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Optimal Selection of Cluster Head in Wireless Sensor Networks Using Particle Swarm Optimization (PSO)

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Abstract
In a wide range of applications, such as the military, healthcare, and environmental monitoring, wireless sensor networks (WSNs) have emerged as a key player. Cluster-based WSNs are a viable method for enhancing the life of the sensor network. Choosing the proper cluster head for wireless sensor networks (WSNs) is a key undertaking that affects the network's performance. Current approaches for selecting the cluster head have a number of drawbacks, such as nodes dying too quickly, uneven energy utilization, and shorter network lifespan. Additionally, conventional techniques like fixed Cluster Head and randomized Clustering are ineffective at extending the network lifetime. In the proposed method, Particle swarm optimization was used to create an optimal cluster head selection that addresses the problem of intra-cluster communication and lowers SN energy consumption. The simulation result shows that the performance improvement of the developed algorithm PSO in terms of network lifetime is 10% against Improved Cuckoo Search Algorithm (ICSA) and 25% against Hybrid Crow Search Algorithm (HCSA), energy consumption is 15% against ICSA and 20% against HCSA, and number of alive node is 4% against ICSA and 6% against HCSA respectively. Therefore, our developed algorithm PSO outperforms ICSA and HCSA in terms of the aforementioned parameters.

Keywords: wireless sensor network, Multilevel clusters, Particle swarm optimization, clustering, cluster head selection.

INTRODUCTION
Due to the limited energy available to the nodes in WSNs, energy consumption is a significant problem. Choosing the right cluster head (CH) is one of the hurdles to maximizing a sensor node's energy consumption (Halil *et al.*, 2017; & Jain *et al.*, 2018). It reduces the network lifetime (Wankhade *et al.*, 2016); As a result, it should be a key point of consideration when looking at WSN energy efficiency. The majority of WSN routing algorithm designs do not take the possibility of network partition caused by CH selection into account. Energy efficiency goals must be met throughout the network, but the CH selection issue must also be addressed (Balamurali & Kathiravan, 2016). Wireless sensor networks depend on the process of choosing an appropriate cluster head (CH) to manage communication and data transfer between the sensor nodes and the base station. The efficient routing of data packets from sensor nodes to

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the base station or sink, to increase network lifetime, is one of the issues in these networks (Sujithra *et. al*., 2016). Typically, in a sensor network, communication occurs between nodes through intermediary nodes called cluster heads, which send packets to the sink. But because sensor nodes have limited energy resources, it's crucial to reduce the number of hops between them and the sink according to Halil *et. al*., (2017) while assuring the dependable delivery of each packet. Thus, it should be taken into account while evaluating the energy efficiency of WSNs. Energy efficiency in the network must be attained, but cluster head selection, which has an impact on wireless sensor network technology, must also be minimized. The clustering procedure involved dividing the nodes into blocks, or clusters, and assigning a cluster head (CH) to each cluster. The cluster head is responsible for gathering data from the nodes of its members and transmitting it to a base station or sink node. In a WSN, single-hop or multi-hop communication is frequently used for data transfer from the sensor nodes to the base station. Both single-hop and multi-hop communication are affected by the CH selection problem. In a single-hop transmission pattern, the CH nodes that are far from the base station use up their energy more quickly due to long-haul transmission in the area where a single-hop inter-cluster routing problem may occur. Due to intra-cluster transmission, data aggregation, and inter-cluster relay, CH nodes adjacent to the base station use more energy in a multi-hop transmission pattern Therefore, they drain out energy faster than the CH nodes much afar from the base station (Seyed *et. al*., 2021). This paper provided an idea on how to overcome the above mention related problem in wireless sensor networks.

To address this challenge, this paper aims to investigate and provided an optimal selection of CH using particle swarm optimization (PSO) that optimizes the packet transmission from the sensor nodes to the cluster heads and from the cluster heads to the sink. The developed algorithm should be able to efficiently route packets through the network while improving the network lifetime and ensuring reliable packet delivery.

In this paper, an optimal cluster head selection was presented using particle swarm optimization and will compare with an improved cuckoo search algorithm (ICSA) and hybrid crow search algorithm (HCSA), there will be an expansion on the current understanding of the proposed algorithms (PSO) in terms of longest network lifetime, minimize energy usage of the sensor node, number of alive node.

The contributions are:

i. Use of particle swarm optimization (PSO) for cluster head selection.
ii. Evaluation of multi-level clusters.
iii. WSN simulation and evaluation of the proposed method based on important criteria in the wireless sensor network and comparison with previous methods.

The rest of this paper is organized as follows. Section 2 presents the related works, Section 3 presents the proposed method PSO, and Section 4 presents the implementation and evaluation of the proposed method. Section 5 result discussion and the paper is concluded in Section 6.

Related Works

Ragvendra *et. al*., (2010) offered a quick study on particle swarm optimization (PSO), its applicability in WSN applications, and how such issues are addressed by PSO. Some issues in wireless sensor networks include effective deployment, node localization, clustering, and data aggregation. These surveys are intended to help researchers find available tactics to promote future research. However, Budha *et. al*., (2012) Particle swarm optimization (PSO) techniques

for cluster head selection and packet retransmission are given. The CH is selected based on the metrics of the lowest average distance from the member node, residual energy, and headcount on the potential head nodes. Researchers must come up with a way to simplify the work and speed up the proposed algorithm's convergence to improve it. Furthermore, a Multi-objective Particle Swarm Optimization (MOPSO) Multi-objective Data Aggregation 395 technique was provided by Ali *et. al.*, (2012). Here, The main objective is to increase the number of clusters in a WSN to deliver an energy-efficient solution; this is done by producing one set of solutions at a time based on the estimated node degree and node residual energy.
To increase network lifetime based on residual energy, distance to the base station, and intra-cluster distance from the cluster head, Amin *et. al.*, (2014) outlined a technique for clustering the sensor network using the best fitness function and particle swarm optimization. The simulation results demonstrate that, in terms of network lifetime and energy usage, the suggested technique outperforms protocols LEACH, CHEF, and PSO-MV.

Subsequently, an adaptive double-layer encoding strategy was presented by Lu *et. al.*, (2014) using Jumping Particle Swarm Optimization (JPSO) to overcome this problem and produce a Pareto-optimal outcome. Sirinavasa *et. al.*, (2016) defined a technique based on energy-efficient PSO-based cluster head selection which is called PSO-ECHS, The researchers took into account these factors: residual energy, sink distance, and intra-cluster distance, The study also discusses cluster formation, in which sensors without cluster heads connect to their cluster heads using estimated weight functions. The experimental results have shown that the suggested technique surpasses the current algorithms LDC, PSO-C, LEACH-C, E-LEACH, and LEACH in terms of overall energy consumption, network durability, and the quantity of data packets received by the base station. For effective clustering of nodes in WSNs, Prasad (2016) introduced the Multi-objective Particle Swarm Optimization Differential Evolution (MOPSO-DE) technique. Based on the fitness function for transmission energy and distance between source and destination, CHs are chosen. When routing the data and choosing the CH, residual energy and signal strength of nearby nodes are also taken into account.

Gupta *et. al.*,(2018) presented an enhanced cuckoo search algorithm (ICSA) whose goal is to balance the cluster head's energy consumption to maximize the network lifetime. Both the fitness value used to pick CHs and the cost function used to evolve the cuckoo's nest is described. The simulation results show that the suggested ICSA performs better than the present algorithms in terms of overall energy usage, residual energy, and network longevity. The implementation was carried out using MATLAB. However, since both the CH and BS use energy, there is a need to increase communication between them.

Praveen *et. al.*, (2021) introduced a hybrid crow search algorithm (HCSA) for energy-efficient data collection to extend network lifespan. It also gave a learning approach that maximizes network lifetime and achieves the highest level of energy efficiency. When we compare it to the current scheme, the effectiveness of the suggested techniques is good. The implementation was done using MATLAB, and the result was obtained by using performance parameters including the overall amount of energy used, the number of active nodes, and the lifetime of the network. However, the quantity of energy used for transmission needs to be improved.
In this paper optimal cluster head selection was proposed using PSO unlike the others in this PSO was used for clustering and selecting the best cluster head that transmits data to the sink node using the metrics remaining energy of the sensor node, closer to the sink node and node density was used as the metrics for CH selection.

METHODOLOGY

PSO Clustering

Sensor nodes are firstly deployed randomly. During clustering, the fitness function for each sensor node is then calculated in a bid to select the cluster head, and more nodes adjacent to each cluster head are added as cluster members. Finally, the best identified points are chosen as cluster heads for the entire WSN. If the fitness function for a sensor node is superior to that of the initially best available globally after an iteration, such node is used as cluster head instead. The process for cluster head selection taken in this study therefore is the clustering cost function and evaluation based on the distance matrix, that is, sensor node with the closest distance to either the next cluster head or sink node is chosen as cluster head (CH) for the cluster under consideration.

After every iteration, cluster head selection is undertaken due to the difference in residual energy harbored by available sensor nodes in every cluster. This process is called updating. As such, updating the cluster head depends on the residual energy of each of the sensor nodes within a cluster, that is, node with the highest residual energy in the next iteration is updated using the mathematical concept below and same process is repeated for the number of iterations.

The mathematical model for selecting the next o new position is represented using initial or random position with the previous velocity. The method used to find the updated initial position of SN is described in Equation 1:

$$Xi(t+1) = Xi(t) + Vi(t+1) \quad (1)$$

Where Xi represents the initial position of every node in the cluster

Where $t+1$ represents the updated position of the node

Vi represents the velocity of the node in position i

The method used to find the updated velocity of the SN can be described in Equation 2

$$Vi(t+1) = \sum w * Vi(t) + C1 * Pi(t) - Xi(t) + C2 * G(t) - Xi(t)) \quad (2)$$

Where $C1$ represents the coefficient values from 0,1

Pi represents the best position and Gt represents the global best position

Where ∑w = sum of the 3 componentsparallel to the previous velocity, $Xi\rightarrow Pi$ And parallel to the vector $Xi\rightarrow G(t)$

The general equation for updating the velocity of the particles

$$Vij(t+1) = \sum w * Vij(t) + R1 * C1\,(Pij(t) - Xij(t) + R2 * C2\,(Gj(t) - Xij(t)) \quad (3)$$

Where R1 and R2 are uniformly distributed numbers in therange of 0.1

Therefore, on every iteration of PSO position and velocity was updated the current best position will be $Pi(t) - Xi(t)$ for the global best $G(t) - Xi(t)$ and the SN again moves parallel to the

$$Xij(t+1) = Xij(t) + Vij(t+1). \quad (4)$$

The proposed method has 3 steps

i. PSO clustering
ii. Evaluate multi-level clusters
iii. Determine the optimal CH using PSO.

Multilevel Clusters

In a single-hop transmission pattern, the CH nodes that are much afar from the base station deplete their energy faster because of long haul transmission the region of the possible occurrence of hotspot problem that may occur due to single-hop inter-cluster routing.
In the multi-hop transmission pattern, CH nodes close to the base station consume more energy due to intra-cluster transmission, data aggregation, and inter-cluster relay, therefore, they drain out energy faster than the CH nodes much afar from the base station. This often disrupts network connectivity. As a result, the network may get isolated and useful information is lost. In a large-scale WSN, multi-hop transmission is more energy-efficient than single-hop transmission. This is because some CH nodes may be unable to reach the base station as a result of the limited transmission range consumption among the nodes, thereby achieving an enhancement in the network lifetime. So multilevel cluster was formed whereby the transmission of a packet was not only dependent on a cluster head that is closer to the sink node but rather based on levels.

Multilevel clusters were done after the network was partitioned into 10 different clusters so in each cluster would have a CH so that the cluster head would be split again into 4 levels where the distance from each level determined the closeness of the nodes to the sink node. The multilevel clusters was represented in Fig 1 where the level of CH is presented by colors, pink color represents level 1 clusters which are far away from the sink node, pitch color represents level 2, lemon color represents level 3 and blue color represents level 4.

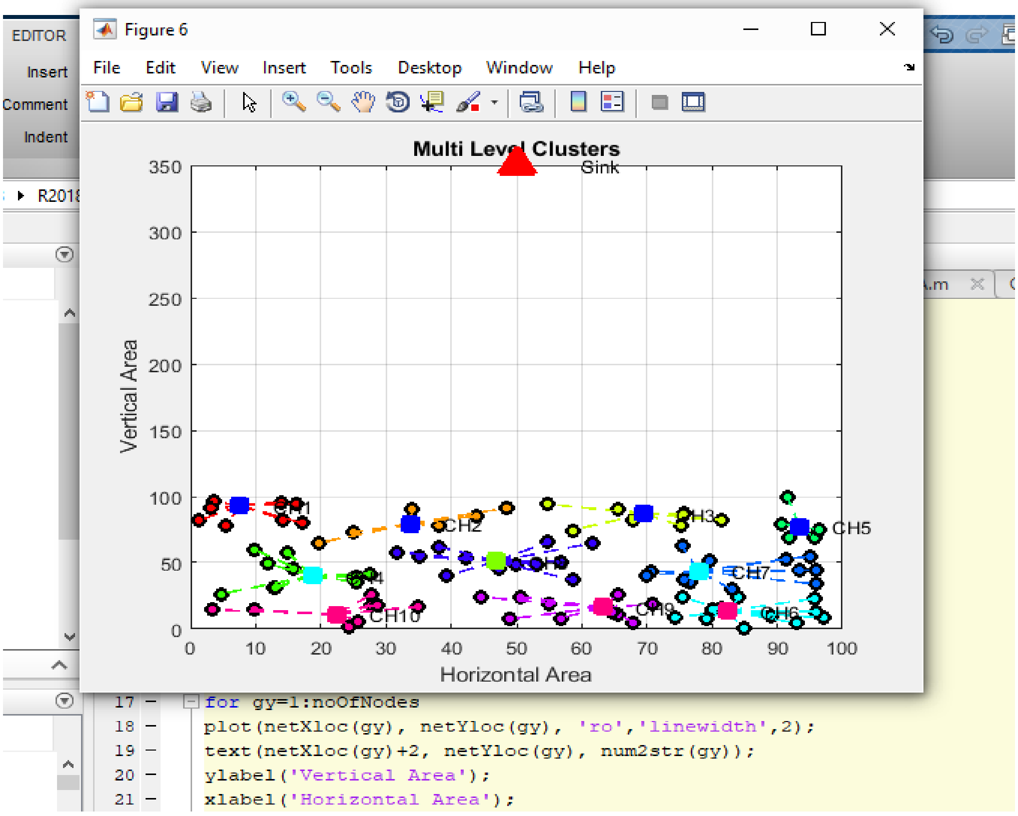

Fig 1 Multilevel clusters

RESULTS AND DISCUSSION

This section presented a performance evaluation of the developed particle swarm optimization (PSO) and its comparison with the previous hybrid crow search algorithm

(HCSA) and improve cuckoo search algorithm (ICSA), for the simulation experiment, a custom WSN simulator was designed using MATLAB where 100 nodes were randomly deployed over a network area of size 100*100 for the model as used the simulation parameters are listed in the table below.

Table 1: Performance evaluation of the developed particle swarm optimization (PSO)

Parameters	Value
Network area	100* 100
Number of sensor nodes	100 nodes
Location of the sink/ base station	50*350
The initial energy of the sensor node	2j, 200j
% of CH	5-25
Eelec	50nj/bit
Efs	10pj/bit/m^2
Emp	0.0013pj/bit/m^4
Do	87.00
Dmax	25m
Packet length	400bit
Network area	100* 100

The network topology was presented in Fig 2

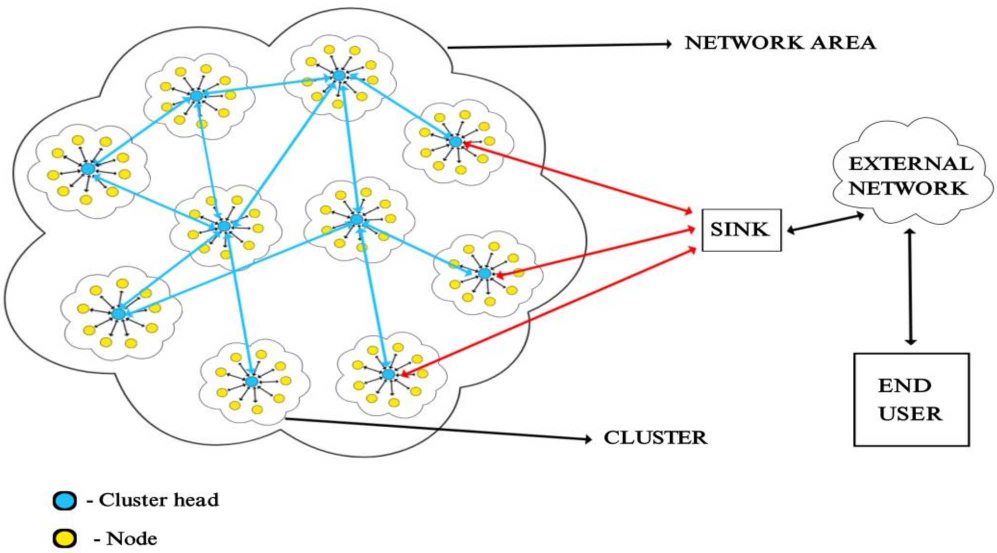

Fig 2 Simulation topology

The topology considered a total of 100 sensor nodes that are randomly deployed in a network area 100 by 100 size and a sink node which represents as a destination node. First initialization, after the 100 sensor nodes are randomly deployed in a network area of 100*100 then the sensor nodes were been partitioned into 10 different clusters or blocks and each cluster was having a cluster head (CH) which was served as the lead node that will collect data from the normal nodes and transmit the data to the sink node. So the selection of the CH that will forward the packet to the sink node was handled by the use of particles swarm optimization (PSO), and the initial position of the CH was taken based on the distances metrics and remaining energy of the sensor nodes which means for each cluster head to be selected two things will be considered whereby nodes with the highest and is closer to the sink node will be consider as CH and evaluating the cost function of the PSO after that in every iteration or rounds the position of the CH was been updated using the above equation 2 formula and the equation was used to get the best position of each CH. After that the best CH that has been choose will be the one that collect the data from other cluster head and forward it to the sink node.

For the evaluation and comparison of the developed algorithm, PSO compare with ICSA and HCSA in terms of CH selection are shown in Fig 3 indicating the presence of three colored lines. The yellow line represents the hybrid crow search algorithm (HCSA) where the number of cluster heads is less as compared to ICSA, while the red line represents the improved cuckoo search algorithm (ICSA) where the number of cluster heads is less compared to the developed algorithm and has more number of CH compare to HCSA and lastly the blue line which is the developed algorithm where it has the highest number of cluster head compared to both ICSA and HCSA. As observed from the graph the developed algorithm PSO was perform better against ICSA and HCSA. The vertical axis represents the number of cluster head the horizontal axis represent the number of rounds.

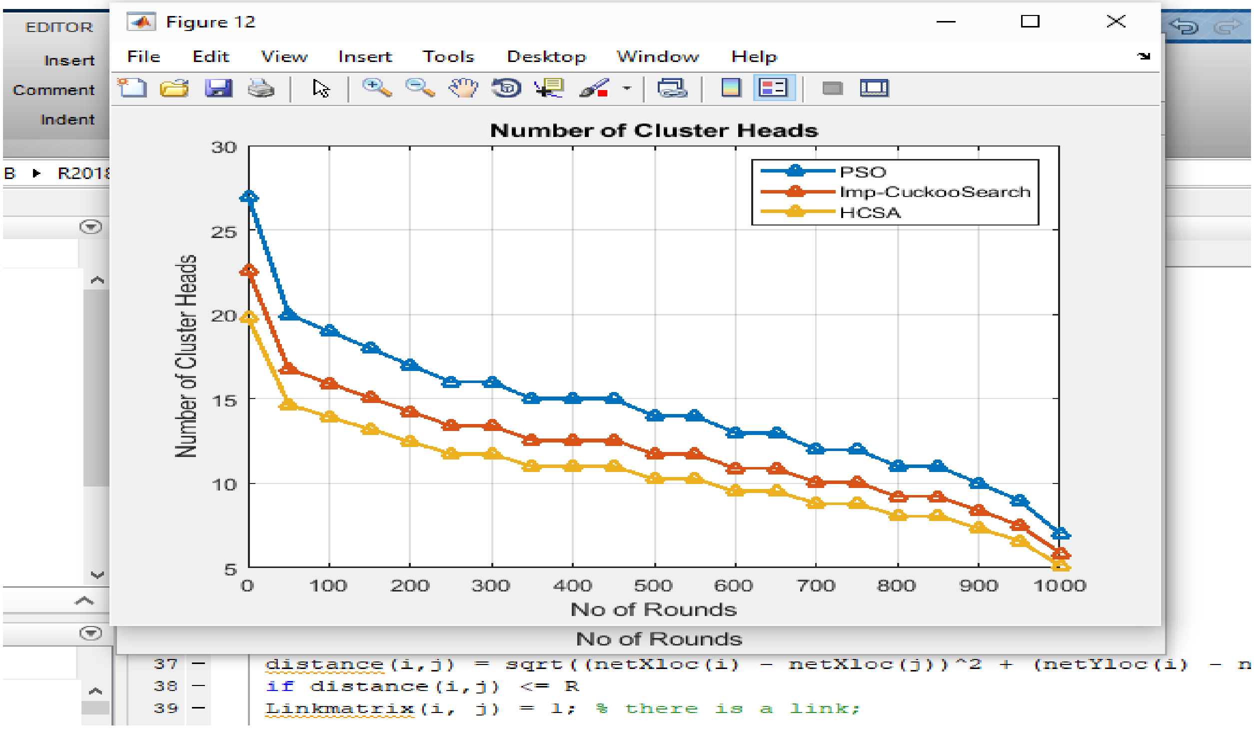

Fig 3 Number of CH

The result of PSO compare with ICSA and HCSA algorithm in terms of energy consumption as shown in Figure 4 indicates the presence of three colored lines. The yellow line represents the hybrid crow search algorithm (HCSA) where 70% for the nodes energy were exhausted which consumed highest energy compare to the developed algorithm and ICSA algorithm, while the red line represents the improved cuckoo search algorithm (ICSA) where 65% for the nodes energy were exhausted which consumed less energy compared to the HCSA algorithm and high energy consumption compare to the developed algorithm HCSA and lastly the blue line which is the developed algorithm where 50% for the nodes energy were exhausted which has the lower energy consumption as compare to ICSA and HCSA algorithms. As observed from the graph the developed algorithm PSO was perform better against ICSA and HCSA. The vertical axis represents the energy consumption the horizontal axis represents the number of rounds.

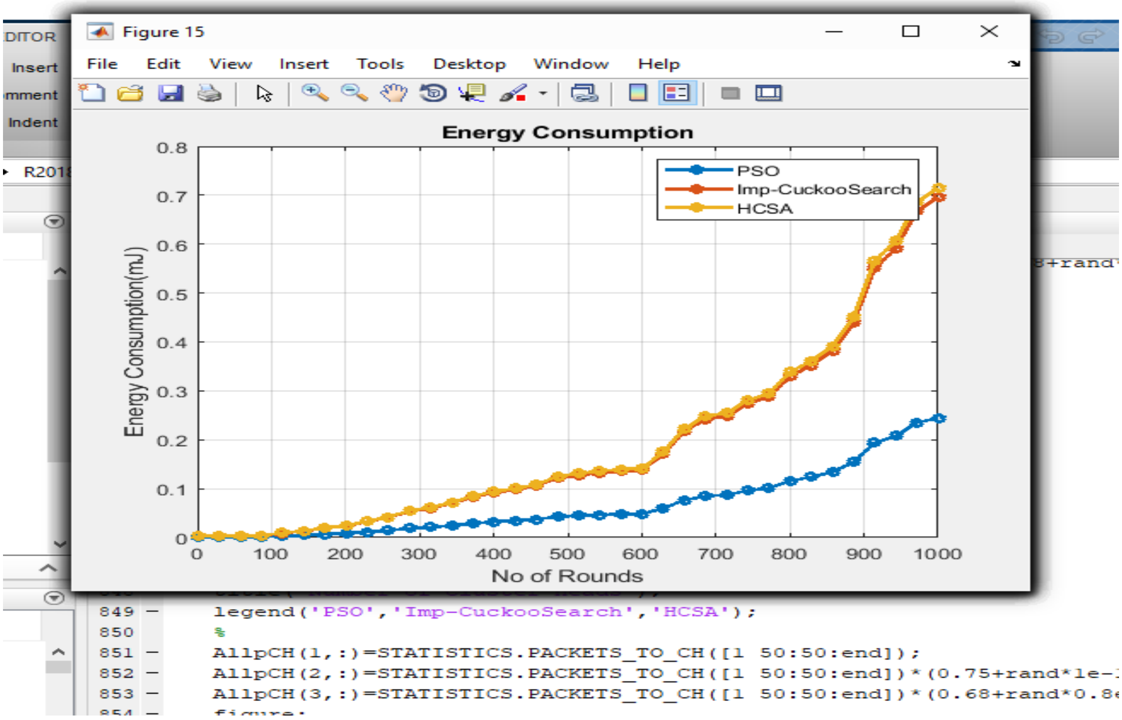

Fig 4 Energy consumption.

The result of PSO compare with ICSA and HCSA algorithm in terms of the number of alive nodes as shown in Figure 5 clearly indicates the presence of three colored lines. The yellow line represents the hybrid crow search algorithm (HCSA) where 61 nodes are still alive out of 100 sensor nodes deployed, while the red line represents the improved cuckoo search algorithm (ICSA) where 63 nodes are still alive out of 100 sensor nodes deployed and lastly the blue line which is the developed algorithm where 67 nodes are still alive out of 100 sensor nodes deployed. As observed from the graph the developed algorithm PSO was perform better against ICSA and HCSA. The vertical axis represents the alive nodes the horizontal axis represents the number of rounds.

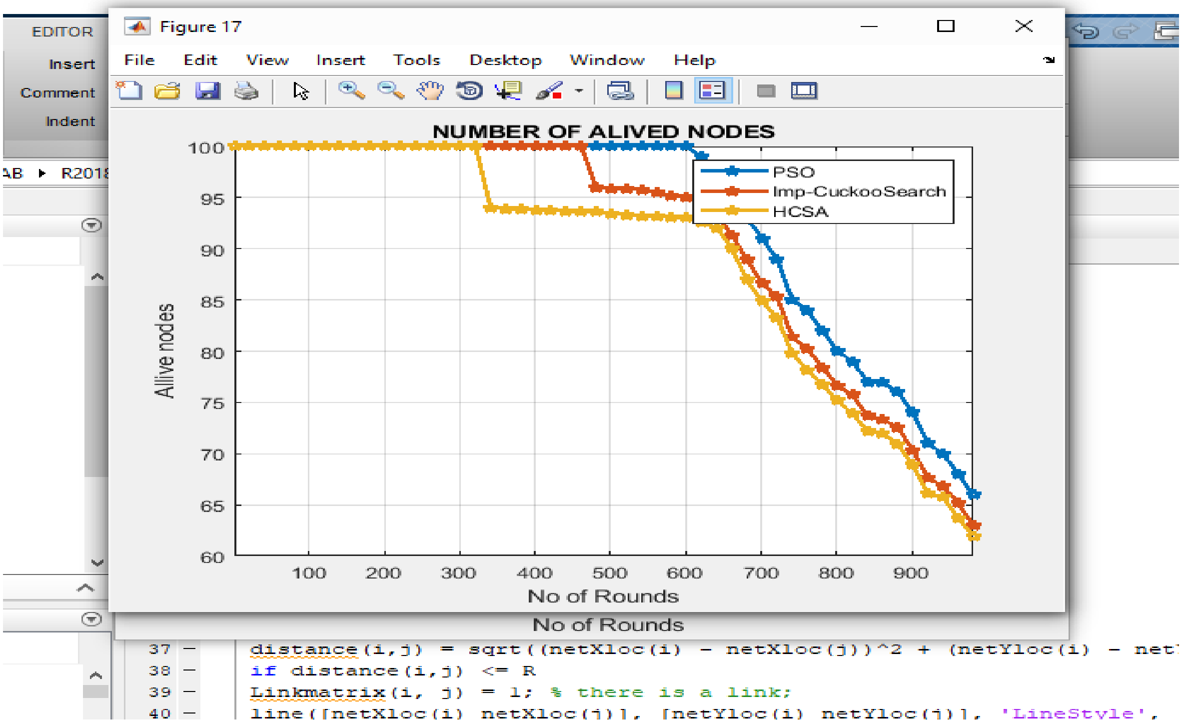

Fig 5 Number of alive nodes

The result of PSO compare with ICSA and HCSA algorithm in terms of network lifetime as shown in Figure 6 clearly indicates the presence of three colored lines. The yellow line represents the hybrid crow search algorithm (HCSA) where the first node died at round 425 out of 1000 rounds, while the red line represents the improved cuckoo search algorithm (ICSA) where the first node died at round 440 out of 1000 and lastly, the blue line which is the developed algorithm the first node died at round 450 round out of 1000. As observed from the graph the developed algorithm PSO was perform better against ICSA and HCSA. The vertical axis represents the network lifetime and the horizontal axis represents the number of rounds.

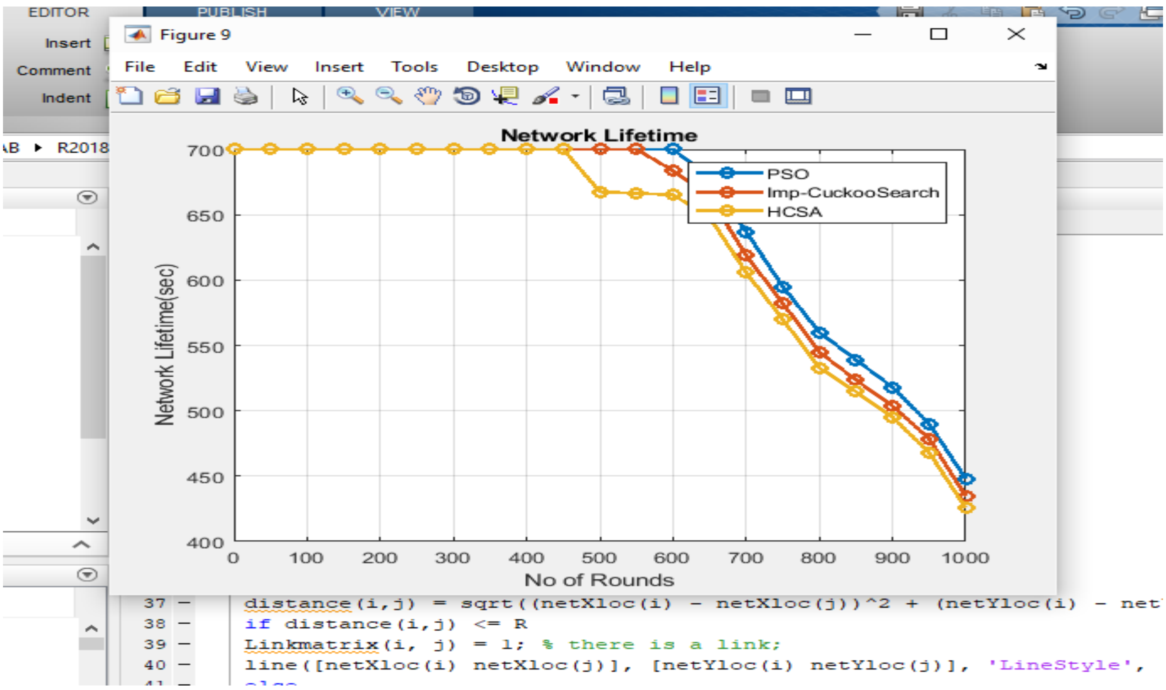

Fig 6 Network Lifetime

The result of PSO compare with ICSA and HCSA algorithms in terms of transmission of a packet from cluster head CH to base station BS as shown in Figure 7 clearly indicates the presence of three colored lines. The yellow line represents the hybrid crow search algorithm (HCSA) where the BS received 6900 packets out of 10000 packets sends from CH to BS, while the red line represents the improved cuckoo search algorithm (ICSA) where the BS received 7900 packets out of 10000 packets sends from CH to BS and lastly, the blue line which is the developed algorithm where the BS received 9100 packets out of 10000 packets sends from CH to BS. As observed from the graph the developed algorithm PSO was perform better against ICSA and HCSA. The vertical axis represents the network packet to BS and the horizontal axis represents the number of rounds.

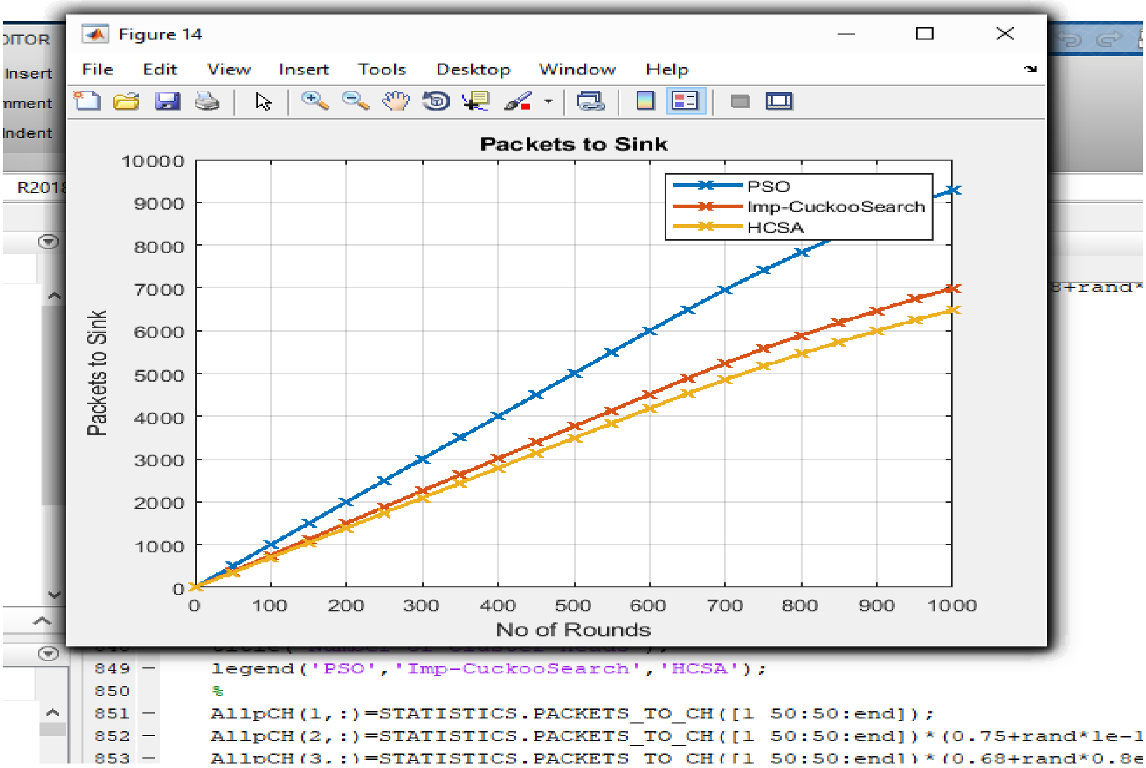

Fig 7 Transmission from CH to Sink

CONCLUSION

In this paper, a network was formed to select an Optimal Cluster Head in Wireless Sensor Networks by using Particle swarm optimization (PSO) which reduces energy consumption and extended the network lifetime based on the parameters such as residual energy, distance to base, and node density. As a means of validation, HCSA and ICSCA are compared with the developed algorithm base on the following parameters network lifetime, number of cluster heads, Packet to Sink, number of alive nodes, and energy consumption. The simulation outcome showed that our develop algorithm PSO performs better in each scenario compared to HCSA, and ICSCA. This approach has the potential to improve the efficiency and performance of WSNs, which is important for a range of applications, including environmental monitoring, healthcare, and security

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