PSO-CHS Routing Protocol for Energy Consumption Enhancement in Wireless Sensor Networks

Abstract :

A wireless sensor network of sensors spread across an area collects environmental data and sends it to the base station. It is utilized in military, physical, and chemical areas. It finds applications in various domains such as military, physical, and chemical areas. It has many applications such as monitoring humidity, temperature, and other indicators, as well as Monitoring war and battlefields is also used underwater in a special type of wireless sensor network. It depends on the basics in its formation, and the most important of these basics is the routing process, through which we ensure that data is transmitted to the Base Station in the best way. However, there are several limitations and challenges in routing to ensure a better result. One of these determinants is the selection of the cluster head for each cluster to collect information from neighboring sensors and send it to the base station. The process of selecting the cluster head is done in several ways, as there are traditional methods that may take some time and high energy to select, but at present, we have been taking advantage of artificial intelligence algorithms to choose the best header, in this research, we will use the PSO-CHS(PSO-Cluster Head Selection Routing Protocol) algorithm to select the cluster head because it provides us with speed and accuracy in the selection, as the proposed solutions for the partitions are represented for a group of nodes, and the steps of the algorithm are implemented to achieve the least energy consumed and extend the lifetime of the network, as well as to ensure sending and receiving the largest amount of packets to the Base Station and ensure the least loss of packets at the best time.

Introduction :

In recent years, wireless sensor networks have spread widely due to their great importance in sensing physical, chemical, and natural phenomena in large areas without the need for human presence[1]. They consist of a group of sensors spread over a wide area and connected to send information to the base station. The WSN faces many challenges; one of the most important of these challenges is routing [2]. The three primary types of routing protocols for Wireless Sensor Networks (WSNs) are flat, location-based, and hierarchical. Topology determines the configuration of the routing channels, whether they are spread out or organized into packets, as well as the quantity of packets. One way in which the hierarchical protocol differs from the flat protocol is that each network cluster has one or more Cluster Heads (CH)[3]. The primary purpose of CH is to act as a conduit for information gathering from various environmental sensors. which are employed to communicate with the BSs or between CHs[4]. This reduces the traffic that is accumulated due to transmission and reception from each node to the base station. Choosing the heads of clusters is a very significant step, and there are myriad protocols and algorithms in this view. The proposed scheme of selecting cluster heads by AI algorithms is a very proper way, for instance, machine learning. [5], deep learning [6], and optimization algorithms. PSO [7] is one of the optimizing algorithms that are used to improve the lifetime of the network together with power consumption. [8].

LITERATURE REVIEW :

AI has been integrated with WSNs mainly to increase the lifespan of the networks. Several works have addressed various approaches for choosing the cluster head and the power management scheme in WSNs.

In this research, Zhang et al. (2023).[9] have put forward a two-layer framework for the edge computing involved in WSNs. The improvement of the efficiency of energy use and the extension of the durability of the power system was the goal for which they worked. Otherwise, the Sparrow search algorithm was employed; this reduced the power usage by 26% and enhanced the network lifetime by 8%.

Along the same line, Prado and Wozniak (2022).[10] applied a deep conventional network that incorporated the BEA-SSA in choosing the proper cluster head where the various criteria such as energy and distance were taken into account to ensure the selection of superior residual energy resulting in better PDR across small and large numbers of networks.

In Rehman et al. (2024).[11] the authors proposed a new fuzzy SMO with an HMM to optimize the selection of CHs; the improvements here averagely increased by 1. A one-month improvement of 2% is what any network has to look forward to when implementing a new network protocol.

Zhang et al. (2023).[12] also introduced the Hybrid Snake Whale Optimization (HSWO) Algorithm for optimizing the selection of the cluster heads along with limitations like delay and energy, the network energy is normalized at 0. 98.

Furthermore, Pazmiño (2023).[13] proposed the application of multipath routing with the HMSN algorithm to increase the packet delivery ratio to 95%. Increase the penetration to 43%, throughput to 263, and stability time of cluster heads to 120 sec.

Recently Lata and Mehfuz (2020).[14] proposed the LEACH-Fuzzy Clustering (LEACH-FC) protocol essentially based on fuzzy logic to elect the cluster head: in this way, the network lifetime increases and energy consumption also increases. Ranging from 37% to 348% across different network configurations.

Rajagopal et al. (2020).[15] proposed the General Self-Organization Tree-Based Energy Balance (GSTEB) protocol which reduced the total energy consumption and increased the network lifetime by 27%. They recommend this protocol be used in applications such as environmental monitoring and air traffic control.

A related study by Praveenkumar et al. (2023).[16] focused on support vector machines and Gaussian regression processes for the dynamic cluster head selection. The research obtained a 98 % correlation in energy consumption with the GRP method.

In Kumar in 2021.[17] Energy efficiency was considered using a modified particle swarm optimization technique that was incorporated with a genetic algorithm. The results signify that energy utilization enhancements of up to 14 percent can be envisaged. 28% are achieved as compared to the best literature techniques.

Prado and Wozniak (2022).[18] proposed the MFA-AOA optimum approach that can optimize the balance between the exploration and exploitation of the possibilities in the selection of the heads of clusters. I believe this strategy significantly increases the network's duration, having reached an impressive 14%. This has been achieved with a visibility of 25% better than the previous techniques used to achieve it.

The Proposed Algorithm :

The PSO-CHS algorithm is one of the artificial intelligence algorithms. It is an optimization algorithm and is used in wide areas to find the best solutions. It relies on the principle of flocks of birds searching for food[19]. This algorithm goes through several stages, including initialization of the particles and then determining the velocity and position of these particles randomly, and then Calculating the fitness function for each cluster. In the next stage, the position and velocity are modified and the fitness function is recalculated and compared with the previous one. This process continues to be iterations until the appropriate solution is reached. This algorithm has been used in this paper to select the best head for each cluster to ensure reducing energy consumption as well as extending the lifetime of the network[20].

Network model :

The network that was used in this scenario has several characteristics that will be mentioned in detail:

The network consists of 90 nodes spread over a fixed area by the deterministic deployment, divided into 6 clusters. Each cluster contains 15 nodes arranged in the form of 3 columns and 5 rows, where communication takes place between them using the Chain-Based method as shown in Figure (1).

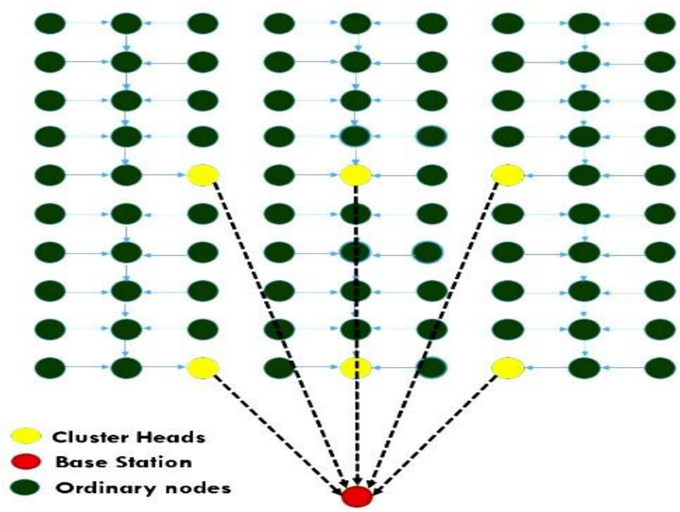

Figure (1): network model with PSO-CHS protocol

In this method, the node that contains the most energy in the row is selected to be the one that sends the packet to the "next hop" in the lowest row until the packets are delivered to the cluster head (CH) that was selected by the PSO algorithm according to the following steps:

1. Initialize the particles: each particle represents a node index.
2. Set a random value to the velocity and position of the particles.
3. calculate the fitness function for each particle as the following equation(1):

$$fitness = \left(\frac{e}{\frac{1}{d}}\right) * cons \qquad \ldots \qquad (1)$$

   where :
   e = energy
   d = distance
   cons= constant (number for normalization)
4. calculate the *Pbest* (personal best fitness for each particle)and the *Gbest* (global best fitness for all particles).
5. update the velocity and position of the particles as the following equations (2):

   velocity update equation(2):

$$v_{p_{[i]}} = w * v_{p_{[i]}} + c1 * r1 * \left(P_{best[i]} - x_{p_{[i]}}\right) + c2 * r2 * \left(G_{best[i]} - x_{p_{[i]}}\right) \quad \ldots \quad \textbf{(2)}$$

Where :

- *Vp[i]:* The velocity of particle p in the [i] dimension.
- *w:* The inertia weight, which controls how much of the previous velocity is retained.
- *c1:* The cognitive coefficient, representing the influence of the particle's own best-known position.
- *r1:* A random number between 0 and 1, which introduces stochasticity in the cognitive component.
- *Pbest[i]:* The best-known position of particle p in the [i] dimension.
- *c2:* The social coefficient represents the influence of the global best-known position.
- *r2:* Another random number between 0 and 1, introducing stochasticity in the social component.
- *Gbest[i]:* The global best-known position in the [i]dimension.
- *Xp[i]*: The current position of particle p in the [i] dimension.

Position Update Equation(3):

$$\boldsymbol{x}_{\boldsymbol{p}_{[i]}} = \boldsymbol{x}_{\boldsymbol{p}_{[i]}} + \boldsymbol{v}_{\boldsymbol{p}_{[i]}} \qquad \dots \qquad \textbf{(3)}$$

- *Xp[i]:* The updated position of particle p in the [i] dimension.
- *Vp[i]:* The updated velocity of particle p in the [i] dimension.

6. Iteration: repeat the previous steps until get the best cluster head.

This PSO procedure is applied to each cluster in the network to select the cluster head that will send the packets to the base station.

The energy model :

The first-order radio model measured the energy consumption during the transmission or reception of a sensor node in each cycle.[21]. The radio model has power control and can spend the minimum energy required to achieve the intended receivers, as shown in the figure (2) below :

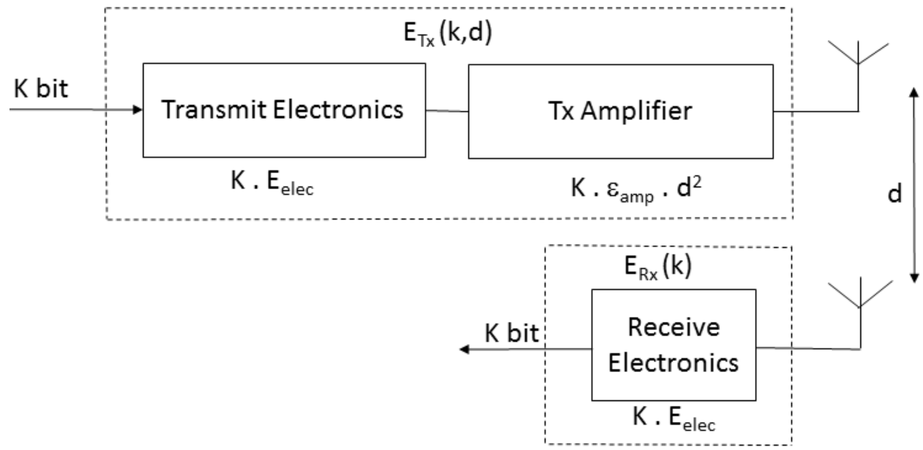

Figure (2): first-order radio model

The equation (4) of the transaction is :

$$\boldsymbol{E_{T_x}(k,d) = E_{elect} * k + \varepsilon_{amp} * k * d^2} \qquad \textbf{... (4)}$$

The equation (5) of receive is :

$$\boldsymbol{E_{R_x}(k) = E_{elec} * k} \qquad \textbf{... (5)}$$

Performance evaluation of PSO-CHS **protocol :**

There are some basics to measure the performance of the PSO-CHS algorithm and compare the results of the simulation with other routing protocols like ETSRP[22] and DCBRP[23] Utilizing NS-3.22 and the C++ programming language in Table (1) :

PARAMETERS	DETAILS
Topology	Grid size (9 × 10)
Type Of The Sensor Nodes	Homogenous
Sensor Nodes Numbers	90
Location Coordinates For BS	(50,120)
Initial Energy	2.0 J
Packets Size	1024 bit
Methods of Deployment	Deterministic
Inter-SN Distance	10 m
Energy Channel	Symmetric for the energy requiredin transmission from A to B is the same as from B to A.
Electric Potential Energy Required To Activate The Electronic Circuit (Eelec)	50 nJ/bit
(εfs)	10 pJ/ bit/m^2
(εmp)	100 pJ/bit/m^2

Table (1): simulation parameters

We will calculate all metrics for performance over the First Node Die (FND).[24, 25]

1. **Delay:** One major disadvantage of chain-based routing methods is the presence of latency. The Delay metric is crucial in determining the delay duration in each round of calculation. equation (6) show that :

$$End - to - End\ Delay_r = \sum_{packet=1}^{last\ packet} (Time_{Resived} - T_{transmit}) \quad \ldots \quad (6)$$

2. **Average Delay**: The average delay is calculated by dividing the overall delay encountered in each round until the first node dies (FND) by the number of packets, which is equal to 90 packets in equation (7).

$$Average\ Delay = \frac{\sum_{r=1}^{r=FND} Total\ Deley}{number\ of\ packets} \quad \ldots \quad (7)$$

3. **Total Power Consumption:** The use of energy is a crucial measure that defines the amount of energy used by each SN in each round, as represented by the equation(8).

$$\boldsymbol{Total\ power\ consumption = \sum_{n=1}^{no.nodes} E_{consumption\ in\ node(i)}} \quad \textbf{... (8)}$$

4. **Average Power Consumption:** The overall power usage is split into 90 packets until the first node dies (FND) within the framework of an equation (9).

$$\boldsymbol{Average\ power\ consumption = \sum_{r=1}^{r=FND} \frac{Total\ power\ consumption}{number\ of\ packets}} \quad \textbf{...(9)}$$

5. **Average Cluster Head Power Consumption:** To reduce energy consumption in each sensor node (SN), a technique called Cluster Head Election (CHE) is suggested. This approach takes into account factors such as distance, and remaining energy. Equation (10) calculates the average power consumption of all Cluster Heads (CHs) until the First Node Death (FND) by dividing it by the number of chosen CHs in the network.

$$\boldsymbol{Average\ CHs\ P.consumption = \frac{\sum_{i=1}^{i=FND} E_{consumption\ of\ CHs}}{number\ of\ CHs}} \quad \textbf{... (10)}$$

6. **Deley * Energy:** The measure described in equation (11) has the greatest impact on chain-based routing protocols compacting both metrics' effects.

$$\boldsymbol{Delay * Energr = Total\ Deley * Total\ Power\ Consumption} \textbf{ ...(11)}$$

7. **Average Deley * Energy**: The performance of the PSO-CHS protocol may be evaluated using two metrics: the product of the Average Delay and the Average Power consumption until the first node dies. As indicated by equation (12).

$$\boldsymbol{Averagr\ Deley * Energy = Averege\ Deley * Average\ PO.Consumption} \quad \text{... (12)}$$

8. **Execution time:** This matric calculates the time required to perform the head selection process for each cluster as shown in the equation(13).

$$\boldsymbol{Execution\ time = \frac{(end\ time - start\ time)}{CLOCKS\_PER\_SECOND}} \quad \text{...(13)}$$

Simulation results :

the energy consumption and the delay are the primary disadvantages of routing protocols and chain-based topology, in this research we mixed the chain-based topology with the AI algorithm to optimize the results, so we used the Particle Swarm Optimization (PSO) in the PSO-CHS protocol and compared the results with the ETSRP and DCBRP protocols, The selection of Cluster Heads (CHs) is based on the amount of remaining energy and the distance between the Sensor Nodes (SNs) and the Base Station (BS). The first node died (FND) with the PSO-CHS protocol at the (1843) round but in the ETSRP protocol, the first node died at the (1567) round, and in the DCBRP protocol the first node at the round (1861). The delay time at round 1000 is (0.0227229) in the ETSRP and is (0.0383824) in DCBRP but is (0.0213824) in the PSO-CHS protocol as shown in the figure (3):

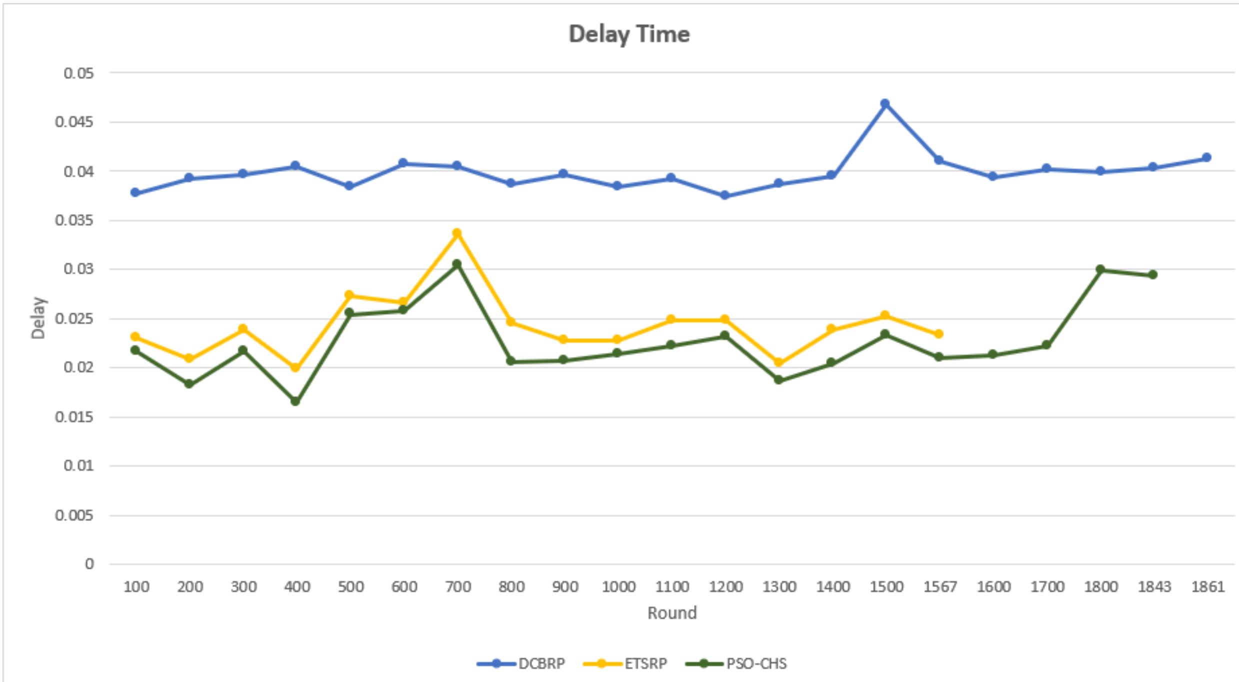

Figure (3) Deley Time metric of the PSO-CHS, ETSRP, and DCBRP

The Energy * Delay metric is often employed by several studies including [23],[26],[27]. This metric gives better results by effectively accounting for the impact of delays on energy outputs, enabling meaningful comparisons with other metrics. In round (1000) it is about (0.0083267) in the ETSRP protocol and (0.0387301) DCBRP but it is (0.00687301) in the PSO-CHS protocol as shown in figure (4):

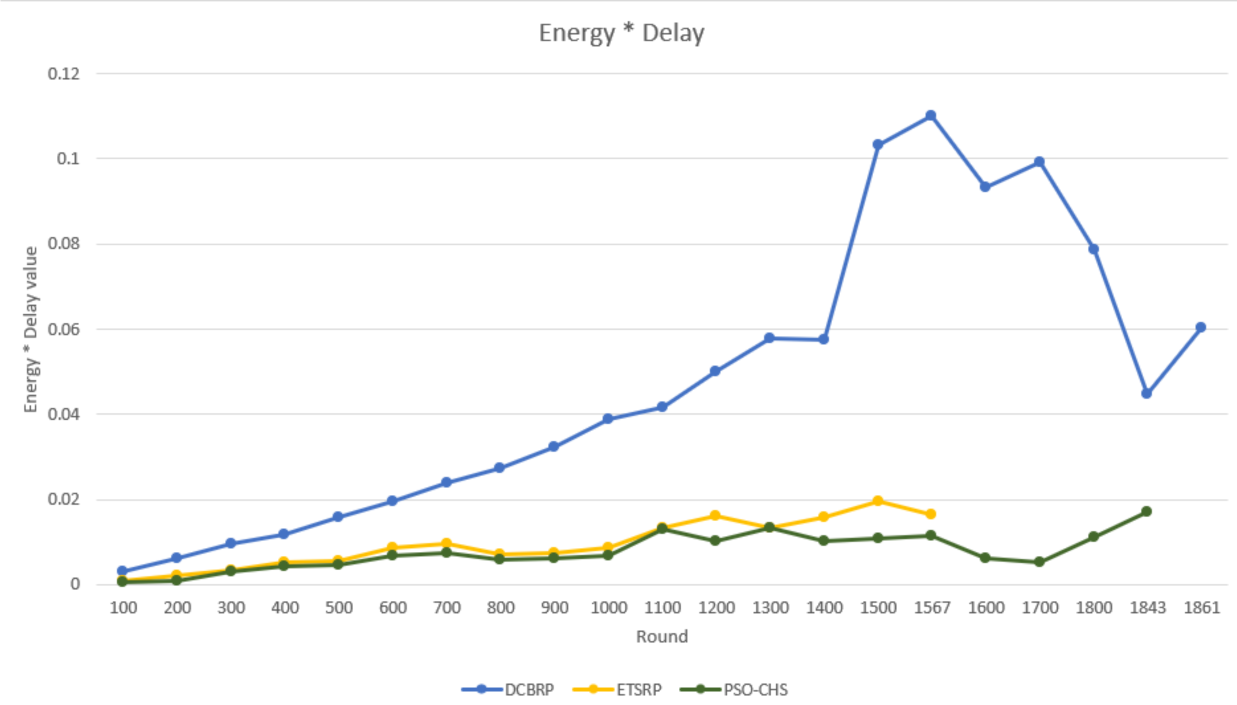

*Figure (4) Energy * Deley metric of PSO-CHS, ETSRP and DCBRP*

By calculating the average of the Energy * Delay we will get results as shown in Figure (5) :

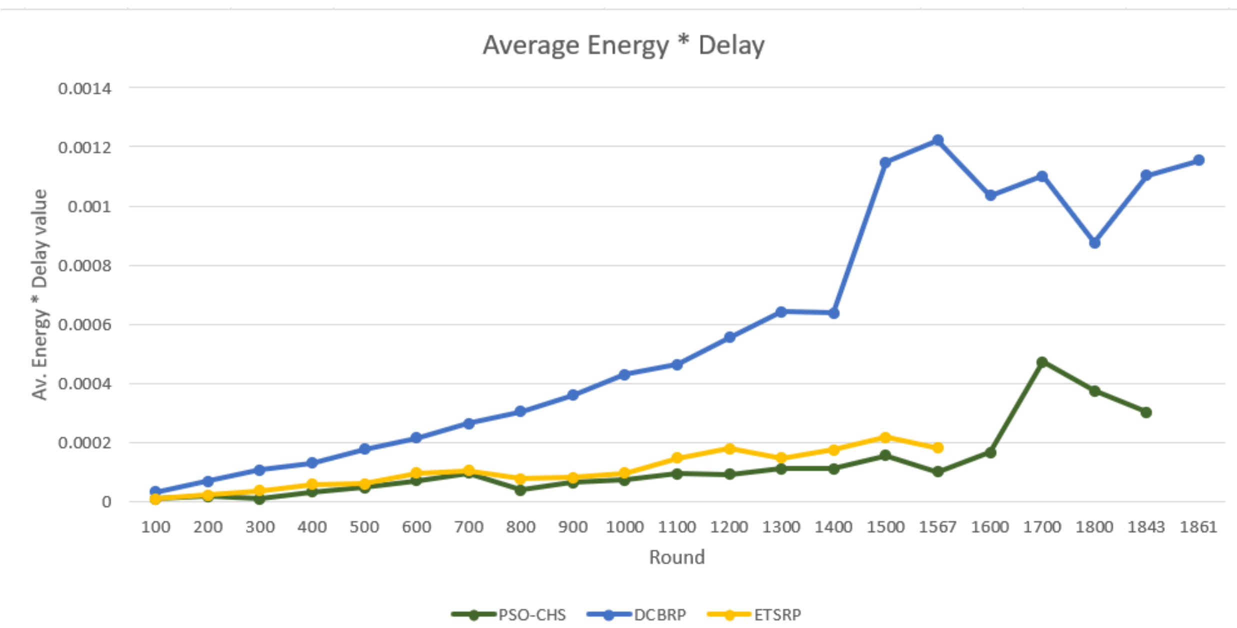

*Figure (5): Average Energy * Delay metric of PSO-CHS, ETSRP, and DCBRP*

The power consumption matric that appears in figure (6) shows the amount of power consumption that is used in each round in the simulation, in round 1000 PSO-CHS gets (0.0123477) but it is higher in the ETSRP to (0.0326554) and is DCBRP is (0.0905114).

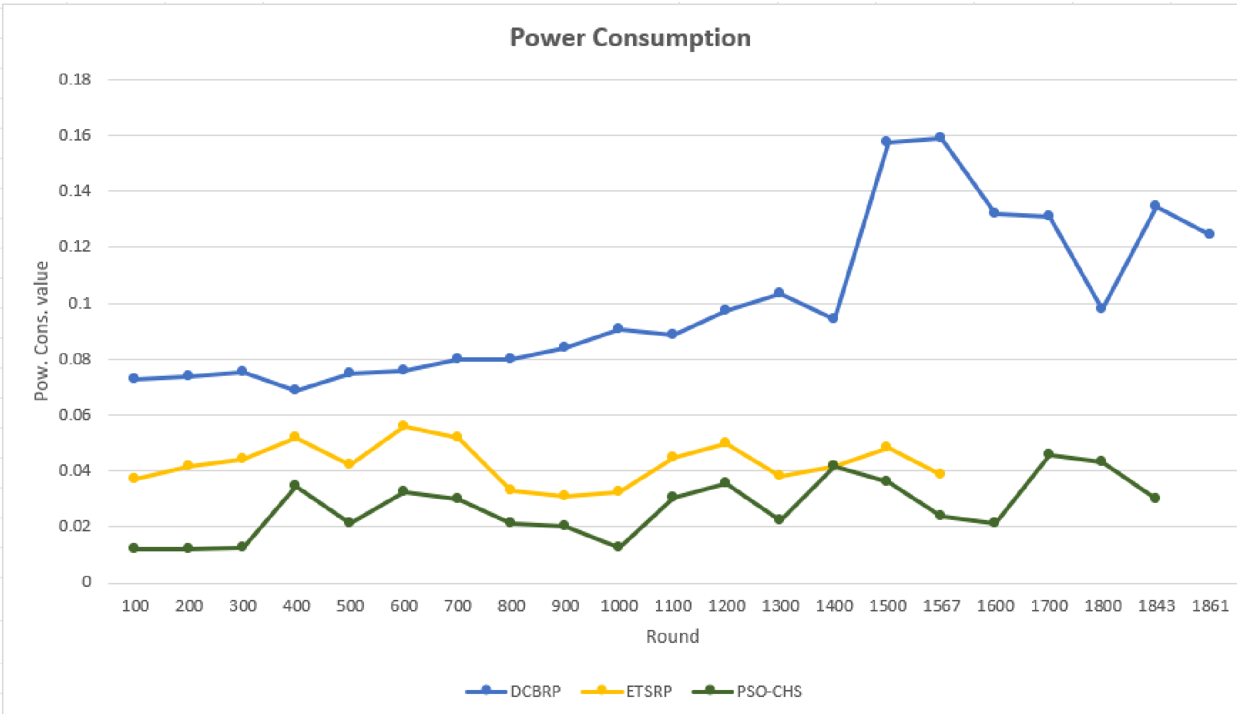

Figure (6): power consumption of PSO-CHS, ETSRP, and DCBRP

The average power consumption is shown in Figure (7).

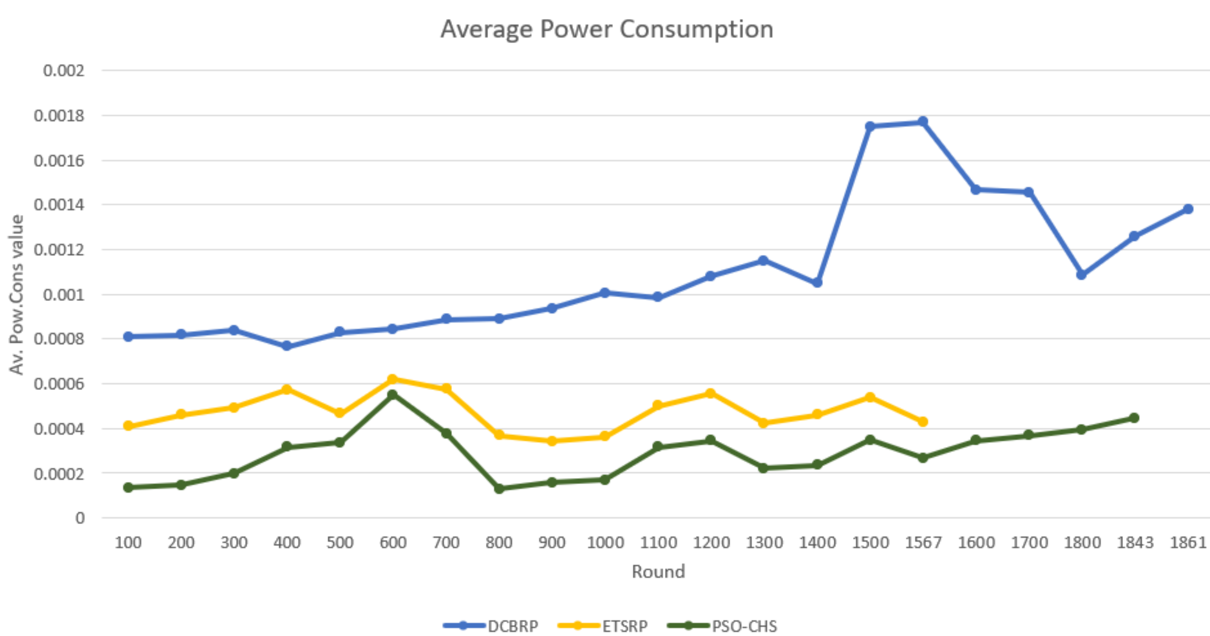

Figure (7): Average power consumption of PSO-CHS, ETSRP, and DCBRP

The total number of cluster heads, which have the responsibility of gathering and transferring all packets to the base station, impacts both the longevity of the network and the latency in packet transmission and reception. The magnitude of this effect is contingent upon the number of clusters in existence and how sensor nodes are interconnected. The number of cluster heads in PSO-CHS is equivalent to the number of clusters, which is 6. Each of the CH's objectives is to gather 15 packets from 15 nodes inside a cluster and transmit them directly to the base station (BS) in a single hop while minimizing any possible delays in power consumption. During round 1000, the power consumption of the CH head in the ETSRP is (5.47557) and is (22.0585)in DCBRP However, in the PSO-CHS, it achieves a lower result of (4.016488) as seen in Figure 8.

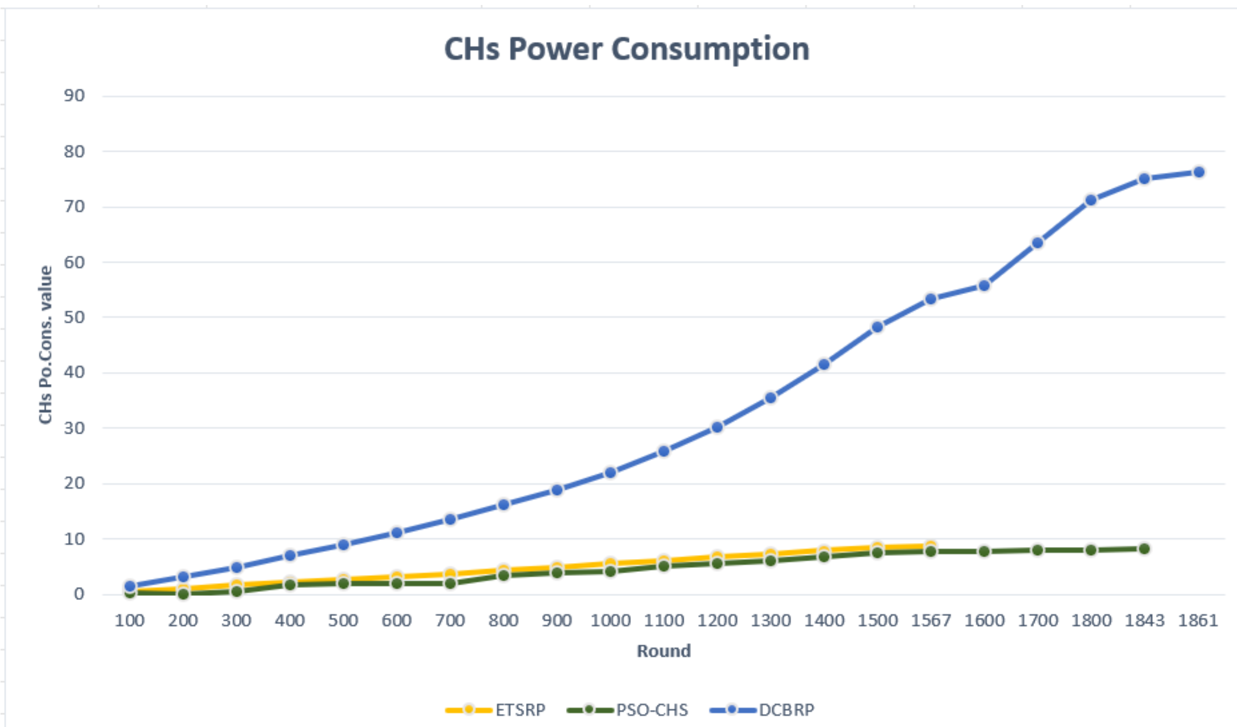

Figure (8): cluster head power consumption of PSO-CHS, ETSRP, and DCBRP

Finally, the execution time for the ETSRP is (0.000063 s) and in the DCBRP is (0.002389 s) but is much better in the PSO-CHS (0.00001 s).

Conclusion :

Delivering packets from nodes to the base station with as little delay as feasible is one of the most significant challenges in a wireless sensor network in order to optimize the life span of the network. In this study, we applied mixed topology for The Next Hope Connection and also applied one of the artificial intelligence algorithms, the Particle Swarm Optimization algorithm. In order to gather data and send it to the Base Station, We decided to partition the network into clusters, each including a head cluster. The PSO-CHS protocol, which was developed to enhance the ETSRP protocol in terms of execution time and energy consumption and hence extend its lifespan, is used to choose the cluster head. With the implementation of simulation, it was discovered that networking and the first node died after more rounds than the conventional technique.

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