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# Energy Efficient Wireless Sensor Networks using Swarm Intelligence based Clustering and Data Aggregation: A Survey

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***Abstract:*** **- The Wireless Sensor Networks (WSN's) are the need of today's world in variety of applications. IoT and Fog are being the emerging and popular areas of application and research have sensor network as their basic foundation. The major research challenges in designing an IoT and Fog Computing based applications are to have the reduction in energy consumption, secured and aggregated data transmission, Routing, Handling massive scaling of IoT network, Handling Heterogeneous devices and platforms etc. Proper design of WSN plays an important role to deal with these issues. In literature many approaches are suggested and already implemented to handle the issue of energy efficiency in WSN. This paper gives the survey different types of swarm intelligence algorithms and explains how they are useful in wireless sensor network. The aim of this paper is to discuss in brief about the Swarm intelligence algorithms, to highlight the importance Particle Swarm Intelligence in clustering in WSN, to survey some of the techniques used previously for clustering, routing and data aggregation, and explains how PSO can be used in Clustering to reduce the energy consumption and balance the network load. Clustering is a non-deterministic polynomial time (NO) hard problems in WSN [1]. PSO particle swarm organization can be used to find fast and effective solutions in clustering and cluster head selection. Proper clustering, selection of good routing mechanism, effective data aggregation scheme can significantly reduce the energy consumption of the network and leads to increase in the life time of the network. [10]**

***Keywords*****: WSN, Energy Optimization, Swarm Intelligence, Clustering, Data Aggregation.**

## I. INTRODUCTION

The basic components of wireless sensor network are light-weight, low power, small sized sensor nodes and a Base Station. The sensor Network is formed by connecting the sensor nodes to a sink node which then further transmits the data to Base Station (BS). Sometimes Base station itself can work as a sink node. There are varieties of sensors used which are application dependent. The sensor nodes collect information from the environment and forward the same to sink node, which further forwards the aggregated data to BS or server. Some of the typical areas of applications of sensor networks are military, civil, healthcare, agricultural, environmental, industrial to commercial. The Nodes in sensor networks are having limited storage, computational power and energy resources. They are generally a battery powered devices. These restrictions place a limit on the types of mechanisms used for routing and deployment. According to their data transmission techniques Sensor networks are classified in two classes as event driven and continuous dissemination networks. This periodicity of communication impacts the routing strategy to be used and clustering. Routing the sensor data is an important task. In literature many techniques are suggested for routing and Data aggregation which leads to considerable energy saving and increase in lifetime [19], and minimum network resource usage [14]. Selection of proper routing mechanism leads to considerable saving of energy and load balancing in sensor networks. The primary focus of this paper is to highlight the importance of swarm intelligence algorithm and suggest some strategy to have significant amount of energy saving in WSN.

## II. BASIC TERMS

### *A. Basic Assumptions*

Basic Wireless sensor networks consist of two kinds of nodes:

1. Sensor nodes Sensor is an electronic component which can sense the environmental parameters like temperature, humidity, pressure, light etc. It is limited in processing power, energy, and memory.
2. Base Station (BS): It has more computational power, energy resources and communication mechanism. It works as a gateway between sensor nodes and server.

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In most of the applications sensor nodes are immobile. They use the direct or multi-hop transmission type of communication to communicate with the BS.
Sink node is a central node to which all sensors nodes have to send data. Most of the times BS is itself is a sink node. It can be stationary or Mobile depending on the application. Sensor nodes sense environment at a fixed rate and always has data to send to the Base Station at regular intervals.
The data to be send to BS can be sent in two ways First, they can directly send data to base station or Second, From Base station to Cluster head and then Cluster head to Base Station (Sensor – CH –BS) if cluster based routing is used.
Sensor nodes are aware of their residual energy and can revise their data to inform the BS about the transmission power of their wireless transmitter.
In cluster based communication one node is elected as cluster head (CH), Cluster head perform data aggregation and BS receives compressed data. The lifespan of WSN is the total amount of time before the first sensor node runs out of power.

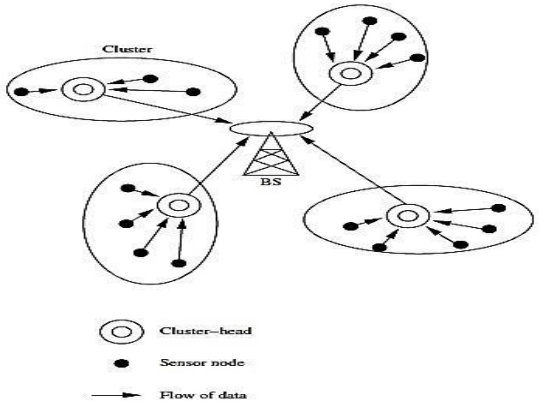


***Fig 1: Basic Sensor Network Architecture with Clustering.***

**B. Clustering**

In sensor networks, nodes will be organized in the form of a cluster within sensing range. This process is performed after deployment of a large number of nodes in the environment of a particular application. The clustering Schemes are classified as Heuristic based, Weighted, Hierarchical and Grid based Schemes [21]. In each cluster, one of the node is selected as a cluster head. Selection of cluster head and forming a cluster is an important step [7], [18]. There are many such clusters with cluster head and these cluster heads can communicate directly with base station [7], [9], [18].
These cluster heads generally will form a tree-based architecture that transmits collected data to base station using multi-hop or direct communication. If the system does not have better routing method, it will not be effective for reducing power consumption of nodes. Proper clustering should attempt to reduce the energy usage, and hereby increase network lifetime [21]. Clustering with adjustable sensing range is introduced in [9] where the parameters used are distance between the furthest node from base station, distance between nearest node from base station and maximum sensing range of the node [9].

***C. Cluster Head and Route Finding***

The CH collects the information coming from sensors in its own cluster, aggregates it using suitable aggregation functions and forwards the information to the BS. Sometimes the cluster heads are selected in every new round after a fixed time interval. By rotating the cluster-head randomly, energy consumption is expected to be uniformly distributed [19].
In each round of the cluster formation, network needs to follow the two steps to select cluster head and transfer the aggregated data [1], [7] [19].
(i) Set-Up Phase: In set-up phase Cluster heads are selected, clusters are formed and the routing tree is constructed if required, followed by a Steady State phase
(ii) Steady-State Phase: In this phase data transmission using Time Division Multiple Access (TDMA) is done [10]. In this Phase data is sent to the sink node.
Selection of cluster head depends on many parameters like its residual energy, neighbor density [7], distance from base station etc.
While selecting the cluster head the points to be considered are, Role of the Sensor nodes, Parameters for selecting Cluster Head, policy for Reselection of cluster Head and Re-initiation of Cluster formation process, selection of suitable method of communication i.e. Single hop or Multi-hop, checking whether the clusters are balanced and Ch are evenly distributed [13], [29].

Following are some Cluster Head selection Techniques,

Deterministic Schemes,
Base Station Assisted Adaptive Schemes,
Fixed parameter probabilistic schemes,
Resource adaptive probabilistic schemes,
Cluster head Selection in Hybrid Clustering [13].

Energy Efficient Cluster head selection in mobile wireless sensor networks are simulated in [13]. PASC-ACO is one of the algorithm designed using Ant Colony Optimization technique for hierarchical data dissemination and clustering [5].

***D. Data Aggregation***

In every Sensor Network the individual sensor nodes sense the information and send it to base station. In clustering data flows from sensors to Cluster Head (CH) and then CH to Base Station. Aggregation is performed to eliminate the duplicate data packets and network traffic. If similar type of data is gathered, forwarded by all the nodes, data redundancy increases, and unnecessary transmission of same data by multiple nodes badly utilizes the transmission

power of the devices. Hence some suitable aggregation functions are applied before forwarding the data.
The way of combining the data and compressing the data belonging to a single cluster is called as data fusion or Aggregation.
It reduces overwhelming traffic and enhances lifetime of network. Data aggregation allows the differentiation between sensed data and useful data the approaches used are: Tree Based, Cluster Based, Multi-Path, Greed Based [19].

**E. Sink Node Mobility**

In some applications Mobility of Sink node becomes an important factor to give best output. E.g. Military Surveillance, Habitat monitoring etc. Managing the Clusters and Cluster Heads with mobile Sink Node Mobility is a Challenge in WSN. SIDG-MS algorithm is been implemented to manage this issue [4] Also Data Aggregation with optimum route maintenance becomes difficult with mobile Sink node.

***F. Energy Efficiency and Load Balancing***

Nodes in sensor networks have restricted storage, computational and energy resources; these restrictions place a limit on the types of deployable routing mechanisms. Sensor networks can be divided in two classes as event driven and continuous dissemination networks according to the periodicity of communication. Routing of sensor data has been one of the challenging areas in wireless sensor network research. Tree Based Data Aggregation and Routing strategies can have considerable energy saving and increase in lifetime. [7] Cluster based hierarchical routing protocols is one of the solution to achieve energy efficiency. [5]. Chain based data integration and aggregation approach is implemented in [9].
Lot of work had already been done for improving energy efficiency in WSN using swarm intelligence based algorithms [1],[5],[7],[9],[10],[18,[19],[28] used many different parameters to improve the energy efficiency of the network. [1] Remaining energy of sensor node is the criteria of CH selection. Link Quality, Network coverage are the other parameters considered for clustering and improving energy efficiency. In [7] Energy consumed in different states and energy spent in different transitions is considered. In [19] had considered initial energy and residual of node, location of nodes as the parameters for CH selection. In [11] residual energy level of the nodes and hop count along the path towards sink are considered.

**G. Swarm Intelligence and applications in WSN**

**Swarm Intelligence**: It is a met heuristic technology and used for solving numerical optimization problems. It is based on collective behavior of various natural creatures and animals like ants, honey bees, birds, fish, Bacteria. Many different Routing protocols in wireless sensors are designed on the basis of the swarm intelligence. Two basic properties necessary for Swarm Intelligence behavior are Self organization and Division of Labor [6] Forging is the process followed by these creatures for finding food sources. It affects the animal's fitness and detects ability to survive and reproduce. Foraging theory is the branch of behavioral ecology.
Different types of Swarm Intelligence algorithms are

Ant Colony Optimization(ACO),
Bacterial Foraging Algorithm(BFO),
Artificial Bee Colony Algorithm (ABC),
Particle Swarm Optimization(PSO).

1) ACO : It is based on Ant's ability to find shortest path from their colony to the food source. It was introduced by Marco Dorigo in 1992 [30]. While searching for the food source ants walk through the surface and deposit a substance called Pheromone on the ground. Other ants which are able to smell the pheromone follow the strong pheromone concentrations and follow the path accordingly. The different ant deposit pheromones leading to a pheromone trail. After some time the path converges to a shortest distance path. Even if there is an obstacle or two paths available the choice of the selected path depends on concentration of pheromone [30]. This algorithm is applied in routing, Scheduling, assignment, machine learning problems [5].

**2) BFO**: It is based on social behavior of Escherichia Coli Bacteria[6]. It is introduced by Kevin Passino in 2002. It consists of four mechanisms.
Chemotoxis : Simulation of the movement of Ecoli cell through Swimming & Tumbling via Flagella. Swimming means moving in one direction and tumbling means alternate movements between two modes.
Swarming: When one cell stimulates high level of succinate release on attractive aspirate. Creating a team/ subsets with high bacterial density.
Reproduction: The healthier bacteria produces their own offspring in the same place and weakest bacteria eventually dies.
Elimination and Dispersal: It is possible that in the environment the population of bacteria is changed suddenly because of some other influence. Means bacteria may be killed or group of bacteria is dispersed near a good food source [6], [22].

**3) ABC**: It is based on the behavior of Honeybees. The algorithm was first introduced by Karaboga in 2005 [23]. Here the algorithm consist of Artificial Honey bees of three types: Employed Bees, Onlooker Bees, and Scout Bees [2].

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Employed Bees: Goes to food source found by them in previous step/ round. They share the food source information to recruit the onlooker bees.
Onlooker Bees: They select the food source. The decision about choosing the food source found by employed bees depends on fitness value. The higher probability of selecting any food source is dependent on the value of fitness function.
Scout Bees: They are selected from few emplyeed bees. They discard their food sources and search for new food sources randomly [14]. Here position of food source represents the solution, Nectar amount of food resembles the fitness value, and Number of employed and onlooker bees is the number of solutions in the population.

**4) PSO**: Is a population based Stochastic optimization technique developed by Eberhart & Kennedy in 1995. It is based on social behavior of bird flocking or fish schooling. It is somewhat similar to genetic algorithm but there are no operations like crossover and mutation. The basic principle is that "Group of birds randomly search for food in an area. There is only one food item available in the area. The birds do not know the exact location of food source but they know how far the food is in each iteration. So the best strategy is to follow the bird which is nearest to food source. [16] Here Birds are mapped as Particles which are nothing but each single solution. Food is the optimal solution, Each particle (Bird) is associated with a fitness value which are evaluated on the basis of fitness function to be optimized. The Velocity is considered as a parameter for flying (Searching the optimal solution) the particles in the problem space. The algorithm works in many iterations and during each iteration every particle is updated with two values,
Pbest : Best solution it has achieved so far,
Gbest: Best value obtained by any other particle so far in given population, it is tracked by an optimizer.

**Basic PSO Algorithm**
Pseudo Code [16] [17], [1]

For Each Particle in the Environment
Initialize Particle
End For
Do
For Each Particle Calculate the Fitness Value
If the Fitness Value is better than best Fitness Value (Pbest) obtained so Far set the current value as new Pbest.
End For
Choose the particle with best fitness value of all the paticles as Gbest.
For each particle
Calculate particle velocity according to
equation I
Update position according to equation II
End For
While the maximum number of iterations are performed or minimum error criteria is reached.
Initially each particle i is randomly assigned a position
P and a velocity V. In each iteration, every particle adjusts its velocity to follow two best solutions. First one is the its own best solution found so far is called as Pbest (Particles Best). This is the solution that has the highest fitness. Second value is the current best solution of the swarm's (Considering all particles participating in the Swarm) best solution called Gbest : Global best. After finding the two best values, particle i then updates both its position and velocity iteratively with the following equations:
**Equation I**
V [] = V [] + c1 * rand () * (Pbest [] - Present[]) +
c2 * rand () *(Gbest[] - Present[])
Equation II
Present [] = present [] +V []

V [] is the velocity,
Present [] is the current value of particle,
The parameters, c1 and c2 are two positive constant called as learning factors,
Usually set as c1 = c2 = 2,
rand () is the random value between [0, 1].

## III. LITERATURE SURVEY

There are many methods and approaches proposed in literature and been successful in terms of reducing the network energy consumption. The techniques suggested had used swarm intelligence in phases like clustering, Cluster head selection data aggregation which leads to energy efficiency in WSN. Some of the important work is given here.
LEACH(Low Energy Adaptive Clustering Hierarchy) and its variants, PEGASIS (Power Efficient Gathering In Sensor Information System) HEED (Hybrid Energy Efficient Clustering Aproach), UCR(Unequal Cluster based Routing protocol), TCAC(Topology Controlled adaptive Clustering), EBCAG(Energy Balanced Clustering approach for gradient based routing), EADC(Energy aware clustering algorithm with non uniform distributed nodes.), LECP-CP(Local Energy Consumption Prediction based Clustering Protocol) are the names of some protocols already designed for energy efficiency in WSN [9], [10].
[1] Riham S. Elhabym Mustapha C.E. Yagoub had suggested optimization protocol for clustering in WSN where the Clustering is done by Base station. Operating time is divided into rounds and each round into two phases, where it uses PSO. CH selection is based on properties like Energy efficiency, Link Quality, Network Coverage. They

mentioned future scope for Node Sleep Scheduling Protocol based on the coverage properties of network nodes. Multi hop link in clustering Approach can be used, which can enhanced the energy efficiency.

[2] M. Thangraj P PunithaPonmalar had used Swarm Intelligence in Secured Data Aggregation in WSN. Wherein Secured Hybrid Data Aggregation Tree Algorithm is implemented.

[9] Samayveer Singh, Satish Chand, Rajeev Kumar designed NEECP: Novel Energy Efficient clustering Protocol for prolonging lifetime of WSN's. wherin Energy distribution is improved. Implementation is divided into rounds and each round has two phases. The algorithm Selects Cluster heads with adjustable sensing range. Performs data Aggregation using Chaining Approach. (Redundant information is discarded at each new node in chain) Adjustable sensing range concept is used. ( The farthest node collects data from monitoring area and forwards it to its nearest node. The process continues till reaching the cluster head.) The drawback here is that Overhead of data aggregation at each node is increased. But each node consumes less energy since it passes data to nearest node. Also Mobility and heterogeneity is not considered.

[10] Saman Siavoshi, Yousef Kavian, Hamid Sharif designed Load Balanced Energy Efficient Clustering Protocol for WSN. They used the Concept of Virtual Circles with variable radiuses. Base Station is at the center. No GPS or other location finding equipment is used. Received signal strength is the indicator for the distance between nodes. Size of the Cluster increases with the increasing distance of radius from base station. Cluster head nodes are changed cyclically. Leader nodes are those nodes which can be next cluster heads. Load balancing and balanced energy distribution is achieved. But cannot be implemented in mobile Sink environment.

[12] Kavita Gupta Aarti Singh Maharishi Markandeshwar University, Mullana suggested An Improved Cluster Head Selection Algorithm for Mobile Wireless Sensor Networks. Hierarchical routing protocol and has also proposed a hybrid data fusion strategy for data aggregation. Proposes an algorithm for selection of new cluster head when the old cluster head moves out of its cluster and the current cluster is left unattended. The node with highest energy starts the election process by sending the message to nodes with higher energy. If node *i* get no response then it declare itself as CH

[13] Muhammad Arshad Muhammad Aasalem, Farhan Siddiqui, JazanUnivJazan, discussed about Energy Efficient Cluster Head Selection in Mobile WSN

[19] Binkal S Ahir, Rohan Parmar, Bintu Kadhiwala implemented Energy Efficient Clustering algorithm for data aggregation is WSN.Demonstrated how cluster head selection and data aggregation can be used in saving the energy of network. They designed EECAD protocol for this.

[16] Raghavendra V. Kulkarni Ganesh Kumar Venayagamoorthy surveyed Particle Swarm Optimization in Wireless Sensor Networks. Different PSO variants are discussed: PSO- Voronoi, PSGO, VFCPSO, PSO Multi Base, PSO-Loc etc. Localization is a one-time optimization process in which solution quality is more important than fast convergence.Data-aggregation is a distributed repetitive process moderately suitable for PSO. Effective Data-aggregation influences overall WSN performance. Data-aggregation needs frequent distributed optimization, and fast solutions

[20] Wei Zheng Di Luo discussed how routing can be done in WSNusing ABC, They implemented Delay Energy Trade off Routing Algorithm (DERA) and ABC is used for route optimization. Microsoft Equation or MathType Equation). "Float over text" should not be selected.

## IV. BASIC OUTLINE OF THE METHOD USED FOR ENERGY EFFICIENT CLUSTERING AND DATA AGGREGATION.

This section just gives an summarized overview of this method used in many references [1], [7], [9], [10], 19],[31]. The Algorithm work in two phases, Setup phase and Steady state phase,

**A) Setup Phase**

i. Each node in the sensor network broadcasts Hello Packet which includes its Identity.

ii. Every other node after receiving the hello packet stores the ID and RSSI (Received Signal Strength Indicator) or Residual energy value into its neighbor table.[10],[7]

iii. Every node broadcasts its ID and RSSI value and Neighbor table to Base Station.

iv. Base Station computes average energy level of all nodes and from all nodes which are having energy level above than average will be selected as candidates for Cluster head (CH).

v. From these candidates cluster heads are selected based on following parameters : Energy Efficiency, Link Quality, Network Coverage,[1],[7] Geographical Location to cover the network. All or Combination of some of the parameter can be used.

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(The goal of PSO here is to optimize the combined effect of all parameters)

vi. After selection of Cluster Head Nodes all other nodes will be informed and they have to join the appropriate CH to form a cluster. It is based on the distance from the cluster Heads. Closest CH is selected generally.

vii. All non clustered members will be assigned to appropriate CH by base station or they have to go in sleep mode.

**B) Steady State Phase**

viii. The CH declares TDMA schedule to transmit the data

ix. Sensor nodes send the data they had collected to CH based on TDMA Schedule.

x. CH aggregates the data and forwards it to base station. This can be done by following any one of the following approach: Query Driven, Event Driven, Continuous

xi. After transmitting the data nodes can enter into sleep mode.

The Setup phase and Steady state phase are performed in different rounds after a fixed time interval. Particle Swarm intelligence is used to select Cluster Heads by selecting and optimizing the effect of suggested parameters. Particle swarm optimization is used in step v in setup phase for selecting the cluster heads based on the combination of parameters used for optimization. In steady state phase the data aggregation and transmission policies define the effectiveness of the method in energy saving. To improve data aggregation for energy efficiency, as discussed in [19] cluster head's are selected as HCH (Head cluster head), This HCH can be elected based on the residual energy and distance from the other CH'. The CH closer to HCH will transmit the data to it. Policy can be set to determine total number of HCH to be set in a large network. This policy is useful because CH to BS transmission of data requires high power communication which is not feasible in large scaled network [19]. Advantage is that All cluster heads need not to communicate with the base station. Another approach that can be used is Chain based approach in which the CH will transmit the data to each other in a chain based method. If any of the CH is too far from the BS, it can transmit the aggregated data to its neighbor CH which is closer to BS and so on up to the data reaches to BS. Every time after receiving the data the next CH ensures to drop redundant data to save the energy. This approach is useful in event driven applications where network is scalable. In[9] during the steady state phase the data aggregation and transmission is implemented using Chain based and integration based approach. The duplicate packets were eliminated during the data transmission over the intra cluster chain[9], [19].

Third approach is hierarchical Tree based approach in which the predefined Tree is formed after CH and Cluster formation and data is aggregated through the predefined path only. In [10] a leader node concept is used where a leader nodes are selected in each cluster if the cluster size is large. These leader nodes send data from sensor nodes to CH. The leader nodes are chosen on the parameters like Centrality and residual energy. As this approach is suitable in static deployment where the applications where network size is average and nodes are stationary. Ant colony based hierarchical data dissemination is discussed in [5]. Information about the residual energy of the nodes is transmitted to BS along with the sensed data; Nodes can enter into sleep mode for fixed time interval or up to the occurrence of next event, after sending the data. Every node need not to communicate with base station [19].

## V. CONCLUSION

Since energy saving is a key constraint in battery driven sensor networks, from the literature survey it is observed that the proper cluster and cluster head selection and data aggregation strategy can improve energy efficiency in sensor networks. Hence it is observed that use of suitable parameters for optimization in clustering and cluster head selection, Selection of suitable method for data aggregation, integration and transmission definitely leads to energy efficient WSN. Particle Swarm intelligence is found to be effective in optimization when multiple parameters are available to decide about the selection of Cluster Head. However there are some applications in which sink node mobility is an important factor. Managing the cluster and Cluster heads, Data Aggregation with a mobile sink node is a challenge to design such methods. PSO algorithms require more memory hence it becomes difficult to be used in problems where optimization is to be done frequently. They are best suitable in static deployment of the network. So applying PSO in Mobile sink or dynamic environment applications is a major challenge.

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