and EPFMR yield 0.48 mJ, 0.42 mJ and 0.37mJ respectively. The proposed model lower by 37.3 mJ, 35.1 mJ and 27.5 mJ than the existing techniques.

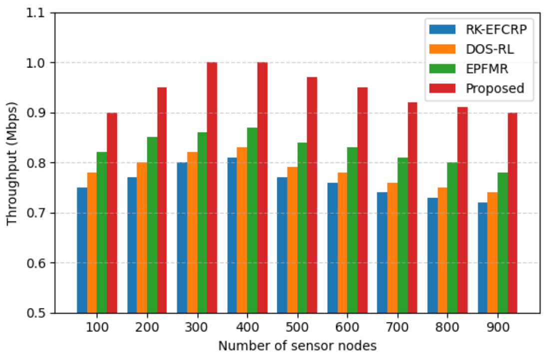

Figure 3: Throughput

Figure 3 illustrates Comparison of Throughput via number of sensor nodes. The suggested model has higher than the existing techniques such as RK-EFCRP, DOS-RL and EPFMR. When the node is 200, the throughput of the suggested model is 0.95 Mbps, and the existing RK-EFCRP, DOS-RL and EPFMR yield 0.76 Mbps, 0.8 Mbps and 0.85Mbps respectively. And when the node is 600, the throughput of the suggested model is 0.96 Mbps, and the existing RK-EFCRP, DOS-RL and EPFMR yield 0.94 Mbps, 0.77Mbps and 0.75Mbps respectively. The proposed model higher by 24.0 Mbps, 20.2Mbps and 13.0Mbps than the existing techniques.

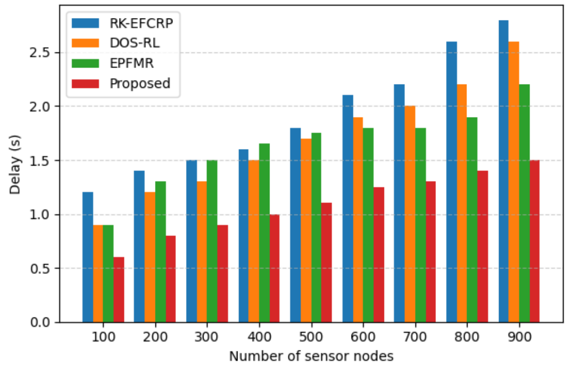

Figure 4: Delay

Figure 4 show the Comparison of Delay via number of sensor nodes. The suggested model has lower than the existing techniques such as RK-EFCRP, DOS-RL and EPFMR. When the node is 400, the delay of the suggested model is 1.0 s, and the existing RK-EFCRP, DOS-RL and EPFMR for the 1.54 s, 1.5 s, and 1.55 s respectively. The proposed model lower by 43.5 s, 39.8 s and 36.6 s then the existing techniques.

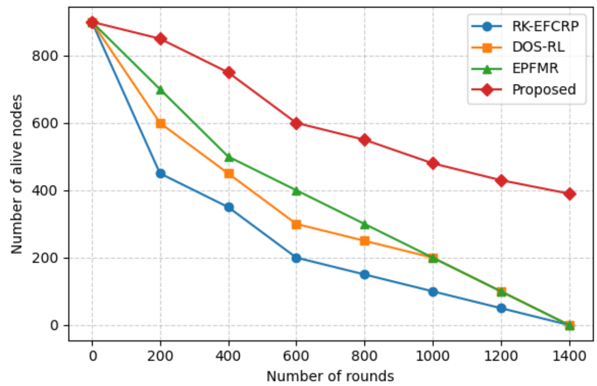

Figure 5: Alive node

Figure 5 shows the Comparison of alive node via number of sensor nodes. The suggested model is higher than the existing techniques such as RK-EFCRP, DOS-RL and EPFMR. When the node is 800, the alive node of the suggested model is 576% and the existing RK-EFCRP, DOS-RL and EPFMR for the 182%, 225% and 310% respectively. The proposed model higher by 20.2%, 29.4% and 34.6% then the existing techniques.

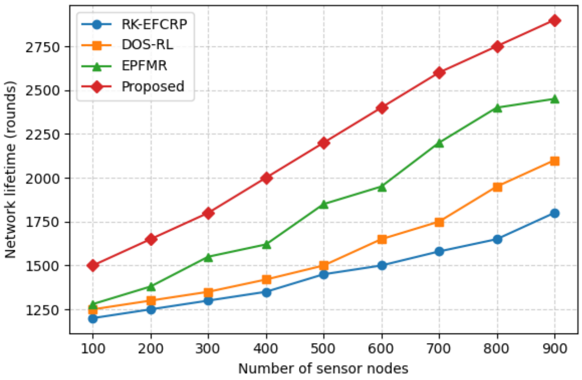

Figure 6: Network lifetime

Figure 6 displays the Comparison of network lifetime via number of sensor nodes. The proposed model is higher than the existing techniques such as RK-EFCRP, DOS-RL and EPFMR. When the node is 100, the alive node of the proposed model is 1500 and the existing RK-EFCRP, DOS-RL and EPFMR for the 1230 rounds (r), 1250 r and 1340 r respectively. The proposed model higher by 59.0 r, 67.3 r and 78.0 r then the existing techniques.

5. CONCLUSION

This paper proposed, a novel Hybrid Optimization using Energy Efficient Cluster Formation and Routing in Wireless Sensor Networks (HOER) has been proposed. Initially C Means clustering is used to improve cluster formation and reduce communication costs. The proposed HWEL techniques mainly uses the ABCO approaches to select cluster head. The ACO utilized best route path from source to destination, then cluster head uses the best route to send data to the base station. Proposed HOER framework achieves network lifetime by 95.8% for proposed then 48.17 %, 39.17 % and 20.25% than the RK-EFCRP, DOS-RL and EPFMR approaches. Future research will extend the HOER framework to mobile and large-scale wireless sensor networks with dynamic topology variations. Machine learning-based intelligence and security-aware mechanisms can be incorporated to enable adaptive cluster formation and secure routing decisions under changing network conditions.

CONFLICTS OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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