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Implementation of PSO towards Energy Efficient Clustering in Wireless Sensor Networks

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ABSTRACT

Wireless sensor networks are one of the promising and interesting areas of research among researchers because of some of the major reasons like their advancement in real world applications or optimization of resources in sensor nodes. Wireless sensor networks include large number of tiny sensor nodes (depends on the application) which are having the limited resources i.e. energy, communication capabilities etc. Energy conservation in these sensor nodes become very important to enhance the network lifetime. Clustering is one of the energy efficient techniques to achieve this goal. Particle Swarm optimization (PSO) is one of the nature-inspired computation algorithm aims to provide optimal solutions of a given problem. In this paper, progress of different research works conducted to perform energy efficient clustering in WSNs using PSO, has been studied & analyzed. In these research works, various fitness parameters have been considered and evaluated for providing the optimal solutions in terms of cluster head, cluster formation and data routing. This paper aims to focus on study of pure PSO based clustering algorithms and provide their comparative analysis in terms of clustering objectives, type of WSN based on initial energy level of sensor nodes, sink movement, parameters to be integrated in fitness function, performance metrics for evaluation, simulation environment, etc.
Keywords: Sensor, PSO, Clustering, Energy-efficient, Fitness function

Introduction

Wireless sensor networks (WSNs) are formed of hundreds to thousands small sized sensor nodes which are connected via wireless communication. These micro sized sensor nodes are capable of sensing, processing and sending the processed data to user. Sensor node can sense or record the physical parameters like temperature, humidity from the environment. Sensor nodes are low power devices which are equipped with sensors (one or more), processor, memory, a radio for wireless communication actuator and power unit [1].

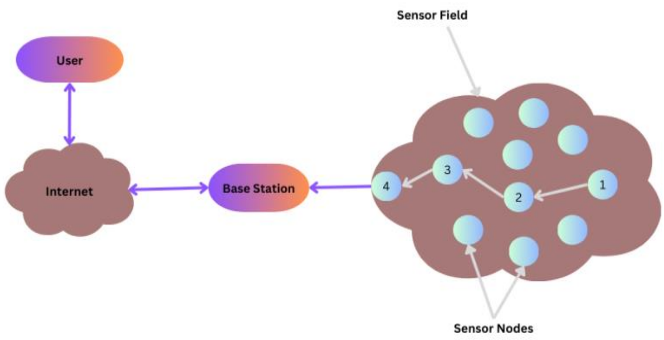

Figure 1: Deployment of Sensor nodes in field

Sensor nodes collect the sensed data followed by its processing and transmit this processed data to destination or base station (BS). The typical functionality of WSNs is shown in figure 1. It is clear from the figure that sensor nodes which are located far from base station (sink node), will consume more energy for transmitting the data and results in rapid energy depletion of nodes. It can be seen that if sensor node numbered 1 has to transmit the data to base station, then it follow the routing path (1->2->3->4).

Energy consumption in sensor nodes can be divided into three domains: sensing, communication and processing of data [2]. Sensor nodes are typically deployed in critical environment like battlefield, forests and defence fields along with limited access to human beings which makes nearly impossible to replace the battery of sensor nodes. Energy conservation in sensor nodes is one of the major challenging problems in wireless sensor networks. Clustering is one of the approaches to address this problem and provides the energy efficient solution. In clustering, a hierarchical architecture of WSNs is implemented with addition of extra virtual layers between sensor nodes and base station.

Sensor nodes are organized into number of groups called cluster in which a certain number of sensor nodes are elected as cluster head. After selection of cluster head, cluster formation takes place where sensor nodes join the particular cluster and then these nodes transmit their sensed data to respective cluster head (CH). Cluster head collects the data from the sensor nodes of respective cluster and performs data aggregation or data fusion to remove redundant (repetitive) information and transmit this processed data to base station. Sensor nodes transmit the data to cluster head instead of base station which helps in reducing the energy consumption of sensor nodes. Clustering in WSNs involves intra-cluster and inter-cluster communication which represents the communication within the cluster and communication between cluster head and base station respectively. Intra-cluster communication generally occurs in single-hop or direct, while inter-cluster communication occurs in form of single hop or multi hop. Single hop communication does not involve any intermediary, while multi- hop communication involves one or more intermediary through which data is transmitted. Clusters placed very near to base station may perform single-hop communication while clusters situated far from sink, may go with multi-hop communication. In figure 2, sensor nodes numbered as 1, 2 and 3 acts as cluster head of their respective cluster and transmit the aggregated data to base station. Cluster head nodes 2 and 3 transmit data to base station via node 1, hence it involves multi-hop communication.

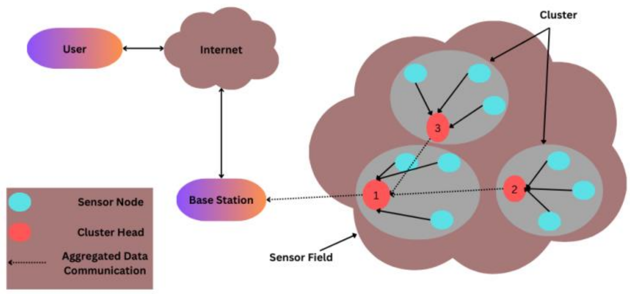

Figure 2: Clustered Wireless Sensor Network

Apart of energy efficiency in WSNs, clustering can be applied to get more primary objectives like fault-tolerance, load-balancing, enhancement of network lifetime, data aggregation/data fusion [3]. Clustering in WSNs is divided into mainly three phases. In the initial phase, selection of cluster head is performed followed by formation of cluster in which sensor nodes join the particular cluster based on some message communication or parameters. Along with the clustering mechanism, energy-efficient routing contributes in minimizing the energy consumption which consequently, extends the network lifetime. Therefore, the design of energy efficient routing protocols in WSNs is challenging because of the constrained power supply in sensor nodes [4]. The routing performs the data transmission from cluster head to base station. All three phases have gained a lot of attention among researchers. Cluster head selection phase determines which sensor nodes will going to elect as cluster head whether is predetermined or randomized or based on some parameters. Cluster heads are suffered from excessive load because they are responsible for collecting the data from member nodes of cluster, perform the data aggregation and transmission of aggregated data to base station. Selection of proper cluster head becomes very important and can affect the entire clustering process. Cluster formation phase decides which sensor nodes will join cluster whether it is randomized or based on some attributes. Proper cluster formation should be conducted to ensure uniform distribution of sensor nodes into cluster along with the distance factor between cluster head and base station and more. The last phase of data transmission decides the energy efficient routing path from cluster head to base station. The aim of this phase ensures routing path with minimal distance to minimize energy consumption in cluster head nodes. All these three issues still are open issues which are being mentioned in different research works. Numerous issues found in active research domain of WSNs including energy efficient clustering and routing, sensing area coverage, sensor nodes deployment and data aggregation techniques which are to be optimized. Several nature-inspired techniques have been proposed to formulate these issues. PSO based different methodologies have been implemented in various research works to address these issues.

This paper focuses on progression of PSO for implementing clustering and cluster based routing in energy efficient way. These several research works have been studied and compared on the basis of some qualifying parameters.

The structure of this paper is organized in various sections which are as follows. Section 2 involves the brief overview of PSO algorithm including its illustration and flow chart. Section 3 covers study of various research works in which PSO based different algorithms have been implemented to provide energy efficient clustering in WSNs. In Section 4, comparative analysis of various research works has been performed. This paper is concluded in section 5.

PARTICLE SWARM OPTIMIZATION (PSO) ALGORITHM: AN OVERVIEW

Optimization methods are one of the important powerful methods, used to solve any complex problems whether it is any of mathematical or engineering domains. It tries to give optimal solutions of any given problem. Nature inspired computation has been extensively used into almost all areas of sciences, engineering and industries, from clustering & mining to optimization, from artificial computational intelligence to engineering designs, from image processing to power & control systems, from medical to industrial applications etc. In other words, it is perhaps one of the most popular research areas comprising multidisciplinary connections [5]. PSO is nature inspired algorithm which was originally introduced by J. Kennedy and R. Eberhart in 1995. It observes and mimics the social behavior of birds [6]. A swarm (group) of birds fly in search space to locate the food and shelter. Each bird uses best knowledge of its flying experience along with the flying experience of its neighbor. The bird with the best position or nearest to target, informs the swarm and the others move to that direction simultaneously. This process is performed in iterative manner until target is achieved. The main concept of this behavior is de-centralized and self-organized as swarm of birds move without any leader and each bird shares its best knowledge with swarm. PSO algorithm finds the optimal solutions of a problem by modeling this social behavior of birds. Various variants of PSO algorithm are also proposed in various research works.

PSO algorithm consists of swarm of N (swarm size) particles, where each particle Pf ($1 \le f \le N$) provides a potential solution in given multi-dimensional search space D (equal for each particle). The fth Particle is associated with position coordinates Xf,d ($1 \le f \le N$, $1 \le d \le D$) and velocity Vf,d. A fitness function is used to evaluate individual particle by verifying the suitability of the solution for a given problem. Let a particle Pf is represented in the multidimensional search space is represented as follows:

$$Pf = \{Xf,1, Xf,2, Xf,3, Xf,4 \ldots\ldots\ldots Xf,d; \ 1 \le d \le D\}$$

The aim of PSO is to find the particle's coordinates in space that produce best evaluation of the given fitness function. In the initialization phase, each particle is assigned with a random position and velocity, to make progress in the search space. During each iteration counter, each particle finds its own personal best position called Pbest and best position of swarm called Gbest. To reach the global best solution, each particle utilizes its personal and best solution among group to update the velocity V(t) and position X(t) at iteration t using the following equations, mentioned in modified particle swarm optimizer [7].

$$Vf,d(t) = \omega * Vf,d(t-1) + w1 * r1 * (Pbestf,d(t-1) - Xf,d(t-1)) + w2 * r2 * (Gbestd(t-1) - Xf,d(t-1)) \quad (2.1)$$

$$Xf,d(t) = Xf,d(t-1) + Vf,d(t) \quad (2.2)$$

Equation (2)

where ω is inertia weight, having the value between 0 and 1. w1 and w2 represents the acceleration coefficients having the value in the range [0,2] and r1,r2 are random generated numbers having the values in the range (0,1).

After updating the velocity and position of each particle, fitness function is evaluated for updated position of each particle and is compared with previous best assessment of given fitness function of each particle to get Pbest. The method for finding Pbest and Gbest for maximization problem can be defined with the help of following equations:

$$Pbestf(t) = \begin{cases} Pf(t), & \text{If } (fitness(Pf(t)) > fitness(Pbestf(t-1))) \\ Pbestf(t-1) & \text{Otherwise} \end{cases} \quad (2.3)$$

$$Gbest(t) = \begin{cases} Pbestf(t), & \text{If } (fitness(Pbestf(t)) > fitness(Gbest(t-1))) \\ Gbest(t-1) & \text{Otherwise} \end{cases} \quad (2.4)$$

The method for finding Pbest and Gbest for minimization problem can be defined using following equations:

$$Pbestf(t) = \begin{cases} Pf(t), & \text{If } (fitness(Pf(t)) < fitness(Pbestf(t-1))) \\ Pbestf(t-1) & \text{Otherwise} \end{cases} \quad (2.5)$$

$$Gbest(t) = \begin{cases} Pbestf(t), & \text{If } (fitness(Pbestf(t)) < fitness(Gbest(t-1))) \\ Gbest(t-1) & \text{Otherwise} \end{cases} \quad (2.6)$$

where Pbestf,d(t) and Gbestd(t) denotes the personal best of fth particle and global best in dimension d at iteration t. Pf,d(t) denotes the position of fth particle in dth dimension at iteration t. fitness(x) computes the fitness of particle x by verify the suitability of solution. The flow chart of PSO methodology for optimizing the maximization problem is shown in figure 3.

Each Particle initialized with position and velocity, move in some direction in a given search space. This represents the first part of Eq. (2.1) and referred as momentum part. The movement of a particle is influenced by two parameters i.e. personal best knowledge (Pbest) and global best knowledge (Gbest).

The personal best knowledge (Pbest) represents the best value experienced by the individual particle so far which points out to the second section of that equation referred as "cognitive part". It motivates the particles to progress toward their own best positions found so far. The global best knowledge (Gbest) represents best solution in swarm achieved so far by any particle which indicates third part "cooperation or social" component. It motivates collective effect of the particles to find the global best solution. PSO algorithm works in this way to optimize problems.

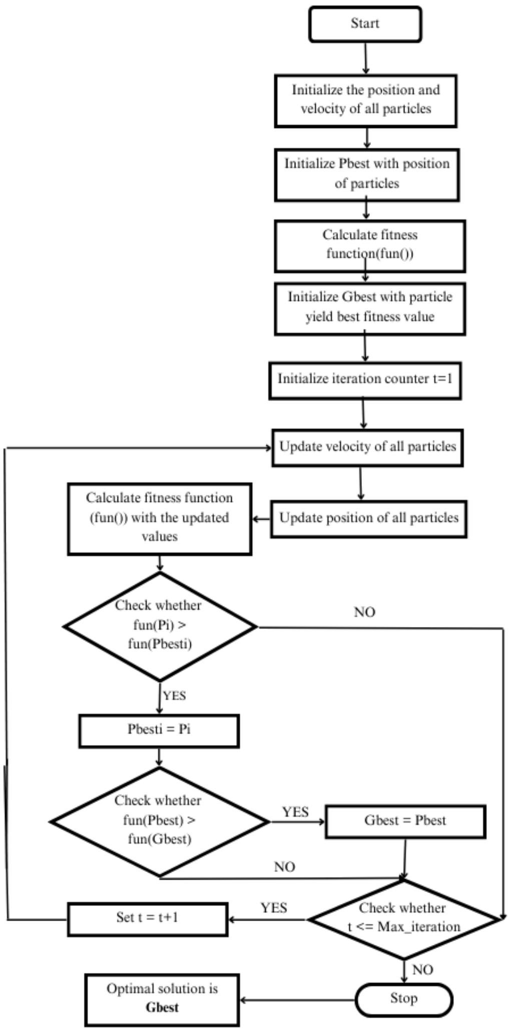

Figure 3: Flowchart of PSO methodology

Illustration: Let take maximization problem f(X1, X2), which has to be optimized. Objective is find the value of X1, X2 (a ≤ X1, X2 ≤ b) such that function f produces maximum value. Let there are 10 particles with 2 dimension (X1, X2) and T iteration count. The final output is best particle (best evaluation of fitness function) among all which gives best evaluation of given function. Let represent the particle Pi in the form which is as follows:

Pi = {Xi,1, Xi,2}

The fitness function f(Pi) represents the cost value of particle that evaluates the fitness of ith particle. Pbesti(t) denotes the personal best value of ith particle at particular iteration t, while Gbest(t) denotes the best or optimum solution at particular iteration t. The PSO algorithm for this maximization problem is as follows:-

Step 1: At iteration t=0, initialize the Vi,d (1≤ i ≤ 10, 1≤ d ≤ 2) and Xi,d for each particle with random values in range [a,b].

Step 2: Initialize the value of personal best value for each particle at iteration t= 0 i.e. Pbesti = Pi

Step 3: Calculate the fitness value for each particle by evaluating f(Pi) and initialize Gbest (best in swarm) with the particle which results in producing maximum fitness value in swarm.

Gbest = {Pbestk; such that f(Pk) = max{f(Pi); 1≤ i ≤ 10}}

Step 4: Initialize Iteration counter t=1

Step 5: Repeat the following steps from (i) to (iii) till t ≤ T

(i) for each particle, perform the action (a) to (d)
  (a) Update velocity using formula given in Equation (2.1)
  (b) Update position using formula given in Equation (2.2)
  (c) Calculate fitness value for each updated position
  (d) Evaluate the personal best value (Pbesti(t)) of each particle using formula given in Equation (2.3)
(ii) Evaluate the best particle of swarm (Gbest(t)) using formula given in Equation (2.4)
(iii) Check whether maximum iteration performed, if yes then go to step 6, otherwise go to step (iv).
(iv) Set t = t+1

(v) Step 6: Optimal solution of given problem is determined by getting the best particle in terms of Gbest(t) consisting both values.

STUDY OF PSO BASED ALGORITHMS FOR ENERGY EFFICIENT CLUSTERING IN WSNs

One of the major challenging and highlighting issues in WSNs is to preserve energy in sensor node. Clustering is one of the energy efficient techniques, where sensor nodes transmit the data to base station without consuming more energy. Various research works have been conducted and much more are in progress to determine energy efficient clustering algorithms in WSNs. The selection of cluster head, cluster formation and energy efficient data routing are the main parameters to achieve this goal. Particle swarm optimization (PSO) is a one of the popular nature-inspired intelligence technique, having the inspiration from bird movement in swarm. Ease of implementation, suitability of solutions, efficient computation and high convergence rate are advantages of using the PSO [8]. PSO method is used to solve various complex problems in every domain. The fitness function constructed for any given problem in PSO can be single objective or multi-objective. PSO based algorithms implement the concept of fitness function which evaluates the quality of solution whether fitness function can give best result of that given solution. Several parameters have been considered to derive fitness function while performing PSO based algorithms in WSNs. A good number of research works has been performed on PSO based different methods towards energy efficient clustering in WSNs. These algorithms are varied from each other in terms of their objectives, consideration of parameters in formulated problem, performance metrics, etc.

Latiff et al. [9] have proposed PSO based approach for energy-efficient clustering (PSO-C) in WSNs. This research works present the multi-objective function for selecting the cluster head on the basis of the average intra-cluster distance and energy efficiency of the network by considering the cluster heads left-out energy. Sensor nodes which are having energy levels above than average energy level of network are considered to be CH in initial phase of rounds.

Chang-jiang et al. [10] have proposed energy-balanced unequal clustering (EBUC) protocol with the idea of non-uniform distribution of sensor nodes into clusters and deploying the small sized cluster near to base station. The author explains idea behind is that cluster head situated near the base station experience the heavy inter-communication traffic load results in rapid energy depletion in these cluster heads. To balance this energy consumption, intra-cluster communication in these clusters is minimized. This work mainly emphasizes on implementation of PSO method for selecting the cluster head based on this principle followed by energy efficient multi-hop routing with the concept of relay node. In the initial phase, the cluster head selection is based on nodes having more energy than average energy of network. The selection of cluster head in further rounds depends on average intra-cluster distance, residual energy of all cluster head followed by cluster formation with optimum number of nodes.

Ruihua et al. [11] have presented PSO based clustering algorithm with the concept of double cluster head as master cluster head (MCH) and vice cluster head (VCH). Master cluster head performs the collection of data from member sensor node, aggregates the intra-cluster data and transmits to vice cluster head. Vice cluster head performs the data transmission to base station. The same fitness function is used for selecting both cluster head. MCH is selected as optimal solution found after completion of all iterations in algorithm, while VCH is selected as optimal solution found in previous iterations. The fitness function is derived on the basis of higher residual energy of nodes and minimum average intra-cluster distance. This paper emphasize on energy balancing of network by minimizing the energy consumption of cluster head by introducing the VCH.

Kuila et al. [12] have presented PSO based energy efficient clustering and routing algorithm. The concept of relay node has been used for routing the packet. In the initialization phase, next hop of each gateway is evaluated using some methodology instead of assigning randomly. Fitness function is constructed based on distance between neighbor gateway (cluster head) nodes and number of intermediate nodes required to transmit the data to base station. Fitness function is minimized to get the energy efficient route. The clustering is performed by base station after routing. Routing information is used for selecting the cluster head in initialization phase which is followed by constructing the fitness function. Maximizing the cluster head lifetime and minimizing the average intra-cluster distance are included in fitness function for selecting the energy efficient cluster head with the objective of maximizing the network lifetime. This paper elaborate CH lifetime factor as ratio of residual energy of CH to total energy spends by CH.

Elhabyan et al. [13] have introduced PSO based two-tier protocol (TPSO-CR) for optimizing the clustering and routing process. For selecting the cluster head, author suggested residual energy of sensor nodes, intra-cluster communication link quality (with reference to RSSI) and ratio of clustered nodes to un-clustered nodes for better coverage and scalability of network. For constructing the cost function for optimal routing path, participation of cluster heads as relay nodes, residual energy of relay nodes and link quality between relay nodes for reducing the packet loss ratio, have been suggested.

RejinaParvin et al. [14] have proposed E-OEERP protocol with the aim of preventing the residual nodes (nodes which are not part of any cluster). Fitness function for CH selection is based on energy efficiency of CH and distance from neighbor nodes. The concept of cluster assistant has been used for sharing the excessive load of cluster head.

Rao et al. [15] have proposed PSO based energy efficient cluster head selection algorithm called PSO-ECHS. In this research work, PSO algorithm has been implemented for cluster head selection and weight function is derived for effective cluster formation. The author derived two-objective fitness function for selecting the ideal cluster head. In the first objective, average intra-cluster distance and average sink distance have been considered. Average intra-cluster distance is computed as average distance of member sensor nodes from selected cluster head of their respective cluster and average sink distance is evaluated as ratio of inter-cluster distance to number of sensor nodes in respective cluster. Second objective of this fitness function has included total current energy of selected cluster heads. The first objective is minimized and second one is maximized to get optimal cluster head.

Azharuddin et al. [16] have proposed PSO based another methodology to discover the energy efficient and energy-balanced routing and clustering. The author has considered energy efficiency and energy balancing factor to get optimal route from gateway (cluster head) to base station. The energy efficiency factor is achieved by minimizing the transmission energy required by a gateway for sending the data packet to next intermediate node which results in discovering shortest inter-cluster distance. Energy balancing is achieved by assigning the more data forwarding load to those cluster heads which are having higher residual energy level. The optimal route information is required to perform clustering process. Fitness function for selection of cluster head is based on achieving maximum lifetime of gateway and reducing the intra-cluster distance by placing sensor node in nearest cluster head. The author has considered residual energy, inter-cluster and intra-cluster traffic for evaluating the cluster head lifetime.

Zhou et al. [17] have proposed a clustering protocol in WSNs based on improved PSO algorithm with the purpose of achieving the well-balanced clustering process. This paper demonstrates the concept of relay nodes which are situated between the cluster head (CH) and base station, to minimize the energy consumption of cluster head by sharing the transmission task. This work involves cluster setup and data transmission phase which are performed in each round. In cluster setup, cluster head and relay nodes are selected using improved PSO algorithm along with determination of transmission path from cluster head to base station. In data transmission, data is guided to base station. This paper basically focuses on selection of cluster head and relay nodes on the basis of multi-objective fitness function. Selection of Cluster head depends on residual energy of nodes and inter-cluster distance. The nodes with higher residual energy and having minimal distance to base station are selected as CH and then clusters are formed with equal distribution of sensor nodes to avoid network unbalancing. Relay node is selected on the basis of higher residual energy and best proximity to cluster head and base station. This paper tries to enhance the network lifetime by introducing the concept of relay nodes to minimize the energy consumption of cluster head.

Edla et al. [18] have introduced another particle swarm optimization (PSO) based routing algorithm with the purpose of enhancing network lifetime. This algorithm is having the goal of constructing the energy efficient route between gateways (cluster heads) and base station. A fitness function is derived using three-objectives. The first objective is the maximum distance between gateways to the base station as it is obvious that lesser the distance between gateways to the base station, lesser the energy consumption will be borne by gateways. The second objective is the number of relay nodes used by the gateway. The concept of relay nodes is defined which is number of intermediate hops between gateway and base station. More number of relay nodes indicates more intermediate gateways to deliver data to base station which results in more delay in delivering the packet. More delay in routing will have the impact of rapid energy depletion in gateways which results in reduction of network lifetime. The last objective is the relay load factor of the network. This factor determines number of times a gateway is involved as intermediate node for route the data and if this value is more than average relay load value of network, then gateway is considered to be equipped with extra load. This paper focuses on optimizing the routing path by minimizing all these factors.

Mehta et al. [19] have proposed multi-objective cluster head (CH) based energy efficient routing algorithm in which PSO algorithm is implemented to select the cluster head followed by Sailfish optimization method for finding the optimal route for transmission. This concept of unequal clustering is used for forming the cluster. The multi-objective fitness function is suggested for CH selection which is derived from proximity of sensor nodes with its neighbor, communication cost of sensor nodes with its neighbor node, residual energy of node and coverage of node. The proximity is defined in terms of distance between sensor and its neighbor nodes whereas communication cost is defined as average distance of node from its neighbor nodes. The first two objectives are minimized and later two are maximized to get proper cluster head. This algorithm focuses on energy balancing of network and wide network coverage.

Sahoo et al. [20] have presented PSO-ECSM protocol which addresses the issue of selection of energy efficient cluster head (CH) and sink mobility in heterogeneous WSNs (three different energy levels of sensor nodes) with the goal of enhancement in network lifetime. The fitness function for selection of CH depends on current energy level of node, average energy of node, distance between sensor node to base station, counting of neighboring nodes by evaluating the distance between nodes, and energy consumption rate. Sink mobility is another energy efficient technique to reduce the inter-cluster distance as base station (BS) move in trajectory path, consists of optimal points. Base station is moved through cluster region points to collect data from cluster head to maximize the lifetime of CH. The cost parameters for formulating sink mobility are residual energy of cluster head, distance between cluster head and sink and cluster size. The idea is to select optimal points in those clusters first in which CHs are having less residual energy, more number of member nodes and longer distance to base station. The base station is moved towards them in priority to save energy consumption in cluster head.

Loganathan et al. [21] have presented PSO based algorithm for selecting the energy efficient cluster head. Sensor nodes which are nearest to centroid point of sensing area, is selected for cluster head in initial phase instead of random ones. The fitness function for finding the optimal cluster head is based on average communication distance (average of distance of intra-cluster and inter-cluster communication), distance between sensor node and centroid point, residual energy of sensor nodes and clustering coefficient (connectivity of sensor node with neighbor). This research work also addresses the fault tolerance and energy balancing issue by selecting assistant cluster head and super cluster head which are responsible for aggregating & forwarding the data to super cluster head and forwarding the data to base station respectively. This paper also point out the extending the network lifetime by implementing multi-hop routing in intra-cluster communication.

Rawat et al. [22] have proposed PSO-EEC protocol for the purpose of selection of ideal cluster head (CH) and relay nodes to conserve the energy level of nodes and maximize the network lifetime. This research work involves selection of proper energy-efficient cluster head in clustering phase and selection of relay nodes (selected among CH) as intermediate hop for data transfer phase using PSO method. The fitness function for cluster head selection is based on residual energy of nodes, average intra-cluster distance and node degree (indicates number of nodes which are present within the radio range of node). The nomination of relay nodes for data transfer is based on residual energy of participating cluster head and inter-cluster distance. During data transfer, cluster heads transmit processed data to nearest relay node and this process continues till delivery of data packet to base station.

COMPARATIVE ANALYSIS OF PSO BASED METHOD FOR IMPLEMENTATION OF ENERGY EFFICIENT CLUSTERING IN WSNS

There are various concerned issues in wireless sensor networks (WSNs) for which they are being explored continuously by researchers. The main fundamental issue among all is limited energy life of sensor nodes for which various techniques have been introduced and much more are in progress. In the previous section, several research works on PSO based approaches for implementing the energy efficient clustering & routing, have been studied. This section draws attention on comparative analysis of those approaches on the basis of clustering objective, WSN type based on initial energy level of sensor nodes, sink movement, fitness parameters integrated in fitness function, performance metrics and simulation environment. The comparative analysis has been summarized in table 1.

Table 1: Comparative Analysis of PSO based different algorithms for Energy Efficient Clustering in WSNs

Author, Year	**Proposed Algorithm**	**Clustering Objectives**	**Sink Mobility**	**WSN type**	**Fitness Parameters**	**Performance Metrics**	**Simulation environment**
Latiff et al. [9], 2007	PSO-C	Network lifetime	Static	Heterogeneous	Intra-cluster distance, Residual energy of	Number of alive nodes, Throughput	Network Simulator NS-2

Author, Year	**Proposed Algorithm**	**Clustering Objectives**	**Sink Mobility**	**WSN type**	**Fitness Parameters**	**Performance Metrics**	**Simulation environment**
					cluster heads		
Chang-jiang et al. [10], 2010	EBUC	Network lifetime	Static	Homogeneous	Intra-cluster distance, Cluster head left-out energy, Ratio of inter-cluster distance to center-sink distance	Number of alive & dead nodes during each round	MATLAB
Ruihua et al. [11], 2011	PSO-DH	Network lifetime, Load-balancing	Static	Homogeneous	Cluster head residual energy, Intra-cluster distance	Residual energy, Number of alive nodes	OMNET++
Kuila et al. [12], 2014	PSO based clustering and routing	Network lifetime, Load-balancing	Static	Homogeneous	**Routing:** Inter-hop distance, Hop count **CH Selection:** Ratio of residual energy to energy consumption of cluster head, Intra-cluster distance	Network life, Energy consumption, Number of dead sensor nodes, Delivery of total data packets to the base station.	MATLAB
Elhabyan et al. [13], 2015	TPSO-CR	Network lifetime, Minimum routing delay,	Static	Both	**CH selection**: Residual energy, Intra-cluster communication link, Ratio of clustered to non-clustered nodes. **Routing:** Residual energy, Relay	Energy consumption, Packet Delivery Ratio, Throughput	OMNET++

Author, Year	**Proposed Algorithm**	**Clustering Objectives**	**Sink Mobility**	**WSN type**	**Fitness Parameters**	**Performance Metrics**	**Simulation environment**
					nodes link factor, Participation of cluster nodes as relay nodes.		
RejinaParvin et al. [14], 2015	E-OEERP (PSO based CH selection followed by GSA based routing)	Network lifetime, Load-balancing, Minimum routing delay	Static	Homogeneous	**CH Selection:** Energy of Cluster head & its neighbor cluster head, Distance between neighboring CH	Energy consumption, Packet delivery ratio, Throughput	NS-2.32
Rao et al. [15], 2017	PSO-ECHS (PSO based CH selection & weight-cost factor based cluster formation	Network lifetime	Static	Homogeneous	**CH Selection:** Average of intra-cluster and sink distance, Left-out energy of CH	Energy consumption, Network Lifetime, Throughput	MATLAB
Azharuddin et al. [16], 2017	PSO-based approach for energy efficient and energy balanced routing & clustering	Network lifetime, Energy-balancing, Fault-tolerance	Static	Partial-heterogeneous	**Routing:** Transmission energy, Residual energy of all CHs **Clustering:** Residual energy of CH, Average intra-cluster distance	Network lifetime, Throughput, Energy consumption, Energy balancing, Number of dead nodes	MATLAB

Author, Year	**Proposed Algorithm**	**Clustering Objectives**	**Sink Mobility**	**WSN type**	**Fitness Parameters**	**Performance Metrics**	**Simulation environment**
Zhou et al. [17], 2017	Clustering in WSN using an Improved PSO algorithm	Network lifetime	Static	Homogeneous	Residual Energy of CH, Inter-cluster distance	Energy consumption, Network lifetime, Number of Alive nodes	MATLAB
Edla et al. [18], 2019	PSO based routing	Network lifetime	Static	Homogeneous	Inter-cluster nodes, Intermediate hops, Relay load factor	Network Lifetime, Number of intermediate hops Average Relay Load	MATLAB
Mehta et al. [19], 2020	MCH-EOR (PSO based CH selection and SFO based data routing)	Network lifetime, Minimum routing delay	Static	Homogeneous	Proximity, Communication cost with neighbor, Residual energy, Coverage	Network lifetime, Number of alive & dead nodes, Energy consumption, Throughput, Packet delivery ratio	MATLAB
Sahoo et al. [20], 2020	PSO-ECSM	Network lifetime	Mobile	Heterogeneous	**CH selection:** Residual and average energy of node, Distance from node to sink, Proximity count, Energy Consumption rate	Stability period, Network lifetime, Number of dead & alive nodes, Remaining energy in network, Throughput	MATLAB
Loganathan et al. [21], 2021	PSO based Energy Efficient	Network lifetime, fault-tolerance	Static	Homogeneous	Intra & inter-cluster distance, Residual	Network lifetime, Number of alive nodes ,	MATLAB

Author, Year	**Proposed Algorithm**	**Clustering Objectives**	**Sink Mobility**	**WSN type**	**Fitness Parameters**	**Performance Metrics**	**Simulation environment**
	Clustering				energy of CH, Proximity to centroid, Cluster Coefficient	Energy consumption	
Rawat et al. [22], 2021	PSO-EEC	Network lifetime	Static	Heterogeneous	**CH selection:** Intra-cluster distance, Residual energy of nodes, Node degree **Relay node selection:** Residual energy of participating CH, Inter-cluster distance	Number of alive & dead nodes, Residual energy, Throughput, CH count	MATLAB

CONCLUSION

PSO method has been used extensively to cover the different challenging issues in wireless sensor networks. PSO based different approaches have been proposed by various researchers to find the energy-efficient clustering process. There is shift from conventional clustering methodology as current clustering process includes data routing in addition to data clustering. The selection of adequate cluster head, proper cluster formation and energy aware routing has been pointed out in these works. In this paper, we have reviewed the progress of PSO approach for the achieving energy efficient clustering in WSNs and performed the comparative analysis on the basis of analytical factors. Some works have included another methodology with PSO in which both speak about different objectives. The main concept of PSO is derivation of fitness function derived from various parameters called fitness or cost parameters. The main purpose behind each approach is to identify the correct fitness parameters for the given problem statement. The performance of these methods has also been evaluated using some performance metrics. Based on this study, it is concluded that these approaches provides more energy efficiency in terms of better network lifetime, than conventional approaches. Apart from this, these approaches aim to provide other clustering objectives like better load-balancing, network stability, minimum routing delay and better network coverage. In the future perspective in this domain, identification of more relevant cost parameters to address this issue and hybridization of PSO with other nature-inspired optimization techniques, helps in enhancing the network lifetime and can be more effective to achieve more clustering objectives in much efficient manner.

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