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Optimized Energy Efficient- Hierarchical Clustering Based Routing (OEE-HCR) For Wireless Sensor Network (WSN)

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Abstract

The study into Wireless Sensor Network (WSN) has grown more crucial as a result of the many Internet of Things (IoT) applications. Energy – Harvesting (EH) technology can extend the lifespan of WSN; however, because the nodes would be difficult to get to during energy harvesting, an energy-efficient routing protocol should be developed. The use of clustering in this study balances energy consumption across all Sensor Node (SN) and reduces traffic and overhead throughout the data transmission phases of WSN. Cluster Head (CH) selection step of the Optimized Energy Efficient-Hierarchical Clustering Based Routing (OEE-HCR) technique involves sending data to the closest CH. In order to analyse and transmit each cluster data, CH will need to use more energy, which will hasten and asymmetrically deplete the network. Whale Optimization Algorithm (WOA) algorithm is introduced for the best number of clusters formation with dynamically selecting the CH. Experimentation analysis, results are measured using First Node Dead (FND), the Half Node Dead (HND), Last Node Dead (LND), and Maximum Lifetime Coverage (MLC) at the time of number of data transmission rounds performed in routing algorithms.

Keywords: Optimized Energy Efficient-Hierarchical Clustering Based Routing (OEE-HCR), Routing protocol, Whale Optimization Algorithm (WOA), Wireless Sensor Network (WSN)

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1. Introduction

A significant number of small nodes which are able to handle sensing, computation, and communication make up a wireless sensor network (WSN). WSN are utilized extensively in a selection of applications, like green agriculture, healthcare, and environmental observation, due to features like simple self-organizing, fast deployment, and real-time monitoring [1, 2]. Nonetheless, almost all of sensor nodes are battery-powered, it may be very hard to substitute or recharge them. To efficiently use the WSN limited energy, an energy-efficient routing protocol has to be developed [3, 4]. There have been many studies on data transmission strategies which combine WSN energy consumption with data compression techniques to decrease the energy needed for data transmission [5, 6].

One of the most commonly utilized techniques to regulate WSN topology is clustering. The research community has concentrated extensively on clustering sensor nodes to accomplish the objective of network scalability. The sensor network lifetime and the amount of radio broadcasts are both enhanced by the clustering approach. Clustering technique continuously modify the results of various metrics like performance, reduced energy usage, fault tolerance, consistency, and low latency [7].

Cluster Head (CH) in the clustering procedure plays a major important role for reducing the energy usage and sends a consolidated packet to the Base Station (BS). In additionally to managing general demands, CH is in the position of receiving sensed data from other sensor nodes in the same cluster and forwarding it on to the sink. Due to it, the CH node consumes more energy than other nodes. The CH in a cluster rotates across sensor nodes to maintain the energy consumption for prolonging the lifetime of this WSN. As a consequence, the CH selection process will have an effect on this network lifetime. The different application scenario settings are going to stick to the multiple lifespan. As a result, the paths used to transmit data to the sink will have an impact on energy usage. The WSN makes significant use of the hierarchical architecture since it offers more flexibility to deal with the data routing problem. Optimized selection of the CH might decrease the energy usage of nodes to increase the network lifetime throughout data transmission from BS to destination.

For the energy-efficient based WSN, the study introduces the OEE-HCR protocol. The proposed OEE-HCR protocol combines the distributed CH scheme via the Whale Optimization Algorithm (WOA) with a node-clustering algorithm to deal with the special issue of WSN where some nodes are idle due to energy efficiency. The clustering algorithm is able to generate suitable node clusters based on the initial node distribution, minimizing the effect of human experience for grouping. WSN nodes data fusion mode and the implementation of WOA to reasonable data transfer will guarantee energy efficiency.

2. Proposed Methodology

For the energy-efficient based WSN, the study proposes the Optimized Energy Efficient-Hierarchical Clustering Based Routing (OEE-HCR) protocol. The proposed OHCR protocol integrates the distributed CH scheme via the Whale Optimization Algorithm (WOA) with the node-clustering algorithm to address the specific issue of WSN where some nodes are inactive due to energy efficiency. By creating appropriate node clusters in accordance with the original node distribution, the node clustering algorithm can lessen the impact of individual knowledge on the topology of clustering. The WSN nodes data fusion mode and the introduction of WOA to reasonable data transfer will ensure energy efficiency. The clustering outcomes would affect the separated node cluster data routing, which would have an impact on the WSN energy procedure. The clustering procedure is completed by the WSN nodes dynamically clustering connected toward the adaptive deployment of the nodes.

2.1 Proposed Methodology

Consider that there are M nodes are optimally located during the position region among their a priori set and identified coordinates by equation (1).

$$C_i = \{X_i\}, i \in M \tag{1}$$

where C_i is denoted as the cluster. Assuming with the purpose of several clustering procedure, the clusters C_{M+a} and C_{M+b} include X_i, X_j and $\{X_k, X_l\}$ correspondingly. Equation (3) has been used toward signify the largest distance $D(C_{M+a}, C_{M+b})$ among 2 clusters.

$$D(C_{M+a}, C_{M+b}) = D(X_i, X_k) \tag{2}$$

$$T = \sigma D_{\max} = \sigma \max\left\{\sqrt{\left(X_i - X_j\right)^2 + \left(Y_i - Y_j\right)^2}\right\}, i, j \in M, i \neq j \tag{3}$$

$X_i = (X_i, Y_i), X_j = (X_j, Y_j)$ has been denoted as the manages of the i[th] and j[th] nodes, and σ has been denoted as practical factor. $d_{ij} < D_c$ is denoted as σ. As a result, the fraction σ was derived might be used in equation (3) toward compute the threshold T.

2.2 Clustering Model

According to Figure 1, the WSN nodes adopted the improved hierarchical clustering technique for sensible clustering. The data is then transmitted to the base station terminating by CH when it has compressed the data it got. Cluster includes of Q nodes, the base station (B), data transmitted from BS in the cluster is denoted as k_{Bs} bits, the distance between the CH and the BS is d_{Bs} bits, and the amount of data by q[th] node in the cluster to transmit via CH node s represented as k_{qs} bits, and the distance among q and s is represented as d_{qs}.

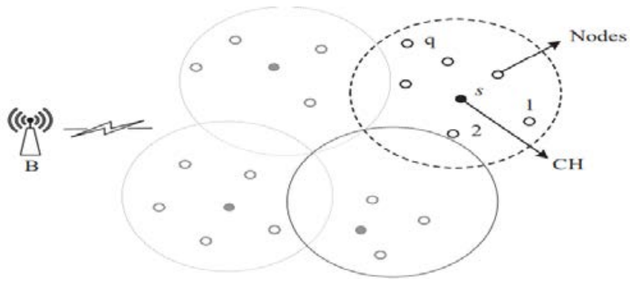

Figure 1. Topology of WSN

Best node is elected as the CH node by location data and position of the other nodes in the cluster for attaining uninterruptible target coverage by energy efficiency.

2.3 Optimized Energy Efficient- Hierarchical Clustering Based Routing (OEE-HCR)

Assume that the $E_{estimation}$ represents the energy usage throughout the transmission of each node data.

$$E_{estimation}(s) = E_{Bs} + \sum_{q=1}^{Q} E_{qs}, q \neq s \tag{4}$$

E_{Bs} is denoted as the energy has been used for the CH node to base station and the E_{qs} is denoted as the energy needed to transmit data to the CH s are included in the $E_{estimation}(s)$.

E_{rest} is denoted as the remaining node energy, and the ρ is the probability of individual chosen by CH for the q[th].

$$\rho(q) = \begin{cases} 1 - \frac{E_{estimation}(q)}{E_{rest}(q)}, q \in G \\ 0, q \notin G \end{cases} \quad (5)$$

where G is represented by group of nodes for the current data transmission cycle. The successor CH should only need a modest amount of energy to send data, and it should have enough energy left over after that. Each node cluster energy savings would be created adaptively. The clustering technique would produce node clusters are equally dispersed throughout the target detection region, and their distance from one another is significantly less than their distance from the BS. CH must provide data delivery to the BS, data distribution to the cluster nodes, and information interaction by successor CH using the energy it has gathered for communication.

2.4 CH selection using WOA

Each CH node must finish the base station data transmission responsibilities at least Z times in a single cycle, the CH nodes energy collection must be higher than the E_Δ by equation (6).

$$E_\Delta \geq Z * \left(E_{Bs} + \sum_{q=1}^{Q} E_{qs} \right), q \neq s \quad (6)$$

Assume that σ_E is the minimum charging time needed to reach E_Δ, and ΔT is the minimum amount of time needed to gather all the data for one cluster. If the network has enough sensor nodes, it can operate forever under specific energy efficiency criteria and the CH node operating mode. However, the redundancy issue would increase the network energy usage. Routine of the network is assured depending on the condition by equation (7),

$$\sigma_E \leq (30\% * Q) * (Z * \Delta T) \quad (7)$$

Equation (7) has been used as minimum Q amount of nodes to perform operation by the nodes locations, communication capabilities, and energy usage. Whale Optimization Algorithm (WOA) is based on how humpback whales hunt [17]. WOA simulates hunting behaviour by using a optimum CH search agent to explore for prey (exploration) and by using a humpback whale spiral bubble-net attacking mechanism to capture prey (exploitation). Whales can grow to a length of 30 meters and can live both individually and groups. Additionally, humpback whales use a distinctive hunting technique termed bubblenet feeding, which often entails hovering close to the target while blowing bubbles in a circle around the prey.

Encircling of Prey: Best CH search agent position, whales are utilized to update their positions by mimicking the encircling behaviour. The following equations (8-9) represent the surrounding mathematically.

$$\vec{D} = |C\vec{X}^*(t) - \vec{X}(t)| \quad (8)$$

$$\vec{X}(t+1) = \overrightarrow{X^*}(t) - \vec{A}.\vec{D} \quad (9)$$

where $\vec{A}$ and $\vec{C}$ are coefficient vectors, $\vec{X}$ is the location vector, and t is the current iteration. The best result that has been found thus far is shown by the location vector $\overrightarrow{X^*}$. If a better solution emerges after each iteration, the value of $\overrightarrow{X^*}$ is changed. The coefficient vectors $\vec{A}$and$\vec{C}$has been computed by equations (10-11),

$$\vec{A} = \overrightarrow{2a}.\vec{r} - \vec{a} \quad (10)$$

$$\vec{C} = 2.\vec{r} \quad (11)$$

$\vec{a}$ has been reduced from 2 to 0 during iterations and $\vec{r} \in [0, 1]$ is a random vector among.

Attacking of Prey (Exploitation Phase): The bubble net assaulting tactic simulates the attack of the prey. For the exploitation phase, two basic approaches the spiral updating position mechanism and the shrinking encircling mechanism have been adopted. Each of these mechanisms has a 50% chance of occurring since humpback whales can use any of these methods to grab their meal. Introduced is a random variable p, whose range is [0,1]. The value of A is determined at random between $[-a, a]$. The exploitation part of this optimization approach involves assaulting prey. Exploitation entails exploring a specific area of the search space in an effort to improve the area surrounding the solution 'S'. $\vec{A}$is between [-1, 1] and therefore when $|\vec{A}| < 1$, search agents then come together to get the best answer when exploitation is encouraged. The updating model can be given by equation (12).

$$\vec{X}(t+1) = \begin{cases} \overrightarrow{X^{*(t)}} - \vec{A}.\vec{D} & if\ p < 0.5 \\ \overrightarrow{D'}\ .e^{bi}.\cos(2\Pi l) + \overrightarrow{X^{*(t)}} & if\ p \geq 0.5 \end{cases} \quad (12)$$

Searching of Prey (Exploration Phase): The exploration phase mobilizes the search agents in hunt of improved CH solutions, is based on the change of vector A. The search agent must diverge far into the CH search space since the value of $|A|$ is set to bigger than 1, which is greater than 1. CH search agents revise their CH location by randomly chosen search agent rather than referring to the best search agent to the exploitation phase. Equations (13-14) can simulate the search mechanism.

$$\vec{D} = |C.\overrightarrow{X(t)}_{rand} - \vec{X}| \quad (13)$$

$$\vec{X}(t+1) = (\vec{X}_{rand} - \vec{A}.\vec{D} \quad (14)$$

The above equations have been used to find the best CH.

3. Simulation results

In this section, shows the simulation results of routing methods and it are simulated using MATLAB. Figure 2 displays the placement of 200 sensor nodes over a 200m×200 m region. Various colors correspond to various clusters in the simulation model. It is also possible to elect or employ the initial CH. Table 1 shows the other simulation parameters [16].

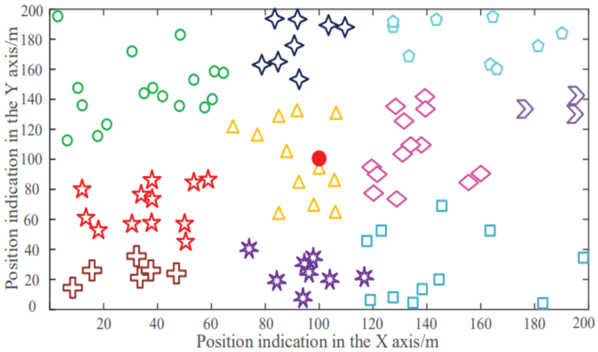

Figure 2. Node Division in WSN

Table 1. MATLAB Simulation Parameters

Parameters	Value
Size of network	200 m × 200 m
No. of Nodes	200
B (Base Station)	(200,200)
Initial Energy	0.5 J
Size of Packet	4500 bit
Header Size	30 bytes/packet
Control Message Size	55 bytes
E_{elec}	55 nJ/bit
E_{fs}	10 pJ/bit/m^2
E_{mp}	0.0018 pJ/bit/m^4
E_{DA}	6 nJ/bit/message

3.1 Network Lifetime Evaluation

The proposed OEE-HCR protocol will be compared to the routing algorithms like Sleep-awake Energy Efficient Distributed (SEED) [15], Novel Efficient Clustering Protocol for Energy Harvesting (NEHCP) [16], and HCEHUC [13] in this part to ensure its validity. The standard routing algorithms lack an energy-harvesting stage. The OEE-HCR technique gives better results in energy efficiency than other methods.

Table 2. Lifetime Metrics vs. Routing Methods

Network Lifetime metrics	SEED	NEHCP	HCEHUC	OEE-HCR
FND	1550	1815	2695	2964
HND	3654	4166	4513	5129
LND	4291	4723	5218	5455
Average	3165	3568	4142	4516

In addition, as shown in Table 2, the proposed OEE-HCR protocol, and existing routing methods has been verified in terms of lifetime metrics like HND and LND.

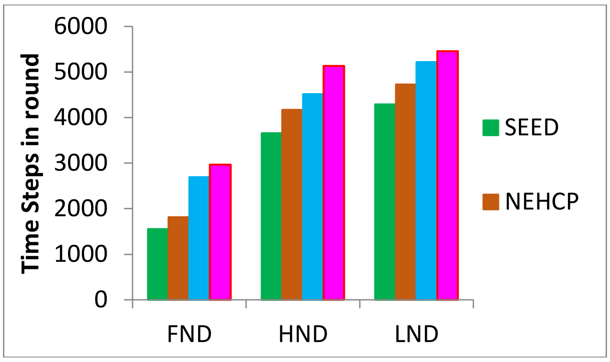

Figure 3. Data Transmission Rounds vs. Routing Methods

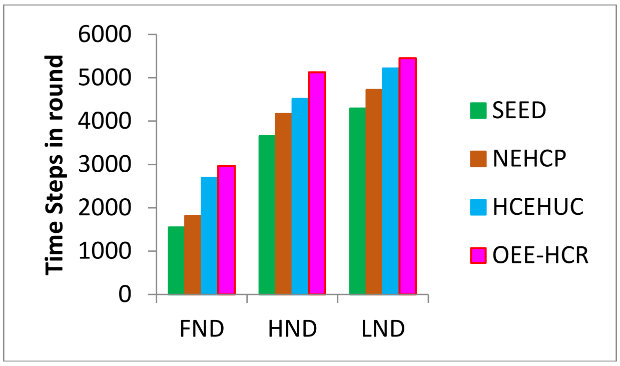

Figure 4. Data Transmission Rounds with Average Network Lifetime

Figure 3 shows the total number of data transmission rounds for all routing methods in relation to the FND, the HND, and the LND. Figure 3 shows that the FND may be extended to 1550, 1815, and 2695, respectively, via the SEED, NEHCP, and HCEHUC routing protocols. OEE-HCR protocol may achieve the optimized clustering of WSN nodes. The FND rounds can therefore be extended by the proposed method to 2964 rounds. Figure 4 illustrates the total number of data transmission rounds using all routing techniques by average rounds. It demonstrates that the average network lifespan for the SEED, NEHCP, and HCEHUC routing protocols is 3165, 3568, and 4142 correspondingly. The OEE-HCR procedure can increase the number of cycles to 4516 on average.

3.2 MLC vs. Various Initial Energy

The energy levels are measured by varying the ranges in various scenarios for routing protocols. It has been discussed in Table 3, and Figure 4.

Table 3. MLC via Different Initial Energy

Initial Energy	SEED	NEHCP	HCEHUC	OEE-HCR
0.25 J	2055	2512	2619	2854
0.5 J	4266	4957	5248	5651
0.75 J	5423	6125	7784	8246
1 J	7658	8457	10323	11214

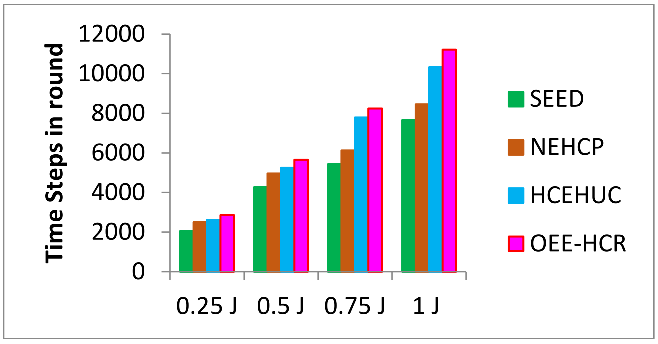

Figure 5.MLC Comparsion vs. Routing Methods

Figure 5 and Table 3 show that without energy efficiency, the MLC network would be extended, and its starting node energy would grow. While previous routing protocols like SEED, NEHCP, and HCEHUC have the MLC of 7658, 8457, and 10323 rounds, the suggested OEE-HCR protocol has a higher MLC of 11214 rounds for 1 J.

Conclusion and Future Work

In this paper, Optimized Energy Efficient-Hierarchical Clustering Based Routing (OEE-HCR) technique has been presented for energy efficiency in WSN. It can achieve distance-based environment-adaptive clustering, which lowers the energy required for data transmission by the cluster and enhances the topological structure in WSN network model. OEE-HCR protocol clustering phase involves forming the ideal number of clusters and choosing the CH in a flexible way. The three key criteria used by WOA to pick a CH are energy efficiency, node residual energy, and data transmission energy model to create an OEE-HCR protocol. The OEE-HCR technique has been presented to calculate the perfect number of clusters and to vigorously decide the CH node from amongst several nodes in the cluster. Finally, the other operating-recharging of the CH node is possible to adaptively decide the topological association and dispersed communication of the node cluster. The proposed protocol findings are then contrasted with those of the SEED, NEHCP, and HCEHUC approaches already in use in terms of network longevity and Maximum longevity Coverage (MLC). Future work routing has been done particularly for target coverage is congested aware.

References

[1] Wu, H., Miao, Z., Wang, Y. and Lin, M.,(2015) Optimized recognition with few instances based on semantic distance. The Visual Computer, 31, pp.367-375.

[2] Lin, B., Guo, W., Xiong, N., Chen, G., Vasilakos, A.V. and Zhang, H.,(2016) A pretreatment workflow scheduling approach for big data applications in multicloud environments. IEEE Transactions on Network and Service Management, 13(3), pp.581-594.

[3] Ma, J., Wang, S., Meng, C., Ge, Y. and Du, J.,(2018) Hybrid energy-efficient APTEEN protocol based on ant colony algorithm in wireless sensor network. EURASIP Journal on Wireless Communications and Networking, pp.1-13.

[4] Zheng, H., Guo, W. and Xiong, N., (2017) A kernel-based compressive sensing approach for mobile data gathering in wireless sensor network systems. IEEE Transactions on Systems, Man, and Cybernetics: Systems, 48(12), pp.2315-2327.

[5] Manchanda, R. and Sharma, K., (2017) Energy efficient compression sensing-based clustering framework for IoT-based heterogeneous WSN. Telecommunication Systems, 74(3), pp.311-330.

[6] Zhang, J., Lin, Z., Tsai, P.W. and Xu, L. (2020) Entropy-driven data aggregation method for energy-efficient wireless sensor networks. Information Fusion, 56, pp.103-113.

[7] Singh, D., Kumar, B., Singh, S. and Chand, S., (2019) SMAC-AS: MAC based secure authentication scheme for wireless sensor network. Wireless Personal Communications, 107, pp.1289-1308.

[8] Zhao, L., Qu, S. and Yi, Y., (2018) A modified cluster-head selection algorithm in wireless sensor networks based on LEACH. EURASIP Journal on Wireless Communications and Networking, pp.1-8.

[9] Sanhaji, F., Satori, H. and Satori, K., (2019) Cluster head selection based on neural networks in wireless sensor networks. International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS), pp. 1-5.

[10] Mody, S., Mirkar, S., Ghag, R. and Kotecha, P.,(2021) Cluster Head Selection Algorithm For Wireless Sensor Networks Using Machine Learning. International Conference on Computational Performance Evaluation (ComPE), pp.445-450.

[11] Gheisari, M., Yaraziz, M.S., Alzubi, J.A., Fernández-Campusano, C., Feylizadeh, M.R., Pirasteh, S., Abbasi, A.A., Liu, Y. and Lee, C.C., (2022)An efficient cluster head selection for wireless sensor network-based smart agriculture systems. Computers and Electronics in Agriculture, 198, pp.1-26.

[12] Hamzeloei, F. and Dermany, M.K., (2016) A TOPSIS based cluster head selection for wireless sensor network. Procedia Computer Science, 98, pp.8-15.

[13] Han, B., Ran, F., Li, J., Yan, L., Shen, H. and Li, A., (2022) A novel adaptive cluster based routing protocol for energy-harvesting wireless sensor networks. Sensors, 22(4), pp.1-16.

[14] Rathore, R.S., Sangwan, S., Prakash, S., Adhikari, K., Kharel, R. and Cao, Y., (2020) Hybrid WGWO: whale grey wolf optimization-based novel energy-efficient clustering for EH-WSNs. EURASIP Journal on Wireless Communications and Networking, pp.1-28.

[15] Ahmed, G., Zou, J., Fareed, M.M.S. and Zeeshan, M., (2016) Sleep-awake energy efficient distributed clustering algorithm for wireless sensor networks. Computers & Electrical Engineering, 56, pp.385-398.

[16] Sah, D.K. and Amgoth, T., (2020)A novel efficient clustering protocol for energy harvesting in wireless sensor networks. Wireless Networks, 26(6), pp.4723-4737.

[17] Mirjalili, S. and Lewis, A.,(2016) The whale optimization algorithm. Advances in Engineering Software, 95, 51–67.