International Journal of Computer Networks and Applications (IJCNA)
DOI: 10.22247/ijcna/2023/223419 Volume 10, Issue 5, September – October (2023)

RESEARCH ARTICLE

Energy Efficient Cluster Formation and Multihop Routing Based on Improved Harmony Search Algorithm for Wireless Sensor Networks

G V Sowmya
Department of Information Science and Engineering, Jawaharlal Nehru New College of Engineering (Visvesveraya Technological University, Belagavi), Shimoga, Karnataka, India.
gvsowmya@jnnce.ac.in

R Aparna
Department of Information Science and Engineering, Siddaganga Institute of Technology (Visvesveraya Technological University, Belagavi), Tumakuru, Karnataka, India.
raparna@sit.ac.in

Received: 17 June 2023 / Revised: 24 August 2023 / Accepted: 05 September 2023 / Published: 30 October 2023

Abstract – Energy efficiency plays a crucial role in extending the operational lifespan of Wireless Sensor Networks (WSNs). It stands as the foremost objective for any routing algorithm designed for WSNs. This study centers on enhancing communication efficiency through a multihop approach guided by the Harmony Search Algorithm (HSA). The process incorporates Cluster Head (CH) selection through the utilization of the HSA and by assessing the quality of the communication channel. There are instances where a channel possesses high capacity, yet it transmits minimal data, leading to resource underutilization. Therefore, if the communication channel's quality is pre-determined, then algorithms can be developed to establish an upper limit for channel usage, ensuring congestion free and error free maximum data transmission. In the proposed methodology, parameters such as residual energy, distance and node degree were taken into account for CH selection. Subsequently, clusters were formed based on Shannon Channel Capacity 'C' and path loss model. Following the CH selection and cluster formation, a communication was established using HSA. A comparative analysis was conducted on network life span, packets sent to Base Station (BS) and energy utilization for the three algorithms, Energy Efficient Harmony Search Based Routing (EEHSBR), Clustering and Routing in wireless sensor networks using Harmony Search Algorithm (CRHS), and Robust Harmony Search Algorithm based clustering protocol for wireless sensor networks (RHSA).

Index Terms – Wireless Sensor Network, Harmony Search Algorithm, Shannon Channel Capacity 'C', Path Loss model, Cluster Head, Harmony Memory.

1. INTRODUCTION

The WSN relies on battery-powered sensor nodes; hence their energy must be efficiently utilized. Sensor nodes are independent devices tasked with a range of functions, including sensing, data processing, and communication. These nodes work together within a network to collectively monitor environmental conditions and transmit data. For long-term sensing, the sensor nodes are dispersed and cooperatively placed statically in a vast region. Nodes should preserve energy as much as possible to cover a large deployment area and offer long-term sensing capabilities. The batteries are allocated for each node, and recharging them in a hostile environment is a highly complex task [1]. As a result, node energy saving is usually regarded as the most important concern in WSNs [2]. These networks' sensors accumulate pertinent information from their surroundings and forward it to a Base Station (BS) [3, 4, and 5].

The energy required to operate the sensing nodes within the WSN is sourced from non-replaceable batteries. During the network operations such as data sensing, data computation, and data exchange between nodes, the battery's energy utilization is notably high. Once a node's battery can no longer provide the necessary energy, the node ceases to function. However, Because of the positioning of sensor nodes within the wireless network and the network's inherent setup, replacing or recharging drained batteries is typically infeasible or impractical. Wireless Sensor Networks (WSNs) find utility in a wide array of applications, such as precision agriculture, weather surveillance, habitat monitoring, and other domains that require real-time data monitoring and processing [6].

In clustered WSNs, non CH nodes gather data and transmit it to a designated Cluster Head (CH). The CH then processes this information and forwards it to the BS, either in one step or via multihop. CH selection is a tedious job. If there are 'm'

RESEARCH ARTICLE

nodes and if 'n' nodes out of it are chosen as CH, then the possible configurations for choosing the Cluster Head is represented by mCn. For instance, if 'n' nodes are selected as CHs out of 'm' nodes and computational difficulty rises with network size. Therefore, it is difficult to overcome using the traditional methods [7]. The numerous scholars look into various elements of WSNs, including suitable CH selection, reduced power algorithms [8, 9, 10], network setup, and routing algorithms for WSNs [11, 12, 13]. The Harmony Search Algorithm (HSA), introduced by Geem et al.[14], stands as a well-known metaheuristic approach employed for addressing various optimization challenges. This algorithm takes inspiration from the artistic process of music improvisation. HSA has been utilized to overcome a variety of real-world challenges, including tour planning, computer science issues and time tabling as well as parts of civil, electrical, and mechanical engineering. Exploration and exploitation are the two fundamental parameters of every metaheuristic algorithm. Randomization, harmony memory acceptance rate and pitch adjustment are the three components that govern both the parameters in HSA. Implementation of HSA is simpler and has minimum reliance on the algorithm's adjustable parameters, allowing researchers to get optimal results with fewer adjustable parameters [14]. Hence HSA could be used for solving NP (Non deterministic Polynomial)-Hard issues related to WSNs.

1.1. Problem Statement

- In any WSN CH selection is very important. Appropriate CH selection will increase the energy efficiency of WSN. This in turn increases the life span of WSN. Therefore the first challenge is to select a group of appropriate CHs.
- Cluster formation is another challenge. The proper formation of cluster around the CH will increase the energy effectiveness of the WSN.
- The messages sent to CH from non-CH nodes have to be forwarded to the BS with minimum interference. The third challenge is to find an appropriate path between CH and BS.

The next part of this article is divided into the following sections. The summary of available CH selection and routing methods is detailed in section 2. The network model and the energy model are covered in Section 3. Section 4 outlines the proposed Cluster Head determination criteria, cluster configuration process and routing technique. The results of the research study and the evaluation to assess the presented method is detailed in section 5. The conclusion of the article is presented in section 6.

2. RELATED WORK

D C Hong et al [15] contributed a clustering protocol depending on the HSA for WSNs. In their work, the CHs are chosen using the harmony search algorithm, which reduces intra-cluster separation and optimizes the network energy efficiency. Parameters like alive nodes and energy utilization are contrasted with available algorithms like Particle Swarm Optimization (PSO) [16] and Genetic Algorithm (GA) [17]. The presented approach is implemented using MATLAB. Their outcomes prove that the assessment of the presented algorithm concerning network lifespan and energy utilization is better than the considered algorithms. But the presented approach is not suitable for complicated engineering problems.

Anupkumar M. Bongale et al. [21] introduced an algorithm for clustering that utilizes a combination of the harmony search and firefly algorithms. The protocol involves a two-stage process for selecting cluster heads. In the beginning stage, Cluster Heads are tentatively chosen through the utilization of the HSA. Subsequently, in the second stage, the chosen Cluster Heads undergo optimization using the firefly algorithm by analyzing the parameters like cluster compactness and energy utilization. The presented technique was contrasted with the available protocols namely LEACH [19], LEACH-C [20] and simple firefly based routing protocols for the comparative factors like active nodes, energy utilization of the network, and information transmits to a BS. The evaluation was carried out using NS2.34 and the outcomes showcased by the presented algorithm indicate superior performance than the available algorithms. But the presented algorithm has not addressed the intra-cluster data aggregation.

The Authors [22] have contributed a clustering algorithm depending on HSA and PSO algorithms. Here, a hybrid approach involving both HSA and PSO algorithms was employed for the CHs selection and to secure a global search with higher convergence. The presented algorithm provides the increased searching capabilities of HSA and the dynamic competence of PSO that extends the network lifespan. The metrics for performance like the active nodes, the remaining energy and the throughput were considered and implemented in MATLAB. The LEACH [19], HSA [15], and PSO [16] algorithms were contrasted with the presented algorithm. Evaluation results indicate that the presented hybrid algorithm outperforms the available algorithms. But authors has not detailed about cluster formation.

Lalwani et al [23] presented the clustering and routing approach for WSN that relies on HSA. In this article, HSA was applied for CH selection and routing algorithm by devising the fitness function depending on the components like distance, node degree and energy. The presented technique was contrasted with LEACH [19], LEACH-C[20] and PSO[16] algorithms by taking the components like remaining energy, information sent to a base station and alive nodes. The presented technique was evaluated using

RESEARCH ARTICLE

MATLAB and the outcomes of the presented technique were superior to the available algorithms. In this article, the authors have not addressed the delay in sending the message to the BS and the fault tolerance.

Bing Zing et.al [24] suggested a routing method for WSN utilizing the Harmony Search Algorithm. In this article, parameters like path control and energy utilization were considered to design objective function. C++ was used to simulate the presented algorithm and the outcomes are contrasted with EEABR [25]. The result demonstrates that the EEHSBR algorithm significantly outperformed with respect to managing energy utilization and extending the network longevity. But, in the routing technique, the steady attributes were considered by the proposed algorithm that may trap the search into local optima which would results in minimized convergence accuracy.

Rani et. al [32] employs a hybrid approach involving PSO and River Formation Dynamics (RFD) to optimize CH selection. They assess performance using comparative metrics such as average end-to-end delay and average packet delivery ratio, comparing against existing protocols like LEACH, PSO, and RFD. Notably, the presented technique has not considered the interference among the nodes.

Wu et al [33] introduced an algorithm utilizing an enhanced Ant Colony Optimization (ACO) technique for calculating the most efficient route for a mobile sink as it moves through the network. The study evaluated performance metrics including network delay and energy utilization, comparing their approach against LEACH, VGEE [34], and EDC [35]. However, the presented approach did not account for data gathering from multiple mobile sinks.

Jatinder Pal Singh [36] proposed a clustering technique where the CH selection was executed using whale based tunicate swarm algorithm while the routing algorithm was executed using the Aquila optimizer. The execution of the presented approach was contrasted with existing technique such as LEACH, PSO-GSA and whale based tunicate swarm algorithm with reference to delay, active nodes, and throughput and energy consumption. But authors have not detailed about the cluster formation.

Tyagi, L. K. ., & Kumar, A [37] presented random forest technique for CH selection and utilizes fuzzy technique for routing algorithm. The evaluation factors such as energy consumption, energy dissipation and network lifespan was utilized to assess with other available algorithms like LEACH, LEACH C, Hybrid Swarm-based algorithm and PSO. But the presented technique has not detailed about the cluster formation.

Quasi Oppositional Jaya Load balancing approach utilized by M. S. Muthukkumar and S. Diwakaran [38] for CH selection, which uses two routing methods single hop and multiple hops. The presented technique prolongs the network longevity and reduces the energy utilization. The presented model is limited to CH selection and they have not tackled the procedure for cluster formation.

Table 1 provides a summary of the literature study's findings. A substantial section of the reviewed articles employ the HSA algorithm for tasks such as clustering and routing, either individually or in combination. The articles centered around the HSA primarily utilize parameters related to remaining energy and distance for the initialization of the harmony memory. Notably, these parameters have demonstrated substantial efficacy in achieving favorable outcomes. Although these parameters contribute positively to extending network lifespan and enhancing throughput, they fall short in evaluating path or channel quality. Thus this article introduces three distinct algorithms. The initial algorithm chooses an optimal collection of sensor nodes as CHs among all sensor nodes. Following this, non-cluster nodes are allocated to these CH nodes, taking in to consideration factors like Shannon Channel Capacity ‘C’ and the path loss model. Finally, the routing algorithm is proposed based on multihop communication and parameters such as Shannon Channel Capacity ‘C’ and path loss model to find the efficient path between CH and BS.

Table 1 Summary of the Literature Survey

Sl. No.	Article	Algorithm Used for Clustering	Algorithm Used for Routing	Parameters Considered for Clustering and Routing.	Remarks
1	D C Hong et al [15], 2010	HSA	Not addressed	Distance, residual energy	Presented technique is not suitable for complicated engineering problems.
2	Anupkumar M. Bongale, et al [21], 2019	HSA and Firefly algorithm	Not addressed	Alive nodes, residual energy	In the presented algorithm the intra-cluster data aggregation is not addressed

RESEARCH ARTICLE

3	T. Shankar et al, 2016[22]	HSAand PSO	Not addressed	Distance, residual energy	In the introduced approach cluster formation process is not discussed.
4	Lalwani et al [23], 2018	HSA	HSA	Residual energy, distance and node degree.	Presented approach will not address thedelay in sending messages to the base station and the interference among the nodes.
5	Bing Zing et.al [24], 2015	Not addressed	Harmony Search Algorithm	Distance, residual energy.	Proposed algorithm that may trap the search into local optima which would results in minimized convergence accuracy
6	Rani et al [32], 2023	Particle Swarm Optimization and River Formation Dynamics.	Not addressed	Position and velocity of the node.	Interference among the nodes were not considered in the presented approach.
7	Wu et al [33], 2022	Depending on remaining energy of the sensor node	Ant Colony Optimization	Residual energy, distance	Data gathering from multiple sink was not considered.
8	Jatinder Pal Singh [36], 2022	Whale based tunicate swarm algorithm	Aquila optimizer	Distance, residual energy.	The presented approach overlooked interference among nodes.
9	Tyagi, L. K. ., &Kumar, A [37], 2023	Random forest technique	Fuzzy technique	Residual energy, distance and node density.	Cluster formation aspect was not discussed in the proposed approach.
10	M. S. Muthukkumar and S. Diwakaran [38], 2023	Load balancing technique.	Not addressed	Residual energy distance.	The presented approach did not include a discussion on the aspect of cluster formation.

3. NETWORK MODEL

Both free space and multipath fading channel model are considered to evaluate energy expanded during receiving and transmitting data. The energy utilization for transmitting 'x' bits of data at transmission distance 'd' is represented by equation (1) and equation (2).

$$E_{Tx} = E_{elec} * x + E_{fs} * x * d^2, d < d_o \quad (1)$$

$$E_{Tx} = E_{elec} * x + E_{amp} * x * d^4, d > d_o \quad (2)$$

Where, E_{Tx}-Energy needed for transmitting 'x' bits.

E_{elec}- Energy needed to run the transceiver circuit.

E_{fs} and E_{amp}- Energy expended by the transmit amplifier in both free space and multipath model .

To obtain data comprising 'x' bits is denoted in equation (3),

$$E_r(x, d) = x * E_{elec} \quad (3)$$

$E_r(x, d)$- Energy required to receive 'x' bits.

The threshold d_o is indicated in equation (4),

$$d_o = \sqrt{E_{fs}/E_{amp}} \quad (4)$$

The following presumptions are laid in this research on a network that consists of static sensor nodes and the BS.

RESEARCH ARTICLE

- Each sensing node commences with the identical initial energy level, rendering the network homogenous.
- Every sensing component has a non-rechargeable battery.
- Due to the symmetrical nature of the radio channel, transmitting information from node x to node y consumes an equivalent quantity of energy as transmitting information from node y to node x.

Each individual sensor node has the ability to monitor the environmental parameters or can operate in sensing mode, sending messages to the CH for data gathering and transmission to the BS.

4. THE PROPOSED MODEL

The proposed model considers the case where a region of M X M m^2 is populated with 'N' sensor nodes distributed randomly and executes in rounds. In each round, there are 3 stages.

1) Choosing the Cluster Head (CH) Stage: In this stage, a group of CHs are chosen from the collection of nodes depending on the HSA. Hence the capacity of the HSA to efficiently reach a global solution is very large.

2) Cluster Formation Stage. Once a group of CHs are selected, then non CH nodes are allotted to selected CHs to create the clusters for each round.

3) Data Transfer from CH to BS Based on HSA. In this stage, the non CH nodes within a cluster send messages to the CH. The CH determines space for each member of the cluster using Time Division Multiple Access (TDMA). Once all the non CH nodes have sent messages, the CH aggregates the received messages and relay them to the BS using multihop communication facilitated by HSA.

4.1. Cluster Head (CH) Selection Stage

The first stage in the algorithm involves selecting CHs with the assistance of HSA. HSA has been chosen since it has demonstrated great success across several optimization challenges and offered several benefits over conventional optimization techniques [26, 27].

The basic HSA includes a) initialization of Harmony Memory (HM), b) Improvisation of HM by considering HMCR and PAR, c) Revise the HM and d) Termination criterion.

a) Initialization of Harmony Memory: The presented approach uses a collection of CH nodes for HM. The initial node of every solution is randomly picked from a collection of nodes ‘N’ and inserted to the HM. The choice of nodes relies on the spacing between the new nodes to be appended to the HM and the currently accessible nodes in Harmony Memory. The dimension of HM can be varied. The modeled HM is presented in equation (5).

$$\text{HM} = \left\{\begin{matrix} F_1 \\ F_2 \\ \cdot \\ \cdot \\ \cdot \\ F_i \\ \cdot \\ \cdot \\ \cdot \\ F_{HMS} \end{matrix}\right\} = \left\{\begin{matrix} (N_{1,1}, x_{1,2}, \ldots x_{1,k}) \\ (N_{2,1}, x_{2,2}, \ldots x_{2,k}) \\ \cdot \\ \cdot \\ \cdot \\ (N_{i,1}, x_{i,2}, \ldots x_{i,k}) \\ \cdot \\ \cdot \\ \cdot \\ (N_{HMS,1}, x_{HMS,2}, \ldots x_{HMS,k}) \end{matrix}\right\} \quad (5)$$

Where, $N_{i,1}$ - Randomly chosen from the group of sensor nodes, N.

F_1, F2…..F_{HMS} - Fitness function.

HMS - Harmony Memory Size.

$$P(i, j) = \begin{cases} \frac{RE_j}{\sum_{i=1}^{n} RE_n} & if\ d(i,j) > d_{opt} \\ 0 & else \end{cases} \quad (6)$$

Where, P (i,j) - The probability that a node i will choose the subsequent node j.

RE_j - The Remaining Energy of j^{th} node.

RE_n - The Remaining Energy of n^{th} node.

$d(i, j)$ - Distance between node i and node j.

d_{opt} - Distance between CHs.

The succeeding node to be incorporated will be determined by the probability equation (6) until 'k' CHs are chosen. The average remaining energy is employed in the calculation of the probability function P(i, j), with the assumption that the selected CH nodes must be d_{opt} apart from each other. d_{opt} refers to the ideal separation distance between CHs, allowing for the allocation of chosen CHs throughout the sensing area [28]. The Euclidean distance between node i and node j is denoted by d (i, j). Assuming that node i and node j, respectively, are located at (x_i, y_i) and (x_j, y_j). The d (i, j) is computed as per equation (7). Steps for CH selection depending on HSA are depicted in Algorithm 1.

$$d(i, j) = \sqrt{(x_i - x_j) + (y_i - y_j)^2} \quad (7)$$

Illustration 1: Consider 100 sensor nodes and 10% of the sensor nodes serve as CHs. Hence, the size of every harmony is 10. Figure 1 represents the initialization of harmony, where CH51 is randomly chosen from the group of nodes. The next CH, CH82 is selected based on equation (6) and further CHs i.e., CH94, CH02, CH36, CH22, CH48, CH53, CH08, CH10 are selected based on equation (6). Then calculate the fitness function F1, according to equation (13). Likewise, F2, F3 and F4 are calculated.

RESEARCH ARTICLE

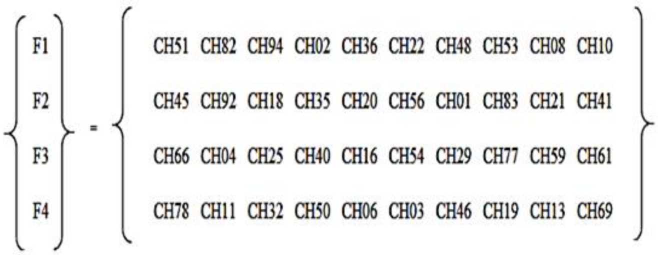


Figure 1 Initialization of Harmony Memory

Input: Set of sensor nodes N={N1,N2,….Nn}

Output: Ideal set of Cluster Heads, CH = {CH1,CH2,…CHk}

Step 1: Set the attributes HMS,HMCR, PAR and NImax to their initial value

Step 2: Harmony Memory vectors generated as per Section 4.1.

Step 3: Measure the fitness function of every harmony by Equation (13).

Step 4: Harmony Memory Improvisation

While (Improvisation < NImax) do

Generate random number R1.

If(R1<HMCR) then

CH is chosen randomly from HM.

Else

CH is chosen from the collection of sensor nodes N according to equation (6)

Endif

Generate random number R2.

if(R2<PAR) then

CH is replaced by its neighbor node.

Endif

End

Step 5: Calculate fitness function of F_{new}

If (the fitness function of F_{new} is better than F_{new} in HM) then

Replace F_{worst} with F_{new}.

Endif

Algorithm1 Steps for CH Selection Based on HAS

b) Improvisation of Harmony Memory: The presented CH nodes for the following procedure are represented by the nodes in the HM. A new harmony F_{new} (set of CHs) is generated during HM improvisation according to the HMCR (Harmony Memory Consideration Rate), which fluctuates between [0, 1]. The initial node of a new harmony F_{new} is chosen randomly, in the array of i^{th} HM and a random integer R1 between [0, 1] is produced while selecting the next node. The next option CH is picked at random from HM if produced random number falls below HMCR; otherwise, CH is chosen from the collection of sensor nodes N as per equation (6) as indicated in Figure 1 and according to equation (8). After producing a new harmony, improvement is resumed depending on the Pitch Adjustment Rate (PAR), whose value ranges from 0 to 1. The PAR is contrasted against an R2, a random value ranging from 0 to 1. A random component from the updated harmony memory is substituted with an alternative neighbor node, as depicted in Figure (3), where R2 is lower than PAR.

$$f` = \begin{cases} f_i` \in \{x_{1,i}, x_{2,i}, \dots, x_{HMS,i}\}, & R1 < HMCR \\ f` \in N, & otherwise \end{cases} \quad (8)$$

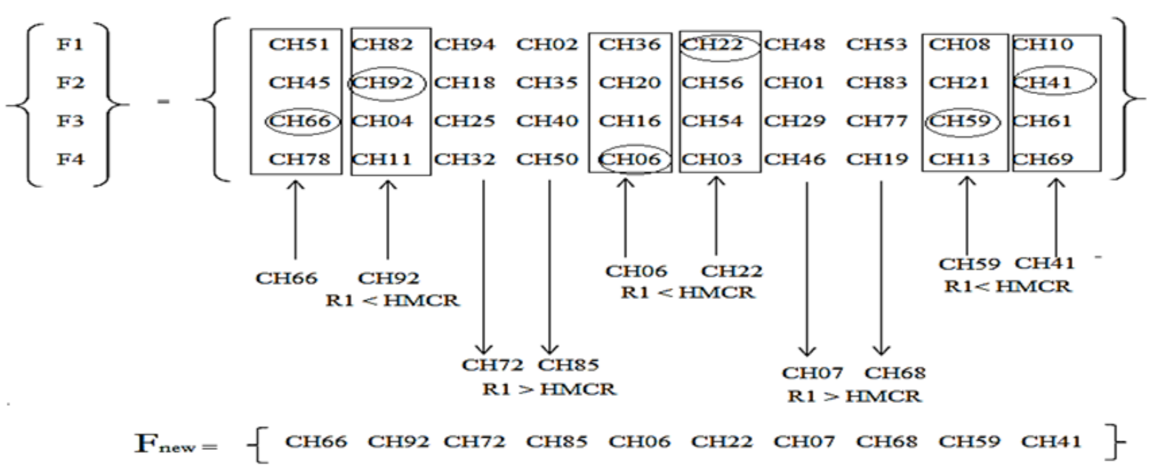


Figure 2 Improvisation of Harmony Memory

RESEARCH ARTICLE

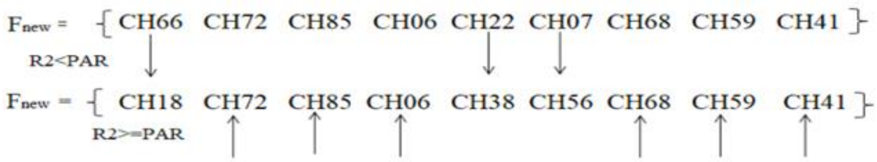


Figure 3 Pitch Adjustment Process

In Figure 2, the initial node of the new harmony, F_{new} is selected randomly from the first column i.e., from {CH51, CH45, CH66, CH78} for instance CH66 is chosen randomly. When selecting the subsequent CH, the value of random number R1 is taken into consideration. If the R1 is smaller than HMCR, then, the following CH is selected at random from HM's second column. In this instance, CH92 is selected. If R1 is larger or identical to HMCR then CH is randomly chosen from the group of sensor nodes N, which in this case is CH78. This procedure continues for selecting up to 10 CHs.

$$\text{Pitch adjusting for } f_i' = \begin{cases} Yes & if(R2 < PAR) \\ No & Otherwise \end{cases} \quad (9)$$

Figure 3 shows the pitch adjustment process of F_{new}, based on equation (9). Consider the random number R2. If R2 is lower than PAR, then the element in the F_{new} is replaced by another adjacent node, here CH66 is replaced by CH18 which is the adjacent node of CH66. The process is reiterated for the following CHs in the F_{new}. If R2 is higher than or identical to PAR the CHs are retained as it is. In this example CH72, CH85, CH06, CH68, CH59, CH41 are retained as it is.

c) Update the Harmony Memory:

In this stage, the HM is adjusted in response to the assessment of the recently pitch-adjusted HM. The fitness function indicated by equation (13) is utilized to assess the success of the new HM, F_{new}. If the new HM is superior to the finest HM, then the superior HM is included and stages (a) and (b) are updated.

d) Verifying halting criteria: Until the highest possible iteration count (NImax) is achieved, steps (a) and (b) are continued. Out of all the HMS, one HM (set of CHs) will be chosen as the most efficient HM when the objective function has given the best value once NImax is accomplished. The fitness function is described in the 4.1.1 section.

4.1.1. Fitness Function

To choose an ideal set of CHs, a fitness function is devised using the Remaining energy, the Distance between CH to the BS and the Node degree.

(i) The CH's Remaining energy (RE_{CH}): Throughout the data transfer stage, the CH collects messages from non-CH nodes and aggregates them before sending them to the BS. Hence CH requires a large amount of remaining energy to complete these tasks. As a CH, a sensor node with a large amount of remaining energy is preferable. Lowering the remaining energy is our primary goal; this is achieved by taking into account the function f1 as indicated in the equation (10):

$$Min f_1 = \sum_{i=1}^{k} 1/(RE_{CH_i}) \quad (10)$$

Where, RE_{CH_i} is i^{th} Cluster Head's remaining energy.

(ii) Distance between the CH and BS (d (CH, BS)): It is the Euclidean distance between each CH and BS. If BS is distant from the CH, it will require a lot of energy to perform its tasks. A fast decline in the energy of CH degrades the competence of the network. Consequently the CH that possesses the shortest Euclidean distance to BS is the better option. Our second goal is to lower the distance between CHs and BS, by taking a function f2, is illustrated in equation (11):

$$Min\ f_2 = \sum_{i=1}^{k} d(CH_i, BS) \quad (11)$$

(iii) Node Degree (ND): It is the overall number of non-CH nodes assigned to each CH. When CHs have a smaller node count, they can last longer. Consequently, the CH with the lowest node degree is recommended. Our third goal is to decrease the node degree by incorporating a function f3, as illustrated in equation (12):

$$Min f_3 = \sum_{i=1}^{k} ND_i \quad (12)$$

The fitness function is devised using attributes like the remaining energy, the distance between CH to the BS and the node degree, as illustrated in equation (13).

$$\text{Fitness function (F)} = \beta_1 * f_1 + \beta_2 * f_2 + \beta_3 * f_3 \quad (13)$$

Where, β_1, β_2 and β_3 are weights assigned to each function $0 \leq (\beta_1 + \beta_2 + \beta_3) \leq 1$.

4.2. Cluster Formation Stage

Assigning Regular Nodes (RNs) to selected CHs is the next step after the CHs for the present round have been selected. Consider a scenario where an RN receives join request information from two or more CHs, and the RN then arbitrarily selects one of the CH in the available algorithms. In this work, A technique is presented for associating RNs to the CHs considering Shannon Channel Capacity, 'C' (bit rate)

RESEARCH ARTICLE

given by equation (14). Sequence for cluster formation is presented in Algorithm 2.

$$C = BWlog_2\left(1 + \frac{T_p[dB] - Pl(d)[dB]}{k*T*BW}\right) \quad (14)$$

Where 'BW' is Channel bandwidth in Hz, 'T_p' is Power Transmitted in watts, 'Pl (d)[dB]' is path loss in dB at distance 'd' from transmitter, 'k' is Boltzmann Constant,1.3806503X$10^{-23}m^2$ kg $s^{-2}K^{-1}$and 'T' is temperature in degree Kelvin.

Two ray ground path loss model is used. Pl (d) dB is given by equation (15).

$$Pl(d) = 40logd - 10(logT_g + logR_g + 2logh_r + 2log_t \quad (15)$$

Where'd' is distance between receiver and transmitter, 'R_g' and 'T_g' are the gain of receiving and transmitting antennas. 'h_r' and 'h_t' are receiving and transmitting antennas height. To get bit rate 'C', substitute equation (15) in equation (14).

$$C_{two-ray} = BWlog_2(1 + (T_p[dB] + 40log\,d - 20logh_r - 20logh_t)/(k * T * BW)) \quad (16)$$

Assume that 'n' CH nodes have been chosen to take part in the round depicted by the set, $SetCH_k$= {CH_1, CH_2... CHn}.These CHs disseminate *Req_Join* messages to the network to create clusters. An arbitrary regular node $RN_i(RNi \notin SetCH_k)$ can accept *Req_Join* from any number of CH nodes. In this work, an RN can

Scenario 1: Solitary *Req_Join* information may be delivered to an RN:

A RN has no choice but to join a single CH from which it obtained a *Req_Join* message if it only gets one *Req_Join* message. In this situation, the RN merely sends an *OK_Join* message to join the only CH that is accessible.

Scenario 2: Two or more *Req_Join* information may be delivered to an RN:

When an RN gets more than one *Req_Join* messages, it represents that it has the choice to join any of the CHs from which it has obtained *Req_Join* messages. In this circumstance, the RN calculates the bit rate 'C' using equation (16). The CH having the highest bit rate gets an *OK_Join* message from RN.

$CHSet_k$←Set of k CH nodes {CH1, CH2…. CHk}

CNn← CH belonging to set $CHSet_k$.

Req_Join ← Broadcast message from CH node, CHn.

RNi← Regular node not belonging to $CHSet_k$.

OK_Join← Response message from Regular node RNi

Step 1: For each CH node, CHn in the network do

Broadcast Req_Join message.

End

Step 2: If (RNi receives Req_Join message from CH nodes) then

Identify accessible CH nodes.

Endif

Step 3: If (RNi heard Req_Join message from more than one CH node) then

Send OK_Join (RNi) to the CH node with the highest bit rate 'C'

Else

Send OK_Join (RNi) to the available CH node

Endif

Algorithm 2 Sequence for Cluster Formation

Illustration 2:

A sensor network comprising a group of Regular Nodes {RN1, RN2...RN12} which includes a group of Cluster Heads, CHSetk= {CH2, CH8, CH9} is illustrated in Figure 4. One or more *Req_Join* messages may be received during cluster formation by RN. A single *Req_Join* is received by {RN6, RN3} from Cluster Head (CH) CH8, similarly from CH9 a *Req_Join* is received by {RN5, RN10, and RN12} and from CH2 a *Req_Join* is received by {RN4, RN7}. Since these RN's receive a single *Req_Join*, the RN's join their respective CHs.

Regular Node RN1 receives *Req_Join* messages from CH8 and CH2 and it must join either of the feasible CHs. RN1 calculates the bit rate 'C' using equation (16) for CH8 and CH2 respectively and joins the CH exhibiting the maximum bit rate 'C'.

Similarly, Regular Node RN11 receives *Req_Join* messages from CH8, CH2 and CH9 and it selects the available CH with maximum bit rate 'C'. The maximum bit rate 'C' is calculated using equation (16).

4.3. Data Transmission Utilizing the HSA from CH to BS

The HSA is utilized in the third step of the presented approach to determine the ideal amount of CHs along the route from the source CH to the BS [31].The HSA has three factors (HMS, HMCR, and PAR), and it has effective global discovery capabilities [29].

Steps for selection of path between the source CH and the destination CH is presented in Algorithm 3 and is discussed in detail in the subsequent subsections.

RESEARCH ARTICLE

1) Initialize Harmony Memory: The Harmony Memory (HM) is composed of 'm' harmonics. Each harmony is produced using a roulette wheel selection technique [29]. Neighbor node selection likelihood relies on Shannon Channel Capacity 'C' and is determined using the roulette wheel selection method. The probability of CH_j being chosen as the next hop by the CH_i is calculated based on equation (17).

$$P(CH_{ij}) = \begin{cases} \dfrac{\sum_{k\in N_i}(C_k) - C_j}{(N_i - 1) * \sum_{k\in N_i}(C_k)}, & if (j \in N_i) \\ 0, & else \end{cases} \quad (17)$$

N_i – Number of Neighbor CH for CH $_i$

C_j - Shannon channel capacity of CH_j

C_k- Shannon channel capacity of CH_k

The next step after calculating the probability of selecting the neighbor node $P(CH_{ij})$, the data transfer process takes place.

Illustration 3: Figure 5 illustrates a WSN with CHs deployed randomly. For the given WSN, all feasible connections from the source CH and the destination CH are derived from the roulette wheel selection method. Four different paths have resulted for Harmony Memory Size of value selected as 4. The initializations of the paths found in HM are presented in equation (18).

$$M = \begin{bmatrix} X1 \\ X2 \\ X3 \\ X4 \end{bmatrix} = \begin{bmatrix} (S & CH13 & CH19 & CH17 & CH23 & CH42 & D) & \\ (S & CH24 & CH23 & CH34 & CH45 & CH50 & CH39 & D) \\ (S & CH12 & CH37 & CH30 & CH27 & CH09 & CH07 & D) \\ (S & CH36 & CH06 & CH16 & CH11 & CH21 & CH07 & D) \end{bmatrix} \quad (18)$$

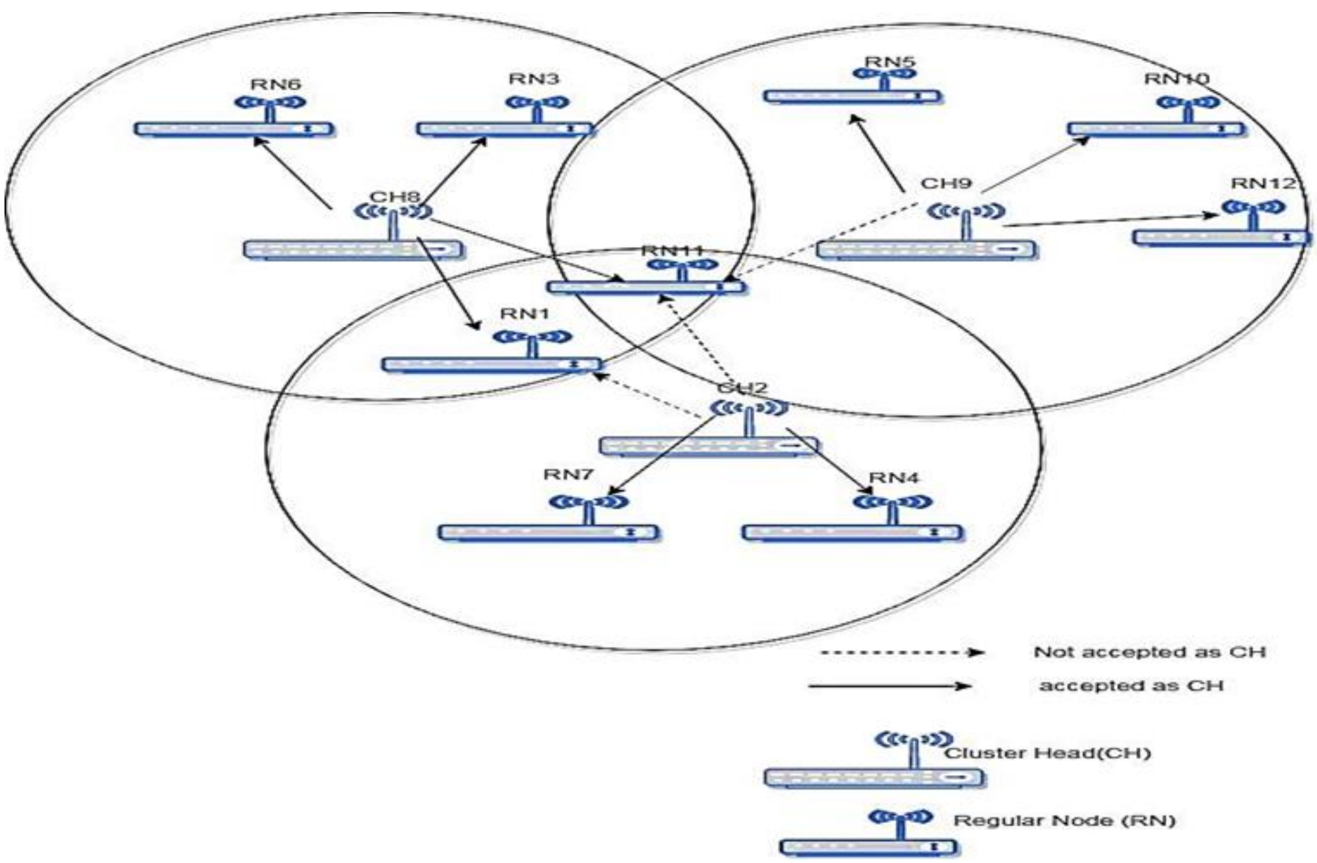


Figure 4 Illustration of Cluster Formation Phase

RESEARCH ARTICLE

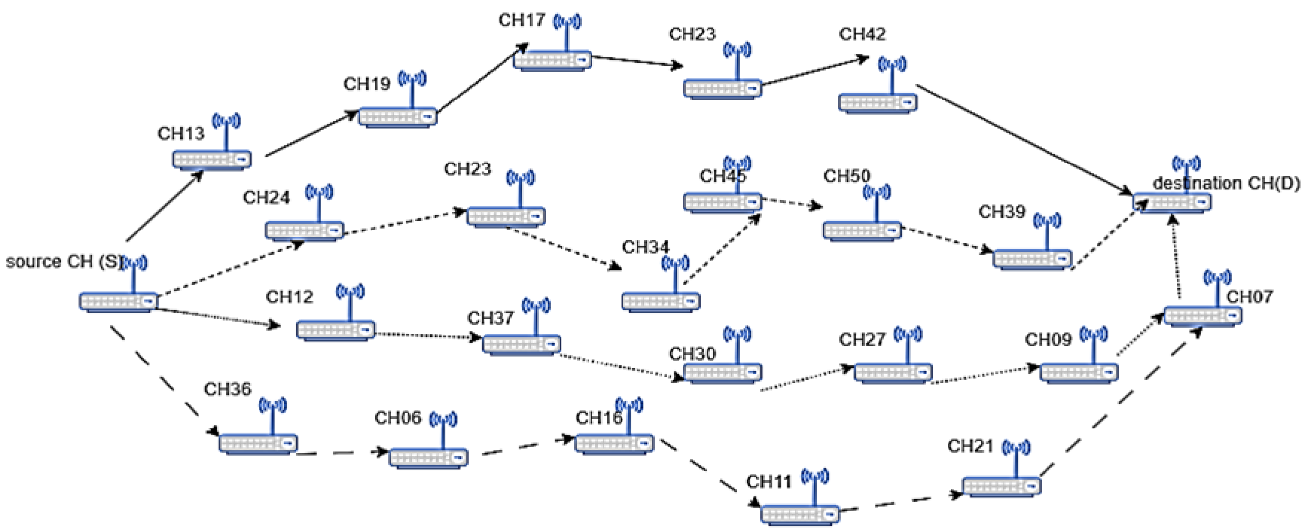


Figure 5 WSN with Various Routes Determined Using Roulette Wheel Selection Technique

2) a) Generating a unique Harmony from the HM: A new harmony Y` = $(s, y_1^{`}, y_2^{`}, y_3^{`}, \ldots, y_i^{`}, \ldots d)$ is generated based on equation(19). The element y`, will be chosen from the new harmony based on HMCR.

$$y_i' = \begin{cases} y_i' \in Y1 \quad if(R1 < HMCR) & \&\& N_{y_{i-1}'} \cap Y2 \neq \emptyset \\ y_i' \in N(y_{i-1}'), & otherwise \end{cases} \quad (19)$$

Where, $Y1 = \{y_{1,i}, y_{2,i}, \ldots, y\}$

$Y2 = \{y_{1,i}, y_{2,i}, \ldots, y_{HMS,i}\}$

Where HMCR, which ranges from [0, 1], refers to Harmony Memory Considering Rate. The set of CH's neighboring CH $y`_{i-1}$ is denoted by $N_{y_{i-1}'}$, RN1 is the random value ranging from 0 to 1. If RN1 is smaller than HMCR and the intersection of $N_{y_{i-1}'}$ and $\{y_{1,i}, y_{2,i} \ldots, y_{HMS,i}\}$ is Ø, then $y`_i$ is selected from $N_{y_{i-1}'} \cap \{y_{1,i}, y_{2,i}, \ldots, y_{HMS,i}\}$ randomly. Otherwise $y`_i$ was randomly chosen from $N_{y_{i-1}'}$, as illustrated in Figure 6. When this phase is utilized in the HM as per equation (19), the subsequent outcomes are obtained.

The source node *S* serves as the initial node of the new harmony as illustrated in Figure 6. While selecting the subsequent CH of source node S if the random integer RN1 is smaller than HMCR, the subsequent CH will be chosen at random from the second column, i.e., from {CH13, CH24, CH12, CH36}. The proposed technique has chosen CH24 as the subsequent CH. For determining its subsequent CH, similar steps are repeated on CH24. If RN1 is larger or similar to HMCR, then a CH will be chosen at random from CH24's neighbors in the WSN to serve as the subsequent CH. In the present case the proposed technique has chosen CH34 as the subsequent CH of CH24. This procedure is iterated until the destination node, D is reached that completes the establishment of a unique harmony.

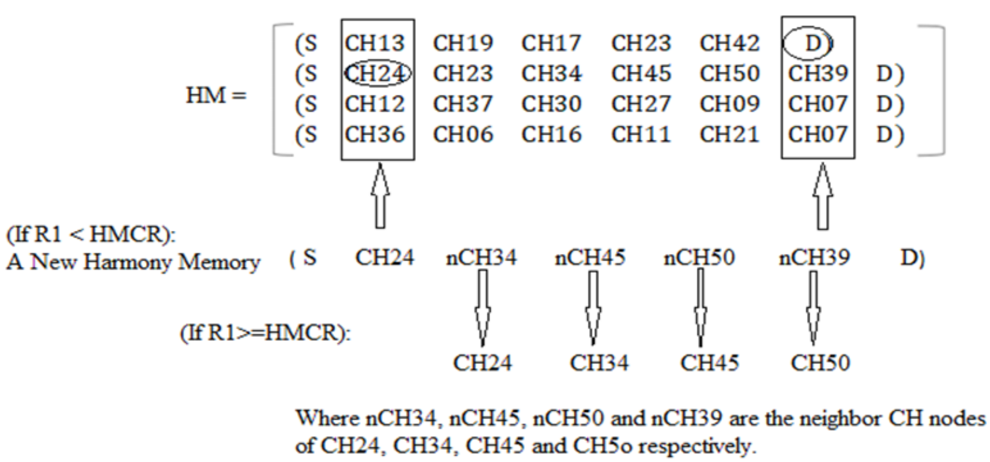


Figure 6 Improvisation of New Harmony

RESEARCH ARTICLE

b) Updation of the unique Harmony Memory: Every pitch chosen from HM must be inspected to decide whether it needs to be pitch adjusted or not to prevent the harmony's length from reducing and trapping in local optima during the repetition. To improve the path selection process, the suggested method makes use of three criteria (replace, insert, and no-change) in comparison to the conventional strategy, which only uses two cases (to change pitch or not to change pitch). The pitch refinement mechanism is represented by $y`_{ij}$, the parameters in the unique harmony is indicated in equation (20).

$$y'_{ij} = \begin{cases} Replace, & 0 \leq \text{RN2} \leq \text{HAPV} * \text{PAR} \\ Insert, & \text{HAPV} * \text{PAR} \leq \text{RN2} \leq \text{PAR} \\ y'_{\text{ij},} & \text{PAR} \leq \text{RN2} \leq 1 \end{cases} \quad (20)$$

PAR stands for Pitch Adjusting Rate, ranges from 0 to 1, HAPV stands for Harmony Adjusting Pitch Variable which ranges from 0 to 1, and RN2 is another random integer with a value between 0 and 1.

Depending on three circumstance(replace, insert and no change) y'_{ij} is changed by a small amount without impacting the route's connection and the new pitch, y'_{ij}, should fits within the range of PAR (0≤ PAR< 1). If the random integer RN2 lies within the range $\text{HAPV} * \text{PAR} \leq \text{R2} \leq \text{PAR}$ then a new CH is added at the back of CHy'_{ij} .If the random number RN2 resides within the range $0 \leq \text{R2} \leq \text{HPAV} * \text{PAR}$ then the CH y'_{ij} is substituted with a new CH. If RN2 lies between $\text{PAR} \leq \text{R2} \leq 1$, the CH y'_{ij} may be used exactly as is without adjustments to the new pitch.

3) Modification of the Harmony Memory: The Harmony Memory is adapted in accordance with the new pitch of the Harmony Memory. Using the objective function equation (24), the effectiveness of the new HM, represented by $\grave{Y}_{new} = (\grave{y}_1, \grave{y}_2, \ldots, \grave{y}_i, \ldots \grave{y}_n)$, is assessed. If the new HM is superior to the best HM, then it is incorporated in the HM and stages (2) to (4) are repeated.

4) Verification of the halting requirements: Until the highest iteration count (NImax) is achieved, steps (2) through (4) are repeated. Out of all HMS, one will be selected as the most effective HM for which the objective function has yielded the optimum value once NI_{max} has been attained. An explanation of the objective function is provided in step 5.

5) Objective function.

To estimate the energy utilization in WSN, an energy paradigm described in [30] is utilized. In a basic radio model, the transmitter energy is represented by E_{tx} and the receiver energy is represented by E_{rx}. To obtain an appropriate E_b/N_o (signal to noise per bit) the transmit amplifier must dissipate E_{amp}=0.1 n J/bit/m2. The transmitter / receiver circuits consume E_{elec}=50 n J/bit. Thus, to transmit a q-bits message in d-meters, the radio expends an energy represented in equation (21):

$$E_{tx}(q, d) = E_{elec} * q + E_{amp} * q * d^2 \quad (21)$$

Similarly for receiving this message, the radio expends an energy represented in equation (22):

$$E_{rx}(r) = E_{elec} * q \quad (22)$$

If a route *Y= (s, y'₂,…,y'ᵢ…,d)* has M *'CHs'*, The following formula is utilized to determine the total energy used along the route for sending q-bits information given by equation (23):

$$\text{E(Y)} = 2 * (\text{M} - 1) * \text{E}_{\text{elec}} * \text{q} + \text{E}_{\text{amp}} * \text{q} * \sum_{\text{i}-1}^{\text{M}-1} \text{d}_{\text{i,i+1}}^2 \quad (23)$$

Where, $d^2_{i,i+1}$ is the square of Euclidean distance between CH_i and CH_{i+1}.

Now, the objective function *f(X)* is represented in equation (24).

$$f(x) = \frac{E_{avg} * M}{E_{min} * E(Y)} \quad (24)$$

Where E_{avg} represents the average remaining energy throughout all CHs in route Y and E_{min} represents the minimum remaining energy of a CH in route Y. E_{avg} chooses a shorter path, whereas E_{min} chooses a longer one with the least amount of remaining energy. Other energy estimates will be valid as well, and the route will be appropriate if the amount of residual energy is of an appropriate value.

5. SIMULATION AND RESULTS

The evaluation of the presented algorithm is executed utilizing MATLAB and compared with the algorithms such as EEHSBR [24], CRHS [23] and RHSA [15]. The comparative analysis of the available algorithms considers performance parameters such as active nodes, dead nodes, energy utilization, residual energy and total count of data packets sent to the BS. Table 2 displays the simulation parameters utilized for both the WSN and the Harmony Search Algorithm.

Table 2 Parameters for Simulation

Parameters	Values
Node density	100, 200, 300 and 400
Area of simulation	200m X 200m
Initial energy of CH	0.5J
E_{fs}	10 pJ/bit/m^4
E_{amp}	0.0013pJ/bit/m^4
E_{elec}	50 nJ/bit
HMS	4
HMCR	0.6
PAR	0.2
NI_{max}	500

RESEARCH ARTICLE

5.1. Assumptions

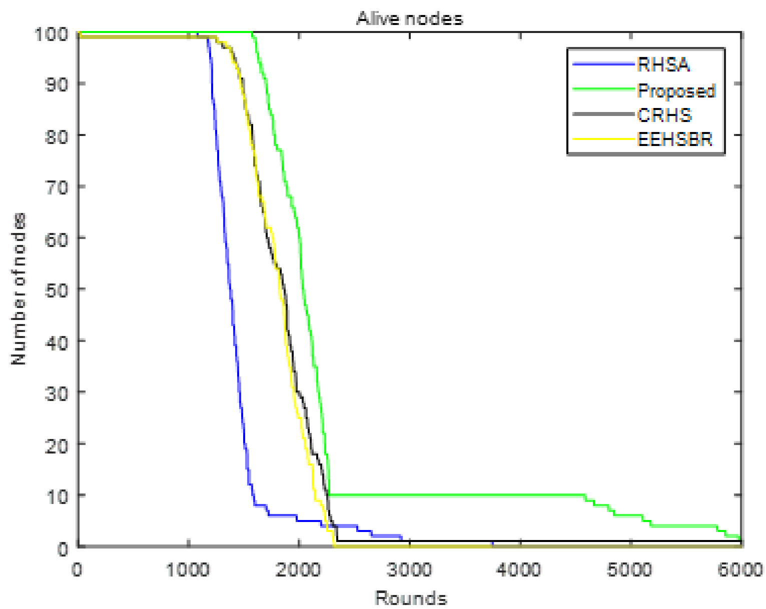
1) The highest number of nodes considered is 400.

2) The maximum area considered is 200mX200m.

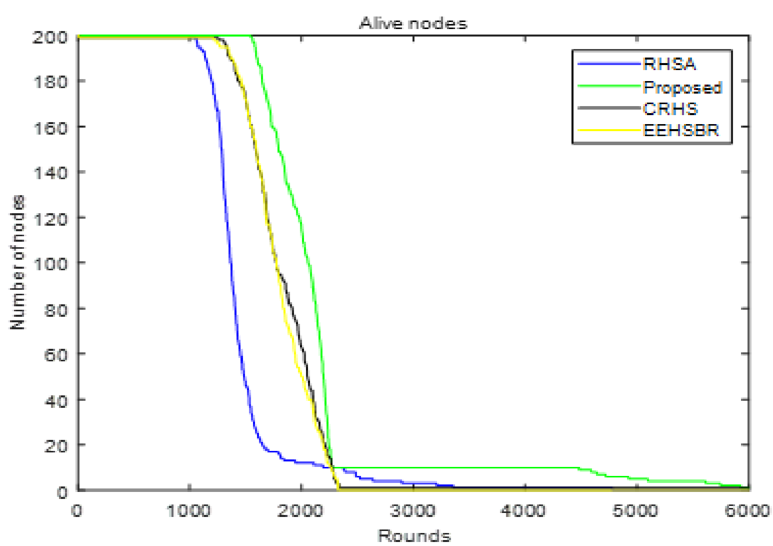
3) As per the assumption 100 nodes were considered within the 200mX200m region. In the 2nd iteration 200 nodes were considered within the same 200mX200m region. Likewise in the subsequent iteration for 300 and 400 nodes the area 200m X 200m was considered.

5.2. Active Nodes

The Active nodes correspond to the sensor nodes that still possess remaining energy. The total count of active nodes reveals that longer the nodes are active, the more effectively the underlying protocol performs. The graphical representation in Figure 7 (a), (b), (c) and (d) depicts the number of active nodes throughout the simulation period for 100, 200, 300 and 400 nodes respectively. The reason for extending the network lifespan of the presented algorithm is because of the selection approach of CH based on HSA and the factors such as remaining energy, node degree and distance in devising the fitness function.

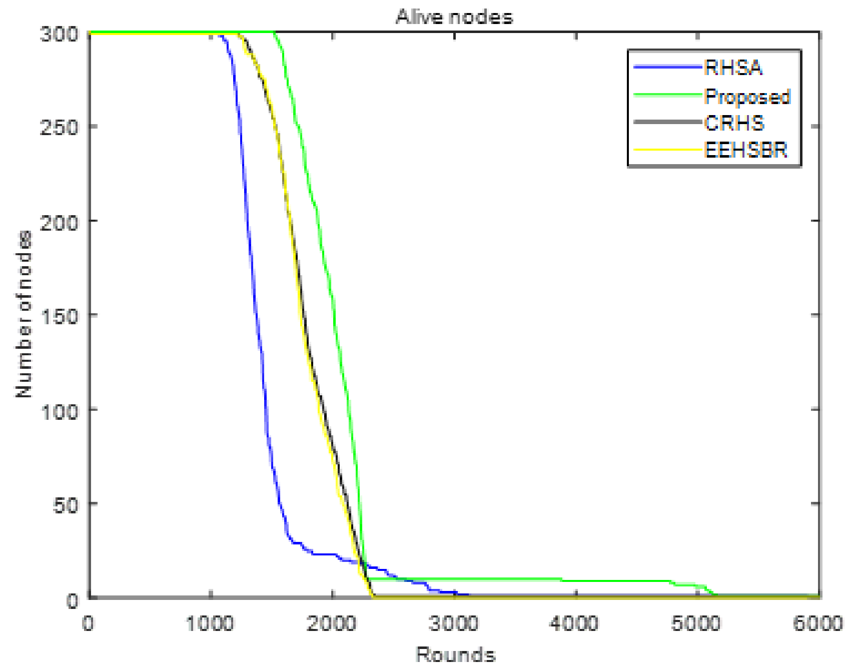


(a)

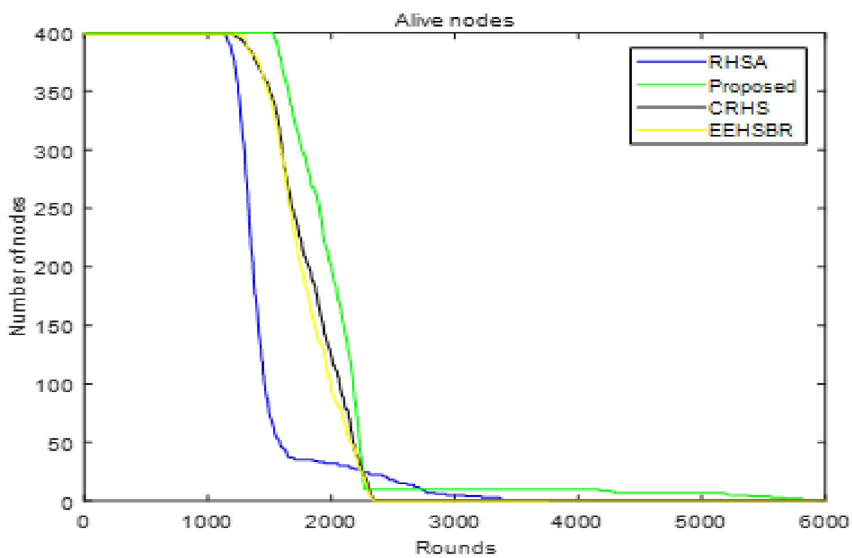


(b)

RESEARCH ARTICLE



(c)



(d)

Figure 7 Active Nodes

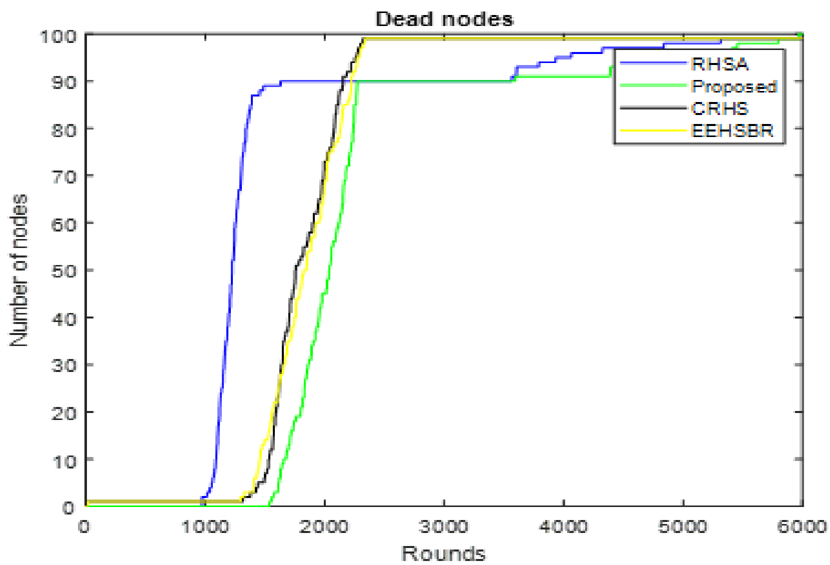
5.3. Dead Nodes

The Dead nodes correspond to the sensor nodes that have utilized all of their energy and are incapable of performing any kind of functions. Figure 8 (a), (b), (c) and (d) present the total count of dead nodes over the simulation period 100,200,300 and 400 nodes respectively. The nodes can be expressed as FND, HND and LND. Table 3 presents the FND, HND and LND of EEHSBR, CRHS and RHSA algorithms. It is clear from Table 3, that the presented algorithm enhances the network lifespan concerning FND, HND and LND. This results from the CH selection technique utilizing the HSA and considering the parameters such as remaining energy, node degree and distance in formulating the fitness function.

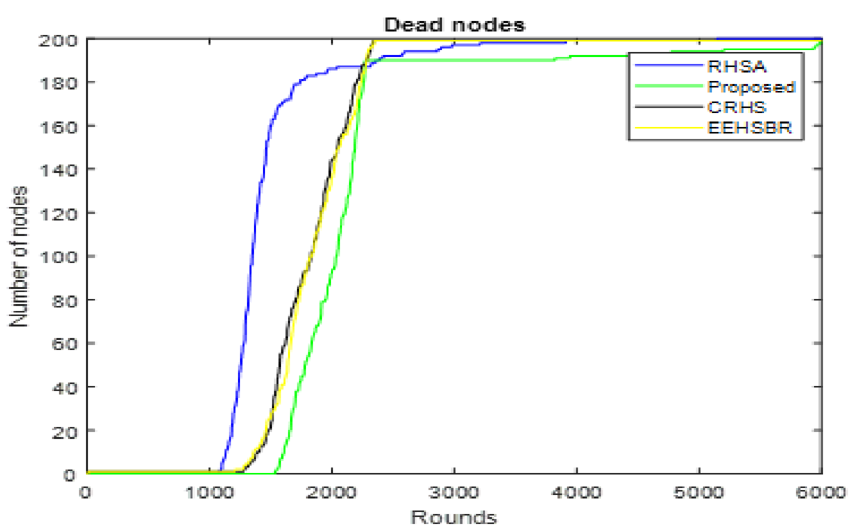
RESEARCH ARTICLE

Table 3 Statistical data of FND,HND and LND

Nodes	RHSA			EEHSBR			CRHS			Proposed		
	FND	HND	LND	FND	HND	LND	FND	HND	LND	FND	HND	LND
100	1104	1826	2523	1232	1862	2529	1238	1878	3022	2536	2626	6010
200	1128	1911	2558	1353	1916	2560	1368	1918	3122	2567	2634	6008
300	1322	1923	2562	1423	1936	2574	1428	1940	3152	2570	2645	6011
400	1420	1998	2565	1562	1972	2570	1565	1987	3255	2575	2658	6001



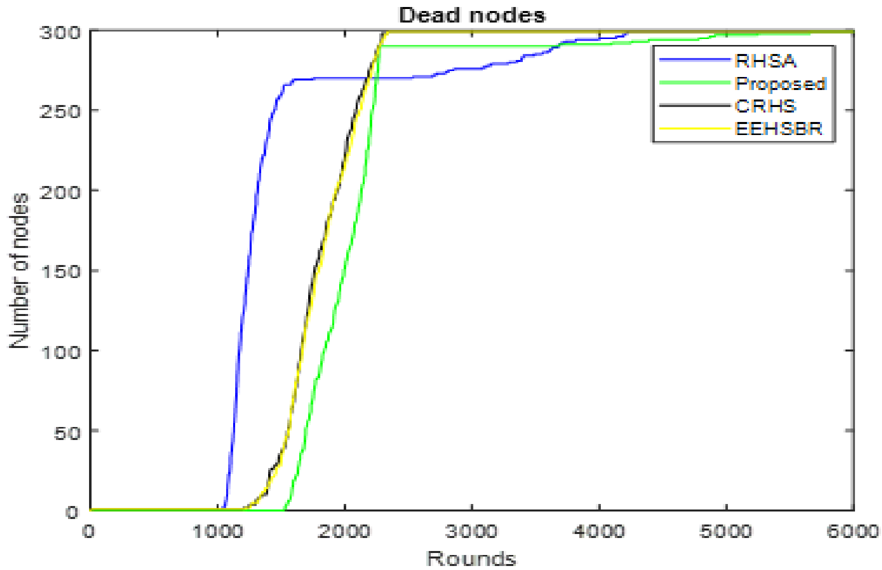
(a)



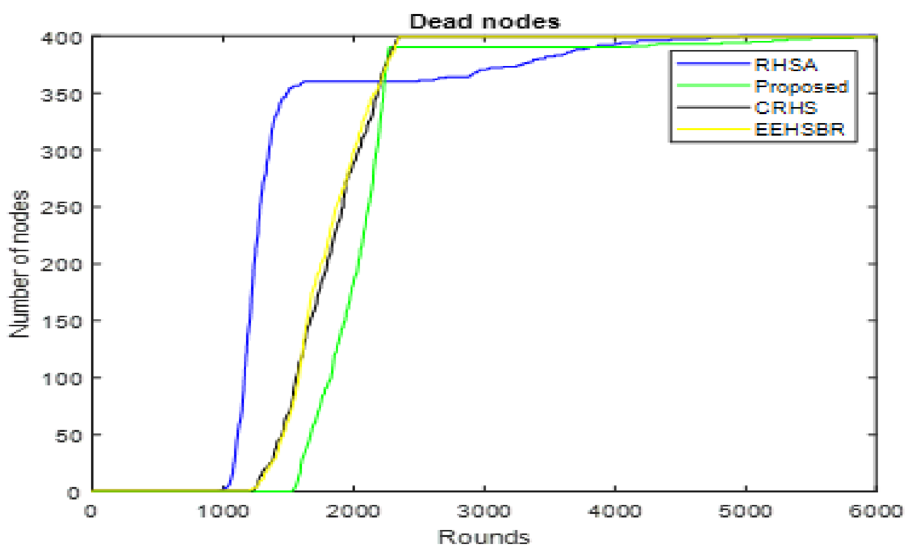
(b)

International Journal of Computer Networks and Applications (IJCNA)
DOI: 10.22247/ijcna/2023/223419 Volume 10, Issue 5, September – October (2023)

RESEARCH ARTICLE



(c)



(d)

Figure 8 Dead Nodes

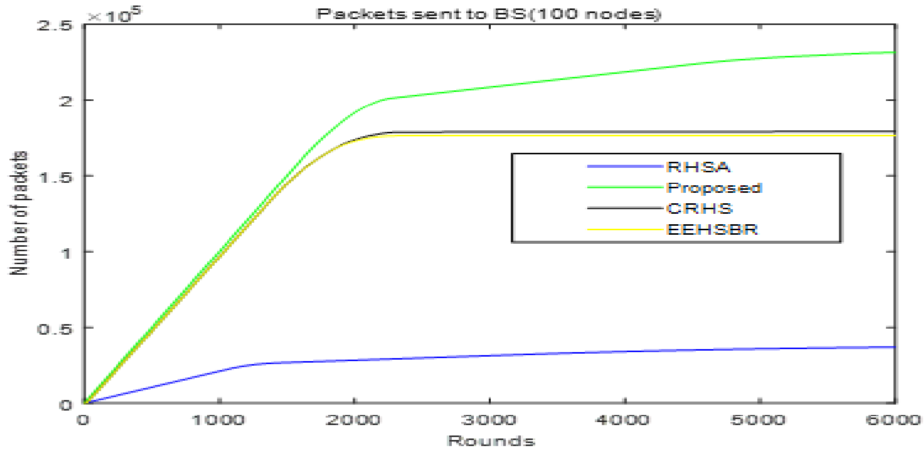
5.4. Packets Sent to the BS

Packets sent to BS refers to the total count of data packets forwarded from CH to the BS. Figure 9 (a), (b), (c) and (d) illustrate the total count of data packets sent to the BS. More packets are sent to the BS in the presented algorithm in contrast with the available algorithms such as EEHSBR, CRHS and RHSA. This is presented in Table 4. The improved outcome in packets sent to the BS of the presented algorithm is because of cluster formation strategy. In the strategy for creating clusters, regular nodes receive *Req_Join* messages from multiple Cluster Heads, then the regular nodes select one CH by sending *OK_Join* message to that CH depending on Shannon Channel Capacity 'C' and path loss model.

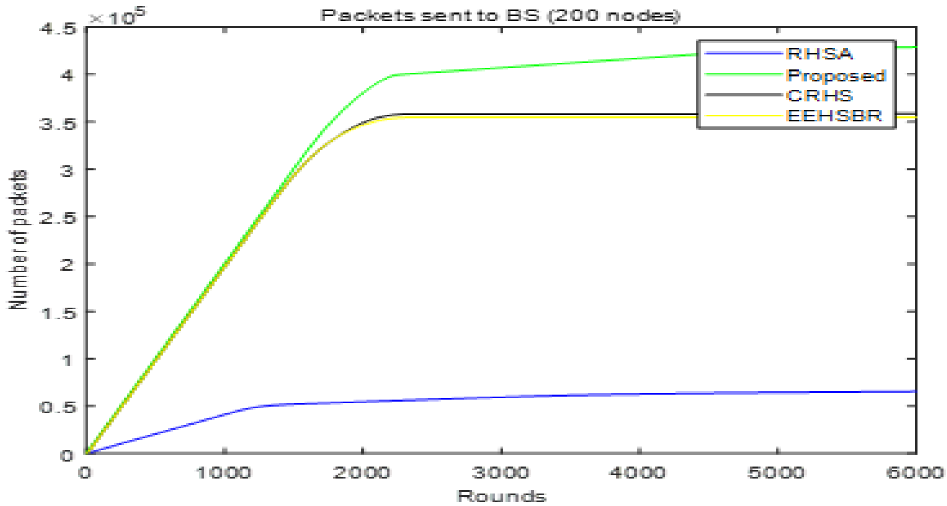
Table 4 Number of Packets Sent to BS

Nodes	RHSA	EEHSBR	CRHS	Proposed
100	35781	174331	175667	227812
200	38538	354879	355742	424358
300	98389	528364	534873	620528
400	123893	713269	714456	816834

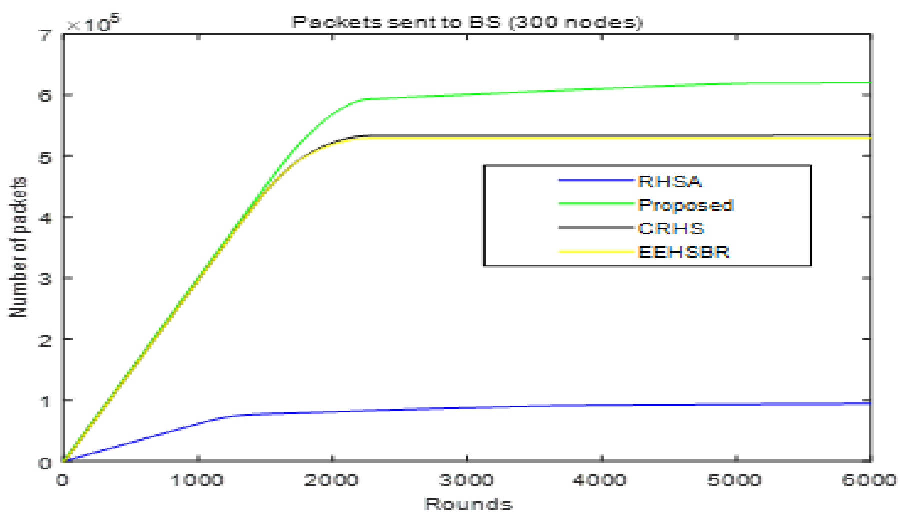
RESEARCH ARTICLE



(a)

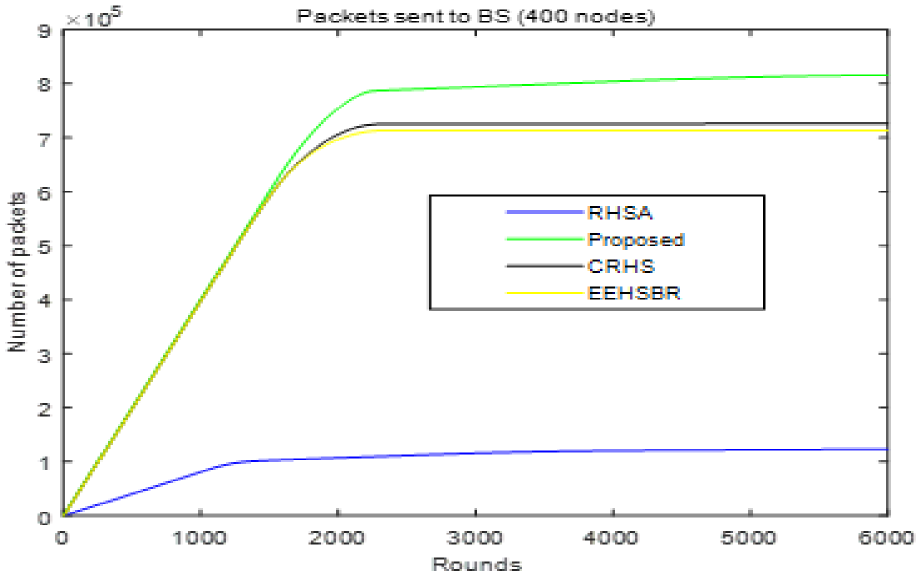


(b)



(c)

RESEARCH ARTICLE

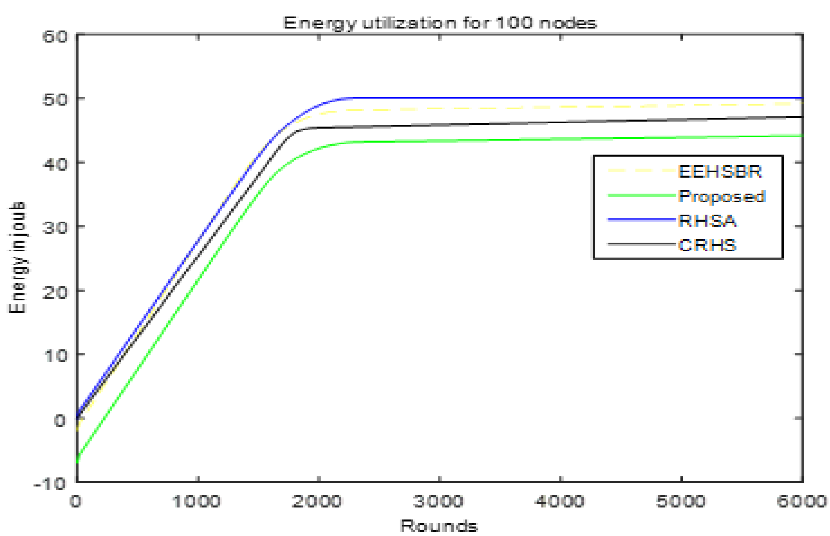


(d)

Figure 9 Packets Sent to the BS

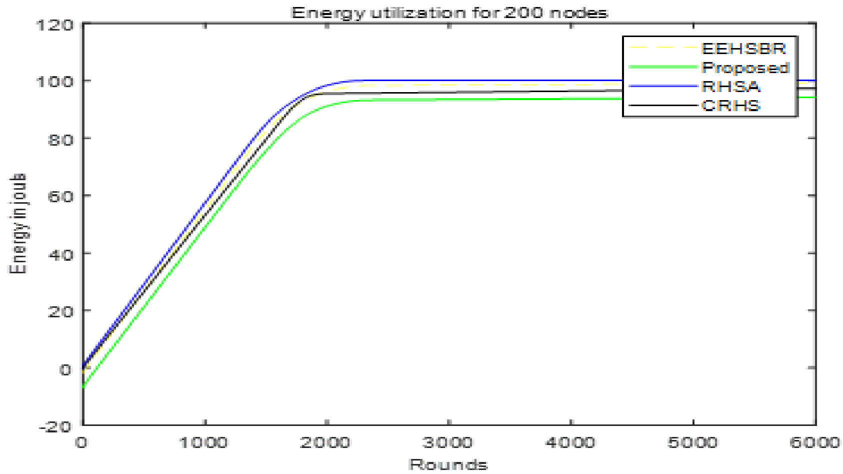
5.5. Energy Utilization

Nodes within a Wireless Sensor Network utilizes energy while performing tasks such as sensing the environment, processing the data, communicating with other nodes and performing computations. Figure 10 (a), (b), (c) and (d) represent the evaluation of energy utilization of the presented method with algorithms such as EEHSBR, CRHS and RHSA for 100, 200, 300 and 400 nodes respectively. The total amount of energy within the network is determined by the total count of nodes in the network. Each node has an initial energy of 0.5 joules is assumed. For a network with 100 nodes, the network's energy would amount to (0.5 x 100) = 50 joules. Likewise, in the cases of networks with 200, 300, and 400 nodes, the total energy would be 100, 150, and 200 joules, respectively. It is evident that the energy usage of the presented algorithm is less compared to EEHSBR, CRHS and RHAS algorithms. The improvement is due to cluster head selection and the path between the BS and CH relies on the Harmony Search Algorithm. The harmony length is tuned by incorporating a new variable HAPV and by devising an efficient objective function.

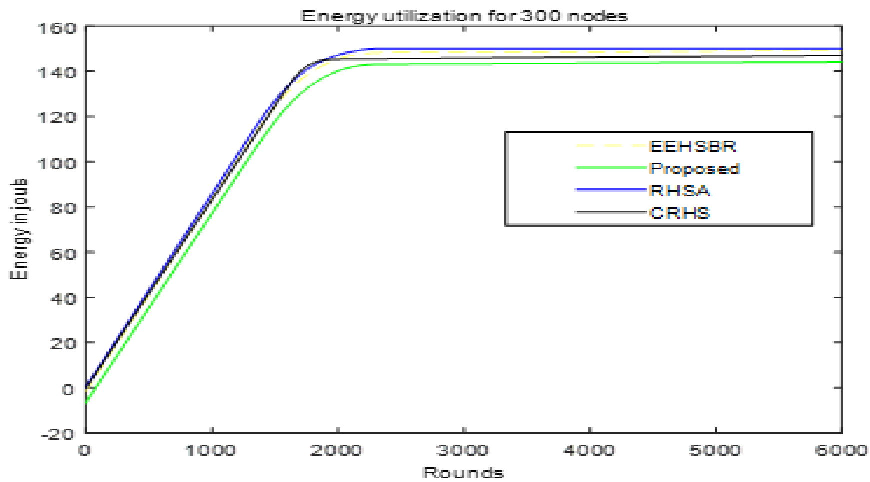


(a)

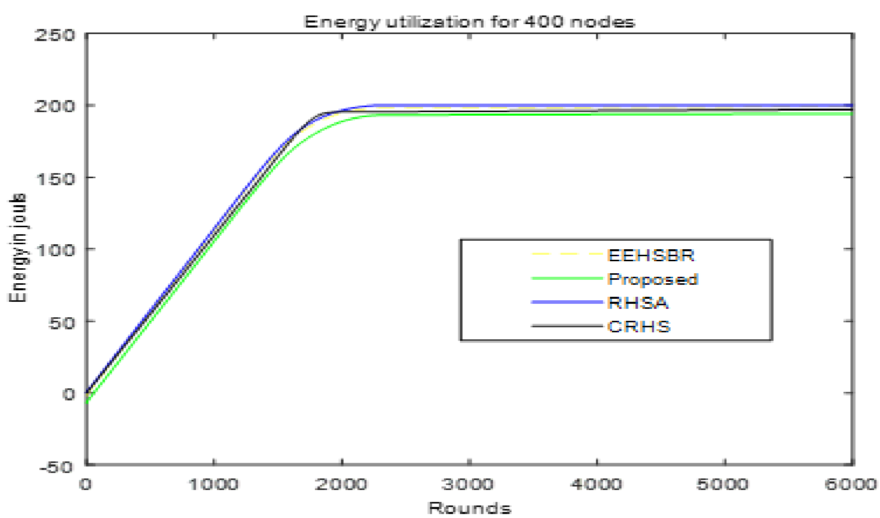
RESEARCH ARTICLE



(b)



(c)



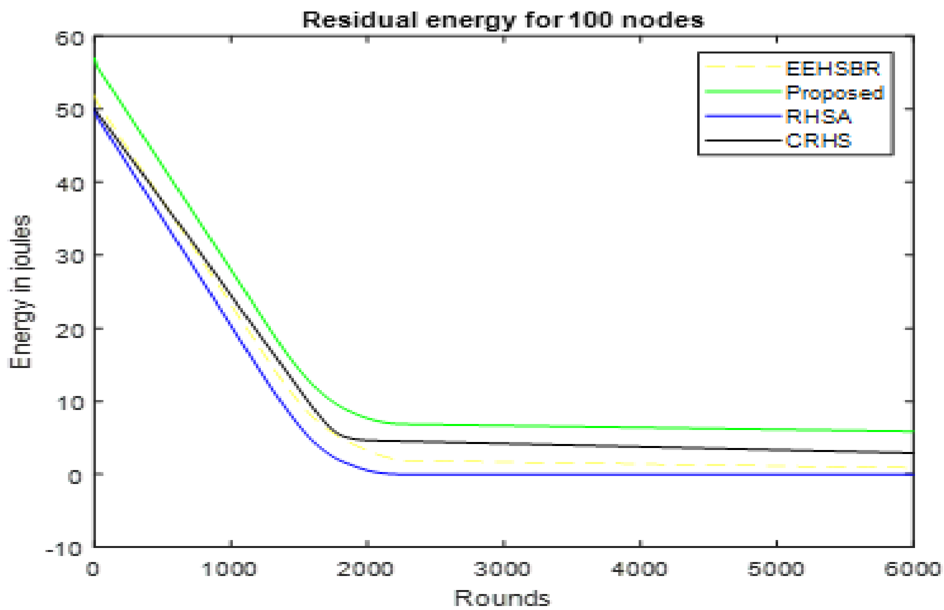
(d)

Figure 10 Energy Utilization

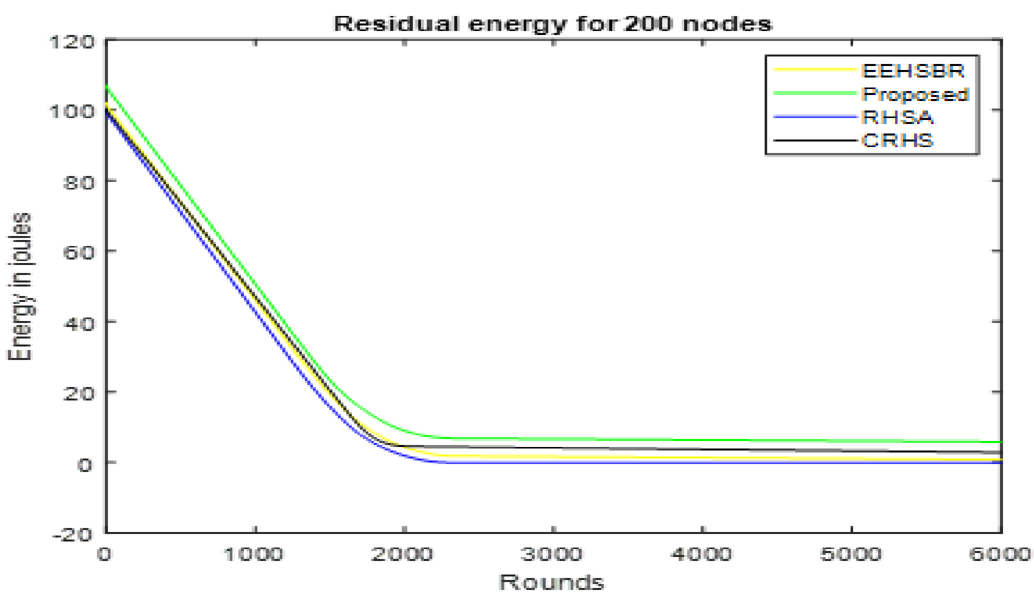
RESEARCH ARTICLE

5.6. Residual Energy

Residual energy within a WSN pertains to the energy quantity remaining within the individual sensor nodes following their operation for a specific duration. Figure 11 (a), (b), (c) and (d) represent the comparison of residual energy of the presented method with algorithms such as EEHSBR, CRHS and RHSA for 100, 200, 300 and 400 nodes respectively. The residual energy of the presented algorithm is more compared to EEHSBR, CRHS and RHAS algorithms. Significant increase in the residual energy can be associated with the Cluster Head selection and the establishment of path between CH and the BS, both of which rely on the utilization of the Harmony Search Algorithm. The adjustment of the harmony length is achieved through the inclusion of novel variable, HAPV and the formulation of an efficient objective function.

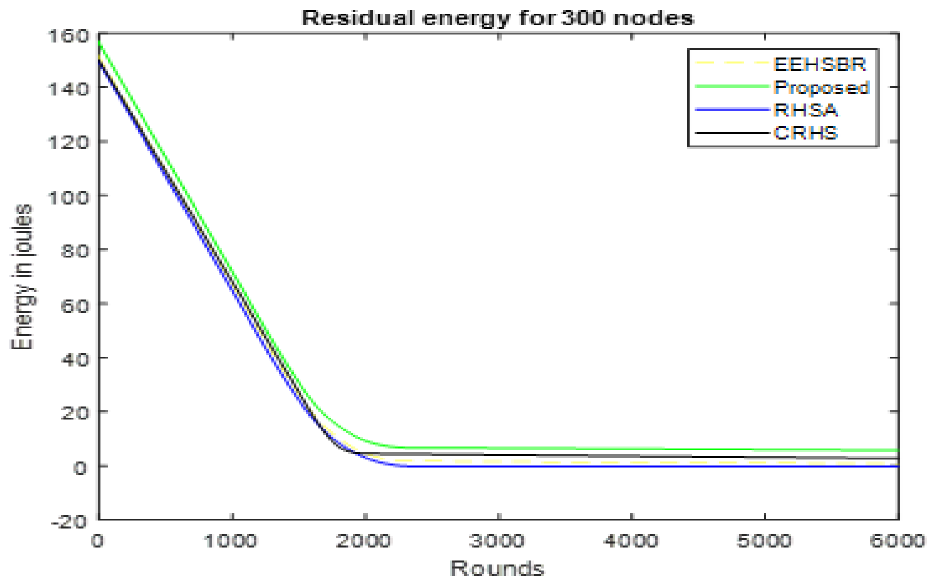


(a)

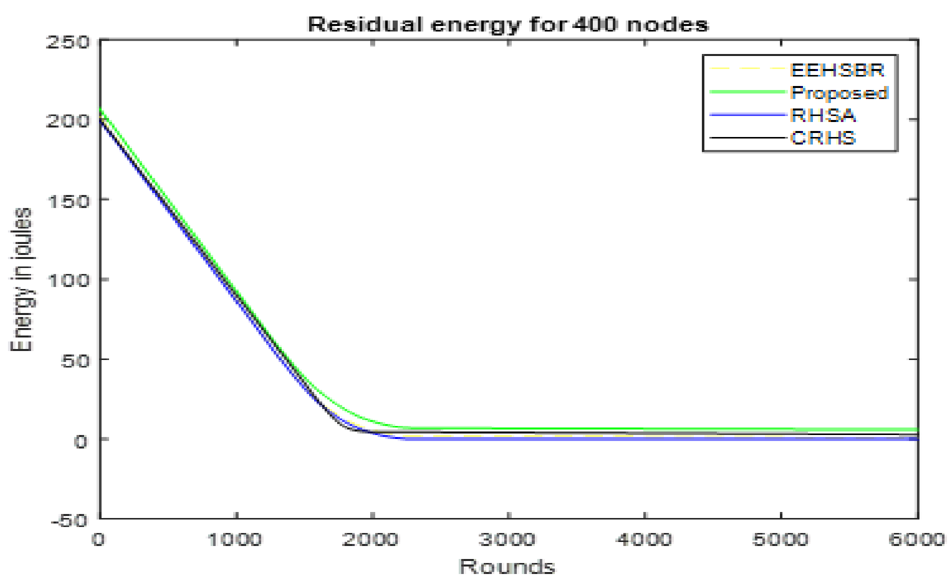


(b)

RESEARCH ARTICLE



(c)



(d)

Figure 11 Residual Energy

5.7. Discussion

The current RHSA algorithm focuses solely on Cluster Head selection, leaving out the routing technique. It initializes the HM using energy and distance parameters. In contrast, the EEHSBR algorithm exclusively employs the HSA for routing technique, while the procedure of CH selection remains undefined. It also utilizes energy and distance parameters for HM initialization. The CRHS algorithm stands apart by utilizing the HSA for both the Cluster Head selection and the routing technique. It employs energy and distance parameters to initialize HM. However, it falls short in providing an in-depth explanation of the process of formation of the cluster. These algorithms share common drawbacks, including a limited network lifespan, excessive energy utilization, inadequate residual energy, and a low count of successfully transmitted messages to the BS. To address these issues, a novel technique is proposed. This technique enhances network lifespan by increasing active nodes and decreasing dead nodes, because of the selection approach of CH based on

RESEARCH ARTICLE

HSA and formulating an effective fitness function by taking in to account the parameters such as remaining energy, node degree and distance. It curtails energy utilization and raises residual energy through an establishment of an effective path between CH and the base station and by devising an effective objective function that considers factors like remaining energy of CH and the total count of CH along the route. Moreover, it increases the total count of packets successfully delivered to the BS by cluster formation strategy that incorporates attributes such as Shannon Channel Capacity ‘C’ and path loss model. The execution of the presented model exhibits substantial enhancements in CH selection, cluster formation, and routing techniques. This improvement is particularly notable when contrasted to the established algorithms such as RHSA, EEHBR and CRHS.

6. CONCLUSION

In this paper, the authors have introduced CH selection and routing algorithm that relies on HSA which utilizes Shannon Channel Capacity ‘C’ and path loss model. To choose an optimal set of CHs, a fitness function is devised using the remaining energy, the distance between CH and BS and the node degree. This has enabled the network longevity to increase significantly. Formation of the cluster is also based on Shannon Channel Capacity ‘C’ and path loss model contribute to augmenting the total count of packets directed towards the BS. An objective function is modeled which consists of factors like the path length and the energy utilization of the network. The presented technique was contrasted with the already available protocols such as EEHSBR, RHSA and CRHS for assessing the performance. Thorough simulation runs were conducted across various node densities to justify the achieved results. The achieved results of the presented approach proved better with respect to network lifespan, packets sent to BS and energy utilization. In the present work the nodes were considered static. In the future work dynamic nodes can be considered. The dynamic nodes can undergo performance evaluation and a comparative study between the static and the dynamic nodes can be executed.

REFERENCES

[1] Semwal, V.B., Mondal, K. & Nandi, and G.C. “Robust and accurate feature selection for humanoid push Recovery and classification: deep learning approach”. Neural Comput&Applic 28, 565-574(2017).https://doi.org/10.1007/s00521-015-2089-3.

[2] Gupta, V.; Pandey, R. An improved energy aware distributed unequal clustering protocol for heterogeneous wireless sensor networks. Eng. Sci. Technol. Int. J. 2016, 19, 1050–1058.

[3] K. Li, W. Ni, L. Duan, M. Abolhasan and J. Niu, "Wireless Power Transfer and Data Collection in WirelessSensor Networks," in IEEE Transactions on Vehicular Technology, vol. 67, no. 3, pp. 2686-2697, March 2018, doi: 10.1109/TVT.2017.2772895.

[4] Zhang P, Xiao G, Tan H-P (2013) Clustering algorithms for maximizing the lifetime of wireless sensor networks with energy harvesting sensors. ComputNetw 57(14):2689–2704.

[5] Jiang Wu, Xuefeng Ding, "Using Wireless Sensor Network to Remote Real-Time Monitoring and Tracking of Logistics Status Based on Difference Transmission Algorithm", Journal of Sensors, vol. 2021, Article ID4084288, 10 pages, 2021.

[6] Sohraby, K., Minoli, D., &Znati, T. (2007). Wireless sensor networks: Technology, protocols, and applications. New York: Wiley-Interscience.

[7] Agarwal PK, Procopiuc CM (2002) Exact and approximation algorithms for clustering. Algorithmica 33(2):201–226.

[8] FaizanUllah M, Imtiaz J, Maqbool KQ. Enhanced Three Layer Hybrid Clustering Mechanism for EnergyEfficient Routing in IoT. Sensors (Basel). 2019 Feb 18;19(4):829. doi: 10.3390/s19040829. PMID: 30781595; PMCID: PMC6413009.

[9] Jacques Bahi, et al.,Efficient distributed lifetime optimization algorithm for sensor networks, Elsevier Journal of Ad Hoc Networks (16) (2014) 1-12.

[10] Keontaek Lee, et al., Satisfying the target network lifetime in wireless sensor networks, Elsevier Journal of Computer Networks (65) (2014) 41-45.

[11] Tarach and Amgoth, et al., Energy-aware routing algorithm for wireless sensor networks, Elsevier Journal of Computers and Electrical Engineering (41) (2015) 357367.

[12] Zhengmao Ye, et al., Adaptive Clustering Based Dynamic Routing of Wireless Sensor Networks viaGeneralized Ant Colony Optimization International Conference on Future Information Engineering (10), (2014)2-10.

[13] M. EmreKeskin, et al., Wireless sensor network lifetime maximization by optimal sensor deployment, activity scheduling, data routing and sink mobility, Elsevier Journal of Ad Hoc Networks (17) (2014) 18-36.

[14] Yang, XS. (2009). Harmony Search as a Metaheuristic Algorithm. In: Geem, Z.W. (eds) Music-Inspired Harmony Search Algorithm. Studies in Computational Intelligence, vol 191. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-00185-7.

[15] D. C. Hoang, P. Yadav, R. Kumar and S. K. Panda, "A Robust Harmony Search Algorithm Based ClusteringProtocol for Wireless Sensor Networks," 2010 IEEE International Conference on Communications Workshops, 2010, pp. 1-5, doi: 10.1109/ICCW.2010.5503895.

[16] Buddha Singh, et al., A novel energy- aware cluster head selection based on PSO for WSN, Human centric computing and information sciences, (2012) 1-18.

[17] David E. Goldberg, Genetic Algorithms in search, Optimization, and Machine Learning, Preason Education, 9th Edition, 2005.

[18] Bongale, A.; Bongale, A.; Kumar, S.; Joshi, R.; Bhamidipati, K. Design and Implementation of EOICHD Based Clustered Routing Protocol Variants for Wireless Sensor Networks. Appl. Syst. Innov. 2021, 4, 25.

[19] Heinzelman, W. R., Chandrakasan, A., Balakrishnan, H. (2000). Energy-efficient communication protocol for wireless microsensor networks. In Proceedings of the 33rd Hawaii international conference on system sciences, HICSS ’00, (vol. 8, pp. 8020). Washington, DC: IEEE Computer Society.

[20] Heinzelman, W. R., Chandrakasan, A., & Balakrishnan, H. (2002). An application-specific protocol architecture for wireless microsensor Networks. IEEE Transactions on Wireless Communications, 1(4),660–670.

[21] Anupkumar M. Bongale, C. R. Nirmala, and Arunkumar M. Bongale. 2019. Hybrid Cluster Head Election for WSN Based on Firefly and Harmony Search Algorithms, Wirel. Pers. Commun., 106, 2 (May 2019), 75–306. DOI:https://doi.org/10.1007/s11277-018-5780-8.

[22] T. Shankar, S. Shanmugavel, A. Rajesh, Hybrid HSA and PSO algorithm for energy efficient cluster head Selection in wireless sensor networks, Swarm and Evolutionary Computation, Volume 30, 2016,Pages1-10,ISSN 22106502, http//doi org/10.1016/j.awevo.2016.03.003.

[23] Praveen Lalwani, Sagnik Das, Haider Banka, and Chiranjeev Kumar. 2018. CRHS: clustering and routing in wireless sensor networks using

RESEARCH ARTICLE

harmony search algorithm. Neural Comput. Appl. 30, 2 (July2018), 639–659. DOI:https://doi.org/10.1007/s00521-016-2662-4.
[24] B. Zeng and Y. Dong, "An Energy Efficient Harmony Search Based Routing Algorithm for Small-ScaleWireless Sensor Networks," 2014 IEEE 17th International Conference on Computational Science and Engineering, 2014, pp. 362-367, doi: 10.1109/CSE.2014.94.
[25] T. Camilo, C. Carreto, J. Silva, F. Boavida, An Energy-Efficient Ant-Based Routing Algorithm for Wireless Sensor Networks, in: M.Dorigo, L. Gambardella, M. Birattari, A. Martinoli, R. Poli, T.Stützle (Eds.) Ant Colony Optimization and Swarm Intelligence, Springer Berlin Heidelberg, 2006, pp. 49-59.
[26] Geem, Zong Woo. (2009). Music-Inspired Harmony Search Algorithm:Theory and Applications.10.1007/978-3-642-00185-7.
[27] K.S. Lee, Z.W. Geem, A new meta-heuristic algorithm for continues engineering optimization: harmony search theory and practice, Comput. Meth.Appl.Mech.Eng.194, pp.3902-3933, 2004.
[28] Bongale, A. M., &Nirmala, C. R. (2016). Eoichd: A routing scheme for wireless sensor network basedon energy and optimal inter cluster Head distance. International Journal of Applied Engineering Research, 11(11), 7256–7266.
[29] Z.W. Geem, J.H. Kim, G. Loganathan, A new heuristic optimization algorithm: harmony search, February 2001 SIMULATION: Transactions of the society for modeling and simulation international 76(2):60-68 DOI: 10.1177/003754970107600201.
[30] B. Jan, H. Farman, H. Javed, B. Montrucchio, M. Khan, and Sh. Ali, “Energy efficient hierarchical clusteringapproaches in wireless sensor networks: A survey,” Wireless Commun. Mobile Comput. 2017, 6457942 (2017).https://doi.org/10.1155/2017/6457942.
[31] Sowmya, G.V., Kiran, M. Improved Harmony Search Algorithm for Multihop Routing in Wireless Sensor Networks. J. Comput. Syst. Sci. Int. 61, 1058–1075 (2022).
[32] Rani, R. U. ., Rao, P. S. ., Lavanaya, K. ., Satyanarayana, N. ., Lallitha, S. ., & Prasad J, P. . (2023). Optimization of Energy- Efficient custer Head Selection Algorithm for Internet of Things in Wireless Sensor Networks. International Journal on Recent and Innovation Trends in Computing and Communication, 11(4), 238–248.
[33] Wu, Z., Wan, G. An enhanced ACO-based mobile sink path determination for data gathering in wireless sensor networks. J Wireless Com Network 2022, 100 (2022).
[34] Y. Liu, D. Jiang, B. Tao, J. Qi, G. Jiang, J. Yun, L. Huang, X. Tong, B. Chen, G. Li, Grasping posture of humanoid manipulator based on target shape analysis and force closure. Alex. Eng. J. 61(5), 3959–3969 (2022).
[35] S. Gao, H. Zhang, S.K. Das, Efficient data collection in wireless sensor networks with path-constrained mobile sinks. IEEE Trans. Mob. Comput.10 (4), 592–608 (2011).
[36] Jatinder Pal Singh and Anuj Kumar Gupta. An Optimized Routing Technique in Wireless Sensor Network Using Aquila Optimizer. International Journal of Intelligent Engineering and Systems, Vol.15, No.4, 2022. DOI: 10.22266/ijies2022.0831.28.
[37] Tyagi, L. K. ., & Kumar, A..(2023). A Hybrid Trust Based WSN protocol to Enhance Network Performance using Fuzzy Enabled Machine Learning Technique. International Journal of Intelligent Systems and Applications in Engineering, 11(9s), 131–144.
[38] M. S. Muthukkumar, S. Diwakaran, "Efficient Load Balancing in WSN Using Quasi –oppositional Based Jaya Optimization with Cluster Head Selection", International Journal of Computer Network and Information Security(IJCNIS), Vol.15, No.2, pp.85-96, 2023. DOI:10.5815/ijcnis.2023.02.07.

Authors

G V Sowmya received the B.E degree in Electronics and Communication Engineering from Kuvempu University, and M.Tech degree in Networking and Internet Engineering from Visvesvaraya Technological University, Belgavi, Karnataka, India in 2001 and 2006 respectively. Currently, she is an Assistant Professor in the Department of Information Science and Engineering, Jawaharlal Nehru New College of Engineering, Shimoga. Her research interest includes Wireless Sensor Networks and Embedded Systems.

Dr. R. Aparna holds a Ph.D from Visvesvaraya Technological University, Belgavi, Karnataka, India. Dr. Aparna is currently working as Professor in Department of Information Science and Engineering, Siddaganga Institute of Technology, Tumakuru, Karnataka, India. Her research area are Cryptography and Network Security, Security in Wireless Sensor Networks, and routing issues in Ad Hoc Wireless Networks. She has published more than 60 articles in various journals and conferences.

How to cite this article:

G V Sowmya, R Aparna, “Energy Efficient Cluster Formation and Multihop Routing Based on Improved Harmony Search Algorithm for Wireless Sensor Networks”, International Journal of Computer Networks and Applications (IJCNA), 10(5), PP: 706-727, 2023, DOI: 10.22247/ijcna/2023/223419.