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Maximizing Lifetime of WSNs using Duty Cycle Regulation via Adaptive Thresholding and Energy Aware Routing

by

Shikhar Basnet

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Computer System and Knowledge Engineering

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APPROVAL PAGE

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled "**Maximizing Lifetime of WSNs using Duty Cycle Regulation via Adaptive Thresholding and Energy Aware Routing**", submitted by **Shikhar Basnet** in partial fulfillment of the requirements for the degree of "**Master of Science in Computer System and Knowledge Engineering**".

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ABSTRACT

Wireless Sensor Network (WSNs) consist of hundreds to thousands of tiny sensor nodes equipped with sensing, data processing, and communication units. These sensor nodes are used to collect information about ambient environment, e.g. temperature, humidity, light, vibration, acoustic, etc. Due to these capabilities, WSNs can be applied in various potential applications such as target tracking, habitat monitoring, healthcare monitoring, surveillance, etc. However, to make WSNs feasible to be employed, a number of requirements in the design and operation of the network need to be satisfied. Since sensor nodes are powered by limited energy source, energy conservation is commonly considered the most key challenge in order to guarantee the connectivity of the network and extend the lifetime of the sensor nodes, especially when the deployment field is inaccessible, and battery cannot be replaced. This research is focused on improving lifetime of WSN by implementing adaptive thresholding while transmitting data, Fuzzy C-means (FCM) and sleeping scheduling based on Particle swarm optimization (PSO). This method aims to provide adequate sensing coverage area by balancing the energy load of the sensing and communication tasks among all the nodes in the network and putting some of the nodes into sleep state while other active nodes collect data. Simulation has been run and the performance has been compared with Low-energy adaptive clustering hierarchy (LEACH) and Minimum transmission Energy (MTE) which shows improvement of lifetime in network.

Key Words:

Wireless sensor network, Fuzzy C-Means, Energy- balance routing, Sleep Scheduling

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List of Abbreviations

WSN	Wireless Sensor Network
BS	Base Station
CH	Cluster Head
IoT	Internet of Things
LEACH	Low-energy adaptive clustering hierarchy
DC	Direct Communication
MTE	Minimum Transmission Energy
FCM	Fuzzy C-Means
PSO	Particle Swarm Optimization
GA	Genetic Algorithm
BPK-means	Balanced Parallel K-means
LDS	Linear Distance
DBSS	Distance based sleep scheduling scheme

CHAPTER ONE: INTRODUCTION

1.1 Introduction

Wireless sensor network (WSN) refers to a group of spatially dispersed and dedicated sensors for monitoring and recording the physical conditions of the environment and organizing the collected data at a central location. WSNs measure environmental conditions like temperature, sound, pollution levels, humidity, wind, and so on. Figure 1.1 shows the sensor nodes in a network.

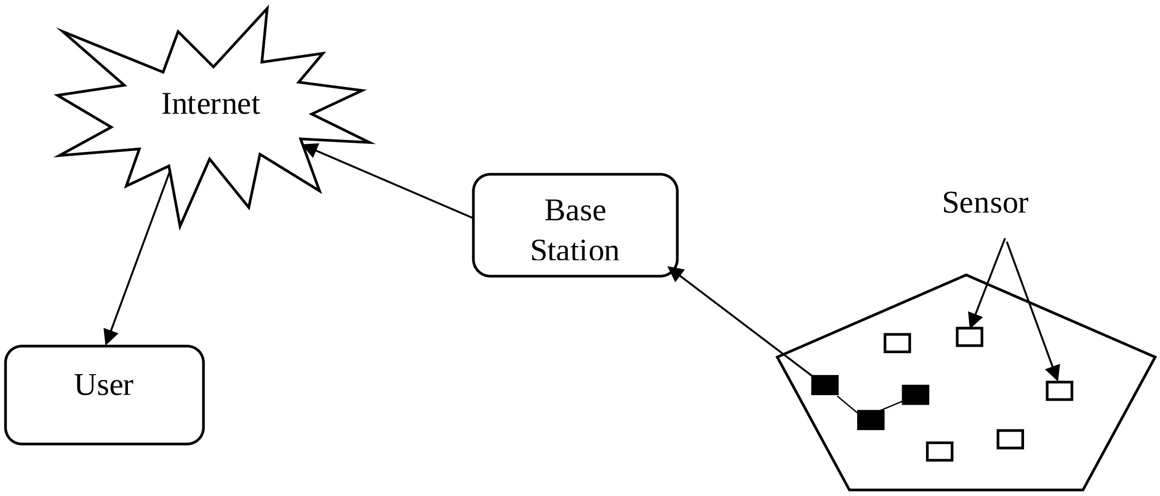

Figure 1.1: Wireless Sensor Network

These are similar to wireless ad hoc networks in the sense that they rely on wireless connectivity and spontaneous formation of networks so that sensor data can be transported wirelessly. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance; today such networks are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring, and so on [1].

The WSN is built of "nodes" – from a few to several hundreds or even thousands, where each node is connected to one or sometimes several sensors. Each such sensor network node has typically several parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting as shown in Figure 1.2.

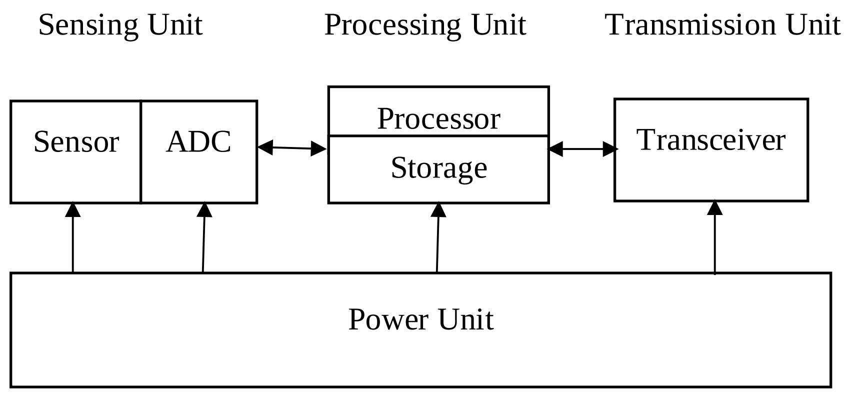

Figure 1.2: Sensor Node Components

WSN based systems are very scalable and flexible, which makes them suitable to observe and monitor various aspects of the physical world in different domains, such as agriculture, military, environment, civilian, health, home, security surveillance, assisted navigation and many other applications [2]. Wireless Sensor Networks (WSN) is also an important key technology to realize Internet of Things (IoT). Thus, huge volumes of data, is being generated by WSN in IoT. The number of active wireless connected devices is forecasted to grow rapidly. Due to the tremendous increment number of sensor nodes, the energy usage is also expected to grow more than double in the future.

In order to make WSNs feasible to be employed, a number of requirements in the design and operation of the network need to be satisfied. Since sensor nodes are powered by limited energy source, energy conservation is commonly considered the most key challenge in order to guarantee the connectivity of the network and extend the lifetime of the sensor nodes, especially when the deployment field is inaccessible, and battery cannot be replaced. Even if unlimited energy source like solar, wind, etc., is utilized, efficient operation of sensor networks is necessary because of the fluctuation and intermittent nature of these sources. It is also recognized that usually communication task consumes the most energy during the network operation. Thus, a new technique for reducing energy consumption through a combination of energy efficient routing protocol and energy balanced sleeping schedule is required to extend the lifespan of WSN.

Routing techniques

Routing techniques are classified into three categories based on network structure which are flat, hierarchical and location-based routing protocols.

1. In flat routing protocol, all sensor nodes are typically assigned equal roles and has the same functionality; sensor nodes collaborate to perform the sensing task as well as communication task.
2. In hierarchical protocol or cluster-based routing method, there are usually two types of sensor node: Cluster Head (CH) and non-CH nodes. Non-CH nodes mainly carry out sensing task and only send the information to the CH when necessary, while CHs collect data from other nodes and send to the end users.
3. In location-based protocol, routing data needs the information of sensor nodes locations in the deployed field.

Among these, hierarchical or cluster-based protocols are well-known techniques with special advantages related to scalability and efficient communication. The concept of hierarchical routing is utilized to perform energy-efficient routing in WSNs [3].

Sleeping Schedule

With all the nodes on the same working state at the same time, the data collected will be highly relevant and redundant, which will waste a lot of energy. And the competition of nodes in the same area for the channel will bring too many packet collisions. In the scenario with energy constrained sensor nodes, it is possible to selectively turn off some sensors when their neighbors can cover most of their sensing range. Therefore, one way to solve the challenges is to schedule the sensors to take turns working. Sensors in most sensor network systems operate in two states: an active state and a sleep state. In the active state, a sensor node can detect events happening in its sensing range, transmit and receive data. In the sleep state, a sensor node enters an energy-saving mode and does not take part in most of the activities. When a sensor node is put into the sleep state, it completely shuts itself down, leaving only one extremely low power timer on to wake itself up at a later time [4].

1.2 Problem Statement

In terms of cost, the sensor nodes are very effective but in terms of energy efficiency, a sensor node lacks efficiency of energy when broadcasting the data from the sensor node. Due to the low energy efficiency, the life of sensor node decreases. So a use of low-energy algorithm, sleep scheduling and an energy efficient routing algorithm is required for power saving in wireless sensor network.

1.3 Objectives

The objectives of thesis are:

- Improve lifetime of WSN by implementing Fuzzy C-means, Particle swarm optimization and duty cycle regulation via adaptive thresholding.
- To seek for performance optimization in terms of energy for wireless sensor nodes.

CHAPTER TWO: LITERATURE REVIEW

Wireless Sensor Networks has been demonstrated in various application scenarios. Many strategies have been proposed for energy conservation through low power circuit design [5] and reduction of power usage of microcontroller [6]. However, there are constraints in hardware techniques due to limited power budget if not supported by signal processing and low power algorithm.

Different protocols related to the clustering routing has also been proposed in WSNs. Low Energy Adaptive Clustering Hierarchy (LEACH) [7] is a typical cluster-based protocol using a distributed clustering formation algorithm. The cluster heads are selected with a predetermined probability, other nodes choose the nearest cluster to join, and based on the strength of the advertisement message they received from the cluster heads. After forming the clusters, cluster heads compress data arriving from the sensor nodes and send an aggregated packet to the BS in order to reduce the amount of information sent to the BS. Although, the lifetime of the sensor nodes and the network is significantly increased, there are still some issues with LEACH. The random selection of the CH may obtain a poor clustering set-up, and CHs may be redundant for some rounds of operation. Another technique popularly used to cluster sensor network is k-means. In [8], the authors proposed a Balanced Parallel K-means (BPK-means) based clustering protocol based on k-means algorithm. BPK-means protocol is developed to reduce energy consumption of the sensor node during communication with the CHs. However, with the random deployment of the sensor nodes in an unattended field, hard partitioning the network by means of using k-means algorithm may result in vagueness of classifying sensor nodes near the boundary of the clusters, thus, the optimization of cluster formation is not obtained.

Although clustering can distribute the management from the base station to the cluster head, the limited resource of sensor nodes is another important problem in wireless sensor network. One way to solve the challenges is to schedule the sensors to take turns working. There are some sleep scheduling schemes discussed in clustering sensor network. In [9] the linear distance-based scheme for cluster based high density network has been discussed. The nodes farther away from its CH have higher probability of sleeping in this scheme. The same author in [10] pointed that LDS scheme may cause uneven consumption of energy among nodes and thus it may cause uneven lifetime in the cluster. In [11] distance-based sleep scheduling scheme (DBSS) in heterogeneous sensor network have been proposed. The work is motivated from the LDS scheme. The results of DBSS have demonstrated improvement over heterogeneous sensor network [12] in terms of energy efficiency. In [13] author proposed an optimal sleep scheduling scheme based on the length of buffer-queue. The packets may continue to arrive at the nodes buffer during the sleep periods, the node cannot transmit them until it wakes up, when it reaches a threshold its control policy force the queue empty out and resume to work after a vacation period. However, these works have not balanced the energy consumption, coverage rate and overlapping rate. In recent studies, duty cycle method to reduce energy consumption of sensor nodes has been proposed. [14] Described a dynamic duty cycle method, to optimize the sleep scheduling of sensor nodes according multiple criteria which are distance to base station, residual energy and backlog queue. Meanwhile, an algorithm to minimize power consumption of sensor nodes through low duty cycle and reduce the delay caused by low duty cycle mode is proposed in [15].

In this research, use of adaptive duty cycle, energy efficient routing and energy balanced sleeping schedule is proposed to increase the lifetime of the network. Duty cycle with adaptive thresholding based on Hampel filter, energy efficient routing will be incorporating fuzzy c-means clustering and energy balanced sleeping schedule based on particle swarm optimization will be used to manage the number of active nodes in the network.

CHAPTER THREE: RESEARCH METHODOLGY

The system consists of a network of multiple wireless sensor nodes. It will enable local data sensing. The base station computes and allocates sensor nodes into clusters according to the information of their location and the cluster head is assigned to the node having the largest residual energy. Each of the nodes of cluster transmits data to the cluster heads where data is aggregated and sent to base station.

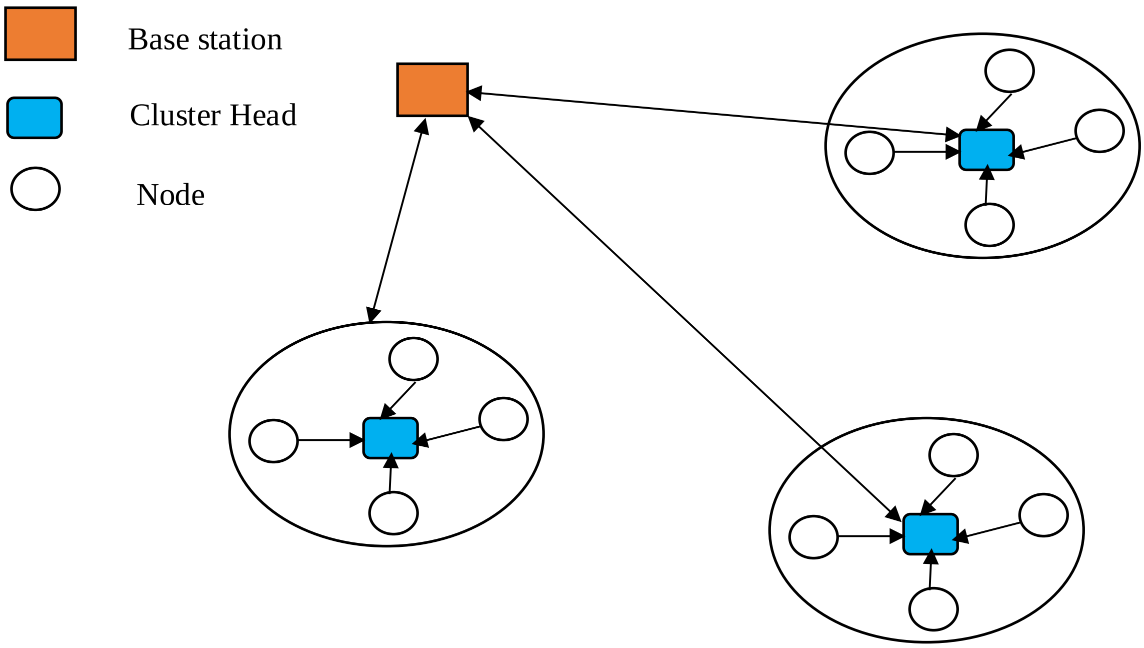

Figure 3.1: - Architecture of the Network

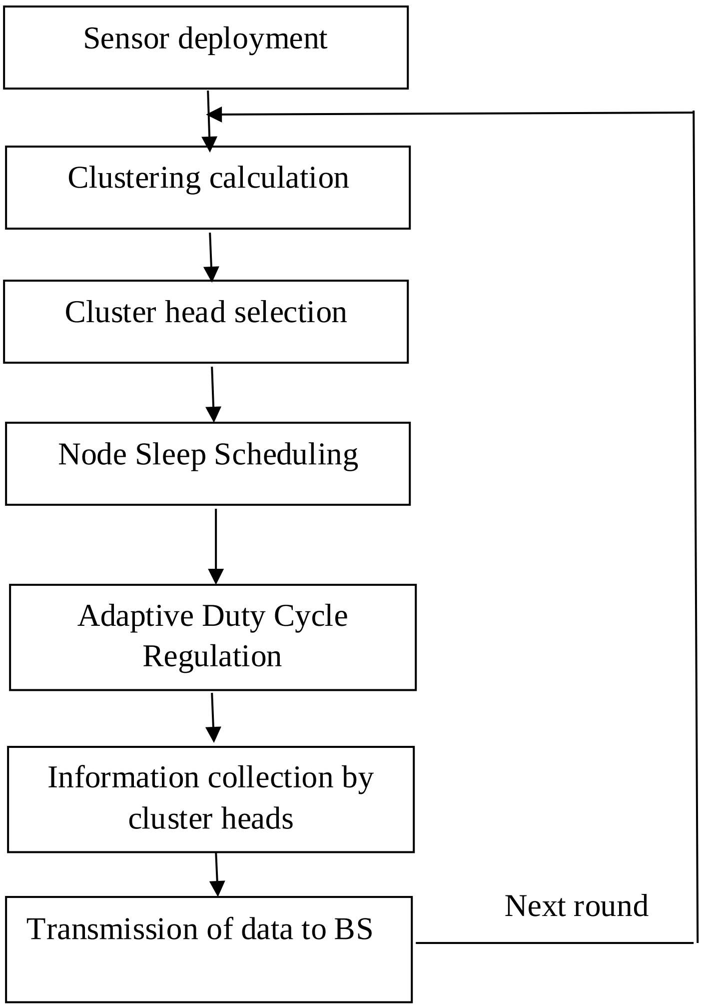

Figure 3.2: A Schematic block diagram of the system

3.1 Sensor Deployment

Sensor nodes are deployed in an area where it is used to collect information about ambient environment. In this work, it is considered the energy consumption of the sensor nodes for communication within the network as it takes the most energy expenditure. Both the free space and multipath fading channel models are used to compute energy dissipated during the process of transmitting and receiving information. The energy consumption for transmitting an l bit message over a distance d is

$$E_{Tx} = E_{elec} * l + E_{fs} * l * d^2 , d < d_0 \quad (3.1)$$

$$E_{Tx} = E_{elec} * l + E_{mp} * l * d^4 , d \geq d_0 \quad (3.2)$$

and for receiving this message respectively is:

$$E_{Rx} = E_{elec} * l \tag{3.3}$$

Where E_{elec} is the energy spent to operate the transceiver circuit, E_{fs} and E_{mp} are the energy expenditure of transmitting one bit data to achieve an acceptable bit error rate and is dependent on the distance of transmission in the case of free space model and multipath fading model. If the transmission distance is less than a threshold d_0, the free space model is applied; otherwise, the multipath model is used. The threshold d_0 is calculated as

$$d_0 = \sqrt{E_{fs}/E_{mp}} \tag{3.4}$$

Another parameter is also taken into account is the data aggregation energy expenditure. Considering a N node network partitioned into c clusters, the average number of nodes in a cluster is N/c, the energy consumption of the CH to receive message from the non-cluster head is

$$E_{Tx-CH} = lE_{elec}\left(\frac{N}{C} - 1\right) \tag{3.5}$$

and to aggregate data into a l-bit message and send it to the BS is

$$E_{Tx-CH} = lE_{da}\frac{N}{C} + lE_{elec} + lE_{mp}d_{to\ BS}^4 \tag{3.6}$$

Where $d_{to\ BS}$ is the average distance from one CH to the BS. Assuming that the distance from the non-cluster head node and the CH is short, the energy consumed by the non-cluster head node to transmit a l-bit message is

$$E_{Tx-nonCH} = lE_{elec} + lE_{fs}d_{to\ CH}^2 \tag{3.7}$$

Where $d_{to\ CH} \approx \frac{1}{2\pi}\frac{M^2}{c}$ which is the average distance from one node to its CH and M is the network diameter. Thus, the total energy dissipated in the network during a round of collecting data and transmitting to BS is

$$\begin{aligned} E_{round} &= l\left(2N\ E_{elec} + N\ E_{da} + cE_{mp}d_{to\ BS}^4 + N\ E_{fs}d_{to\ CH}^2\right) \\ &= l\left(2N\ E_{elec} + N\ E_{DA}cE_{mp}d_{to\ BS}^2 + N\ E_{fs}\frac{1}{2\pi}\frac{M^2}{C}\right) \end{aligned} \tag{3.8}$$

This total energy expenditure consists of the average energy dissipated by data transmission of non-cluster head nodes and CHs and the energy consumption for data collection and fusion of the CHs.

3.2 Routing Techniques

3.2.1 Cluster Calculation and cluster head selection using Fuzzy C-Means (FCM)

FCM clustering protocols is centralized clustering algorithms, the base station computes and allocates sensor nodes into clusters according to the information of their location and the cluster head is assigned to the node having the largest residual energy. A network of N sensor nodes is considered which is partitioned into c clusters: C_1, C_2... C_c. The purpose of the cluster formation in this protocol is to minimize the following objective function

$$J_{M}= \sum_{I=1}^{C}\sum_{J=1}^{N} U_{ij}^{m}\, d_{ij}^{2} \quad (3.9)$$

Where u_{ij} is node j's degree of belonging to cluster I. d_{ij} is the distance between node j and the center point of cluster I. The degree u_{ij} of node j respected to cluster is calculated and fuzzyfied with the real parameter m >1 as below.

$$u_{ij} = \frac{1}{\sum_{k=1}^{c}\left(\frac{d_{ij}}{d_{kj}}\right)^{\frac{2}{m-1}}} \quad (3.10)$$

The distance between the sensor node and the center point is Euclidean distance. By achieving minimization of the spatial distance, the energy balance among sensor nodes is optimized. FCM clustering protocol include 3 phases: clustering calculation, cluster head selection and data transmission. The operation of the protocol is partitioned into rounds where after certain interval of time the cluster calculation process is invoked. In each round, the cluster heads collect data from all cluster members and transfer to the BS.

3.2.1.1 Clustering calculation

N sensor nodes are deployed randomly into a field with an area of $M \times M m^2$. After being spread out, these sensor nodes send a HELLO message to the base station with the information of their geographical location; based on this information the base station will calculate the cluster centers and allocated sensor nodes into cluster using FCM algorithm. In the case of this application, FCM algorithm is applied to cluster the sensor nodes. Each node is assigned a degree of belonging to cluster head rather than completely being a member of just one cluster. Therefore, the nodes close to the boundary of a cluster may become members of the cluster with a degree approximating the degree of belonging to the neighbor clusters. The convergence is achieved when the difference between the coefficients in two iterations is less than a threshold or a large number of iterations is reached. After forming the clusters, the BS chooses the nearest nodes to cluster centers to become CH. Once the cluster creation is complete, base station send the information of the cluster head and to which cluster a node belongs to all of the nodes. Following formula is used to identify the number of clusters.

$$C_{opt} = \frac{\sqrt{n}}{\sqrt{2*\pi}} \sqrt{\frac{E_{fs}}{E_{mp}}} \frac{M}{d_{to\ BS}^{2}} \tag{3.11}$$

3.2.1.2 Cluster head selection

Once the cluster is created, the non-cluster head nodes send data toward the base station through the cluster heads. The process of selecting clusters is repeated every round of exchanging data among sensor nodes. Only at the first stage, the cluster head of each cluster is chosen by the base station; after that the current cluster head makes decision of selecting which node will become the cluster head at the next round. During the transmission from the sensor nodes to CH, residual energy of each nodes are attached to the data packet, this information assists the CH choose the node with the highest residual energy and nearest to the cluster center to be cluster head at the next round. The operation of re-clustering and data transmission continues for many cycles until the death of all the nodes. If the size of the cluster is smaller than the predefined threshold, the cluster merges with the neighboring clusters.

3.2.2 Low-energy adaptive clustering hierarchy

The operation of LEACH is broken up into rounds, where each round begins with a set-up phase, when the clusters are organized, followed by a steady-state phase, when data transfers to the base station occur. In order to minimize overhead, the steady-state phase is long compared to the set-up phase.

3.2.2.1 Advertisement Phase

Initially, when clusters are being created, each node decides whether or not to become a cluster-head for the current round. This decision is based on the suggested percentage of cluster heads for the network and the number of times the node has been a cluster-head so far. This decision is made by the node n choosing a random number between 0 and 1. If the number is less than a threshold T (n) the node becomes a cluster-head for the current round. The threshold is set as:

$$T(n) = \begin{cases} \frac{1}{1-P*\left(r \bmod \frac{1}{p}\right)}, & if\ n \in G \\ 0, & otherwise \end{cases} \tag{3.12}$$

Where P the desired percentage of cluster heads, r the current round, and G is the set of nodes that have not been cluster-heads in the last $\frac{1}{p}$ rounds. Using this threshold, each node will be a cluster-head at some point within $\frac{1}{p}$ rounds.

Each node that has elected itself a cluster-head for the current round broadcasts an advertisement message to the rest of the nodes. The non-cluster-head nodes must keep their receivers on during this phase of set-up to hear the advertisements of all the cluster-head nodes. After this phase is complete, each non-cluster-head node decides the cluster to which it will belong for this round. This decision is based on the received signal strength of the advertisement.

3.2.2.2 Cluster Set-Up Phase

Each node has decided to which cluster it belongs, it must inform the cluster-head node that it will be a member of the cluster. Each node transmits this information back to the cluster-head. During this phase, all cluster-head nodes must keep their receivers on. The cluster-head node receives all the messages for nodes that would like to be included in the cluster.

3.2.3 Direct communication and Minimum transmission energy

In case of direct communication each sensor sends its data directly to the base station. If the base station is far away from the nodes, direct communication will require a large amount of transmit power from each node. In case of MTE the base station decides the next-hop for every node using Dijkstra's algorithm. Then it broadcasts this information to all network. This function builds a graph with weights/cost related to each pair of network based on which the data is transmitted from node to base station. Data will have to go through n transmissions and n receptions before it reaches the BS.

3.3 Node Sleep Scheduling

As selecting several sensor nodes to sleep is a combinatorial optimization problem, an approximation algorithm can help to solve this problem. An adaptive discrete Particle Swarm Optimization (PSO) is used to select the sleeping nodes. This algorithm takes both energy balance, coverage rate and overlapping rate into consideration to extend the lifetime of the network.

3.3.1 The Presentation of Particles

The dimension of particle is equal to the number of the sensor nodes in the cluster [4]. Each dimension is randomly initialized in the range [0...1]. If the random number is larger than the sleep probability, the dimension of the particle will be set 1, and the corresponding sensor node is selected to active; otherwise it will be set 0, and the corresponding sensor node is selected to sleep. The sleep probability pro of a sensor node is defined as following. Each particle is initialized with the defined sleep probability.

$$\text{Pro} = e \times \left(\frac{I_n - 1}{I_n}\right) + f \times \left(\frac{D_c - 1}{D_c}\right) \tag{3.13}$$

Where e, f are constants, which satisfies that e + f = 1, D_c is the distance of the node to the cluster head, I_n is the number of neighbor nodes within the distance of d ($I_n \geq 1$), $0 < D < R_s$. The sleep probability that a sensor node is selected to sleep depends on the distance it is located from the cluster head and the number of neighbors, lowering the variation of energy consumptions by all sensor nodes.

3.3.2 The parameter setting

Inertia weight of PSO algorithm has been proved to be an important parameter that can control exploration ability and the convergence of the PSO. Small inertia weight is conducive to local search, while great inertia weight is good for global search. Therefore, the inertia weight should decrease while the iteration goes on. The traditional linear decreasing inertia weight strategy is adopted for this purpose.

3.3.3 The Updating of Particles

In the basic PSO algorithm, there are three parts: the inertia part, the personal cognition part and the social cognition part. To conquer the phenomenon of premature stagnation and inspired by the GA, the notion of mutation operator and crossover operator is incorporated. Different from GA, there is only a new particle generated after crossover operation in EBSS-PSO to ensure that the size of population remains unchanged. The velocity and position of the particle updated using following equation.

$$V_i^{t+1} = wV_i^t + c_1(P_i^t - X_i^t) + c_2(G^t - X_i^t) \tag{3.14}$$

$$X_i^{t+1} = V_i^{t+1} + X_i^{t+1} \tag{3.15}$$

Where G^t is the global best position, P_i^t is the previous best position, X_i^t is the current position, w is the inertia weight, c_1 and c_2 are the accelerating factors.

3.3.4 Fitness Value Function

Sleep scheduling schemes can effectively reduce the total energy consumption in the network. Most of the scheduling schemes have not taken the energy balance into consideration. Then the coefficient of variation of sensor nodes' energy consumption may be relatively high. This is not desirable for sensor networks, as one of the design goals of the sleep scheduling scheme is to extend the network lifetime. Unbalance energy consumption will shorten the lifetime of the overall network. If a certain fraction of the sensor nodes in the network consume much more energy than others, the batteries of these sensors die out quickly, greatly affected the performance of the network. Therefore, for fitness value function, the remaining energy is taken into consideration. Another aim of this approach is to decrease the overlapping rate while maintain the coverage in the network. The higher overlapping ratio the network has, the higher relevant and redundant the collected data will be, which will waste a lot of energy. Moreover, the redundant data will increase the communication cost of the network and the competition for the channel. Hence the coverage rate and the overlapping rate have been incorporated into the fitness value function.

$$fit = \propto \times \left(1 - \frac{\sum_{i=1}^{k} E_{ci}}{\sum_{i=1}^{k} E_{mi}}\right) + \frac{\beta}{R_{cover}} + \lambda \times R_{overlap} \tag{3.16}$$

Where ∝, β, λ are constants and ∝ + β + λ = 1; k is the number of sensor nodes in the current cluster; E_{ci} is the remaining energy of node i, which is in the active state, in the current cluster. And E_{mi} is the initial energy of node i. With more remaining energy, the population will have better fitness value, which will effectively balance energy consumption in the network; R_{cover} is the coverage rate of the cluster; $R_{overlap}$ is the overlapping rate in the current cluster. In this fitness value function, population with higher coverage rate and lower overlapping rate will has better fitness value.

3.4 Adaptive Duty Cycle Regulation

To ensure the sensor nodes could adaptively adjust the frequency of sending sensor data to master node according to the time-series trend of data, Adaptive Duty Cycle has been used. Each of the nodes collects data from its ambient environment. Continuous transmission of data is not required as there is very small variation in the collected data. So, the data are stored in buffer and are transmitted only in case if there is large variation in data or the buffer is full. The threshold to determine the variation of data is calculated based on current trends of sensor data. Hampel filter has been used to detect this. For collected data, the median of a window composed of the data and its six-surrounding data, three per side is calculated. The standard deviation of each data about its window median using the median absolute deviation is also computed. If the data differs from the median by more than 3 standard deviation it is treated as variation and the data that is being stored in the buffer is send to the cluster head. Otherwise the nodes keep on collecting and storing the data in buffer until the buffer is full before sending the data.

3.5 Collection and transmission

The cluster head gathers information from all the active nodes in the cluster and sends the aggregated information to the base station. Once the data has been transmitted, current CH chooses a new head based on highest residual energy and nearest to the cluster center.

CHAPTER FOUR: RESULT AND ANALYSIS

In this work it is assumed that the sensor has been deployed in area of 250 x 250 m^2 with base station at its center. The simulation is done using pymote due to its rich scientific functions' library and strong support for scientific computing and calculations. Following assumptions [3] are made about the senor network

1. Sensor nodes as well as base station are stationary after being deployed in the field.
2. The network is considered homogeneous and all of the sensor nodes have the same initial energy.
3. A sufficient number of sensor nodes are deployed over a sensing field such that some sensor nodes can go into the sleeping mode without degrading the sensing coverage of the network.
4. Each sensor node belongs to the same cluster throughout the current round.
5. All nodes have both cluster head and sensing mode, and each node performs sensing tasks periodically.

Simulation parameters and value used in simulation are mentioned in Table 1. The result obtained from the simulations are explained below.

Table 1: Parameters used in simulation [3]

<table>
<tr><th colspan="2">Simulation Parameters</th><th>Value</th></tr>
<tr><td colspan="2">Electronics Energy (E_{elec})</td><td>50nJ/bit</td></tr>
<tr><td colspan="2">Data Aggregation Energy (E_{da})</td><td>5nJ/bit</td></tr>
<tr><td colspan="2">Number of Nodes (N)</td><td>300</td></tr>
<tr><td colspan="2">Sensing Area (m^2)</td><td>(250 x 250)</td></tr>
<tr><td>CH to BS</td><td>Amplification Energy ($d < d_0$)
Amplification Energy ($d \geq d_0$)
d : transmission distance
d_0: threshold</td><td>E_{fs} = 10pJ/bit/m^2

E_{mp} = 0.0013pJ/bit/m^2</td></tr>
</table>

4.1 Results and analysis

➢ Deployment of sensor nodes (● represent nodes and ■ represent BS)

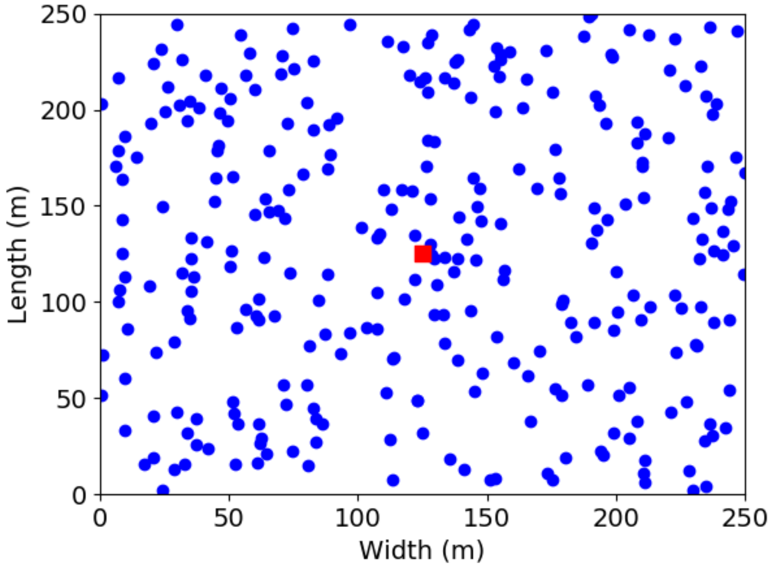

Figure 4.1: Deployment of sensor nodes

The sensor nodes have been deployed randomly in area of 250 x 250 m^2 .300 sensor nodes have been deployed with initial energy of 2J node each. Once the sensor nodes are deployed each of the sensor nodes begin sensing data periodically. Each sensor nodes can operate either in sensing mode to monitor the environment parameters and transmit to the base station or cluster head mode to gather data, compress it and forward to the base station.

FCM protocol has been used to divide the senor network into cluster with a degree of belonging to each cluster rather than hard partitioning them into only one cluster. At the beginning when all nodes are alive, the number of clusters created is five which is the optimum number of clusters. Once cluster has been created, the nodes that is present in the centre of the cluster and nearest to base station is selected as the cluster head. The created cluster head is responsible for collection of data from its cluster nodes and transmitting it to the base station. This way traffic load is balanced among the cluster heads in the global network and energy consumption is balanced among sensor nodes in the local cluster. After each round of 20s, the current cluster head selects new cluster head based on largest residual energy of the nodes. With the start of the death of nodes, there are a lesser number of nodes present in each cluster now. Thus, as the number of alive nodes starts decreasing with cycles, the number of clusters also decreases, and the decrease in the number of alive nodes eventually results in the reduction in the number of clusters. In case when the elected cluster head dies, the base station starts the process of cluster head selection when no transmission occurs from elected cluster head for a certain interval of time.

➢ Coverage rate increases with increase in number of nodes.

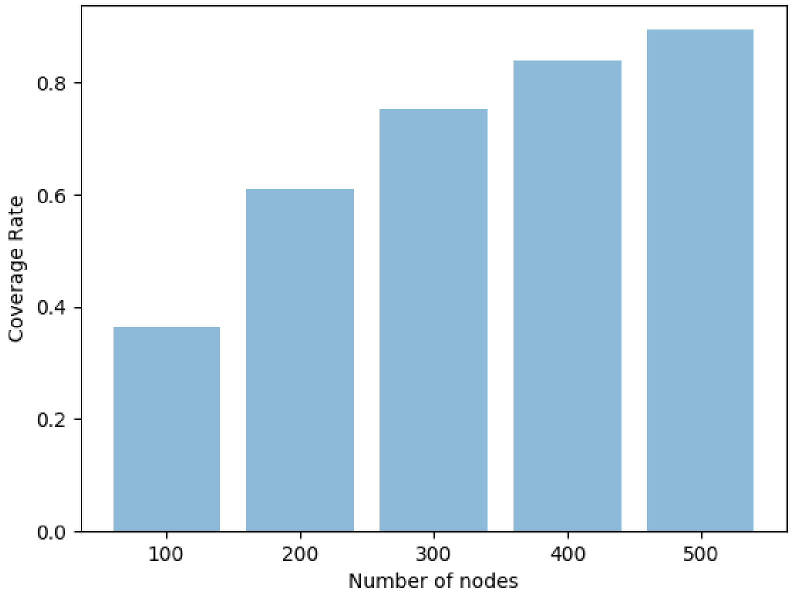

Figure 4.2: Coverage rate of network

Here the simulation has been run with different numbers of sensor nodes distributed in the network area, from network with 100 nodes to that with 500 nodes. From the Figure 4.2 it is observed that as the nodes in the network is increased after implementation of energy efficient sleeping schedule, the coverage area is improved. With increase in number of nodes in network, the overlapping area is increased between nodes due to which redundant information is obtained from neighbour nodes. Hence, more number of nodes can be put into sleep mode without affecting the coverage area of the network.

- Sleeping rate decreases with increase in number of nodes

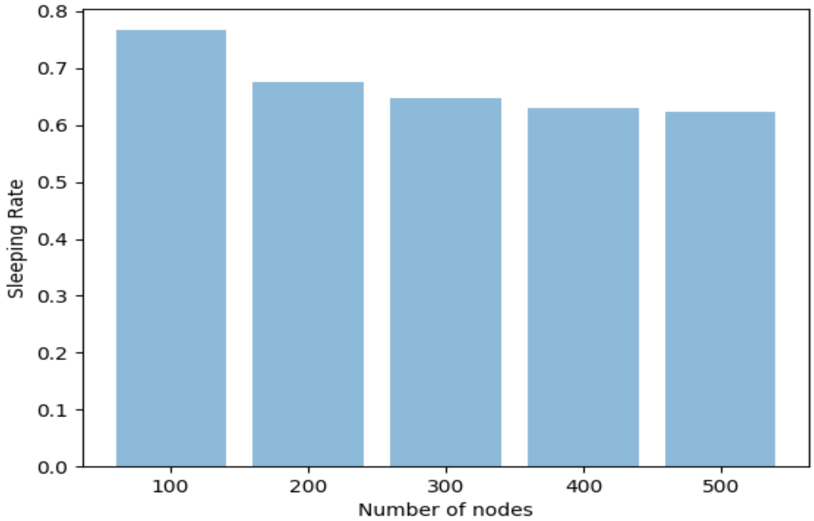

Figure 4.3: Sleeping rate of network

Sleeping rate is the rate of the active sensor nodes after scheduling and the number of sensor nodes in the original network. Sleeping ratio is relevant to the coverage rate and the energy consumption of the network. From the Figure 4.3 it can be observed that as the nodes in the network is increased, sleeping rate decreases. With decreasing sleeping rate, more number of nodes in the network is put into inactive state, which will decrease the data redundancy, energy consumption and increase the lifetime of the network.

➢ Use of FCM protocol and energy-based sleeping schedule shows improvement in life time of network.

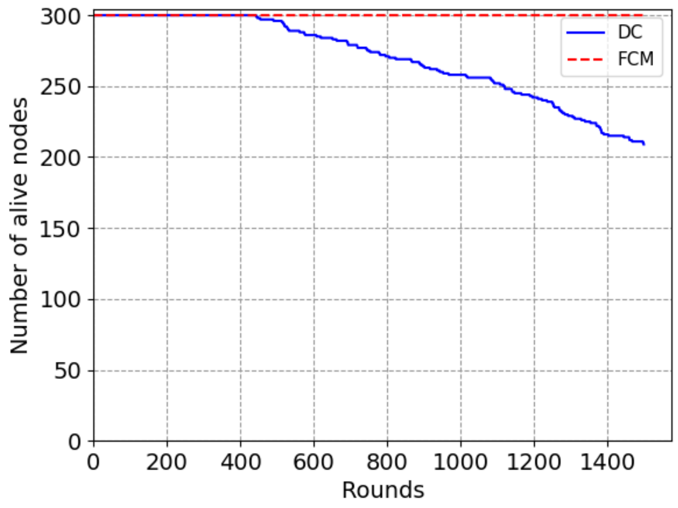

Figure 4.4: Number of node alive over the time

From the Figure 4.4 it can see that the duration of alive nodes is increased while FCM protocol is implemented in the network.

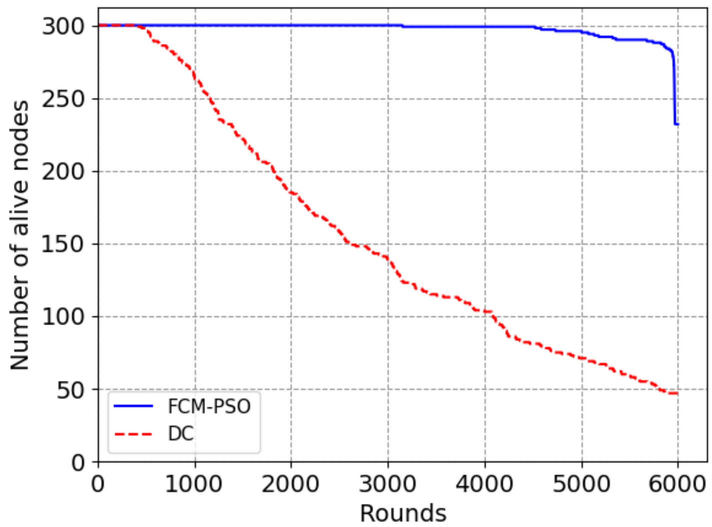

Figure 4.5: Number of node alive over the time (6000 rounds)

Here the simulation has been run with BS at (125,125) with 2J energy of each nodes. From the Figure 4.5 it can be seen that lifetime of network with 100% node alive is increased when combination of FCM protocol and sleep scheduling of nodes is implemented. Depletion of complete energy of nodes only begins after 3000 rounds by implementing this method whereas using DC method nodes energy depletion begins at very early rounds and 30% of the nodes are already dead by 1500 rounds. From Figure 4.5, it can be seen that in case of FCM-PSO there is sharp decline in number of alive nodes around 5900 rounds which is due to depletion of energy of nodes from same area. Due to balanced energy load distribution, energy of nodes in same area deplete in same manner. From simulation results it is seen with 600J of total initial network energy that the energy consumed in case of DC is 366.26J (61.04%) at 1500 rounds and 497.09J (82.84%) at 3000 rounds but in case of this implementation energy consumed is 155.76J (25.96%) at 1500 rounds and 314.95J (52.45%) at 3000 rounds.

- Implementation of duty cycle regulation via adaptive thresholding

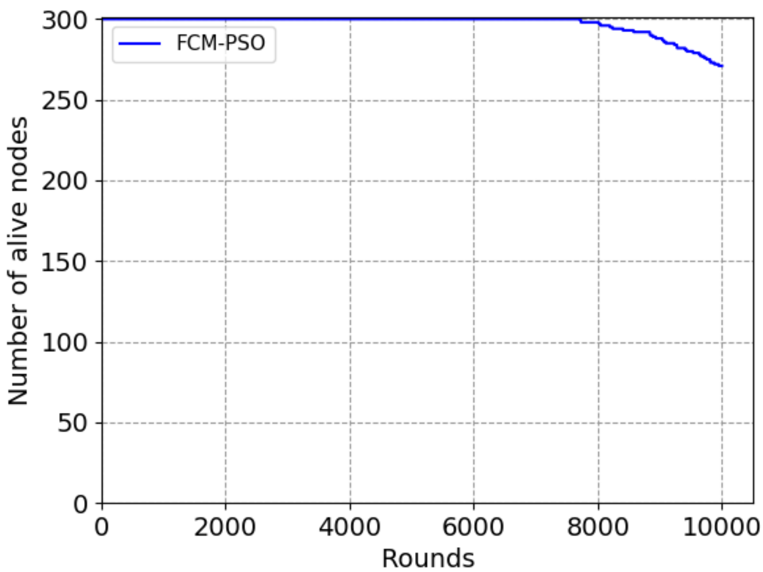

Figure 4.6: Duty cycle regulation via adaptive thresholding

The duration of the 100% node alive is further increase after implementation of duty cycle regulation. From Figure 4.6 we can see that complete depletion of energy begins only after 7800 rounds. In this simulation each node has been initialized with 1J energy with BS at (125,125). Instead of continuous transmission of data, the data is sent only in case of the new data sensed is in anomaly region or the buffer of size 500 byte is used to store the collected data until it is full. By implementation of adaptive thresholding important data isn't lost because it is treated as anomaly and in case when there are slight variations in data it is stored in buffer to be transmitted later. Since most of the node's energy is lost during communication task, this implementation helps save the energy that is lost in continuous transmission of data which helps to further increase network life time.

Hence it can be seen that use of energy aware routing (FCM), energy-based sleeping schedule and duty cycle regulation via adaptive thresholding can increases the network life time of WSN.

4.2 Comparison with DC, MTE and LEACH

- Plot Distribution of dead nodes (● represent alive nodes, x represents dead nodes and ■ represent BS)

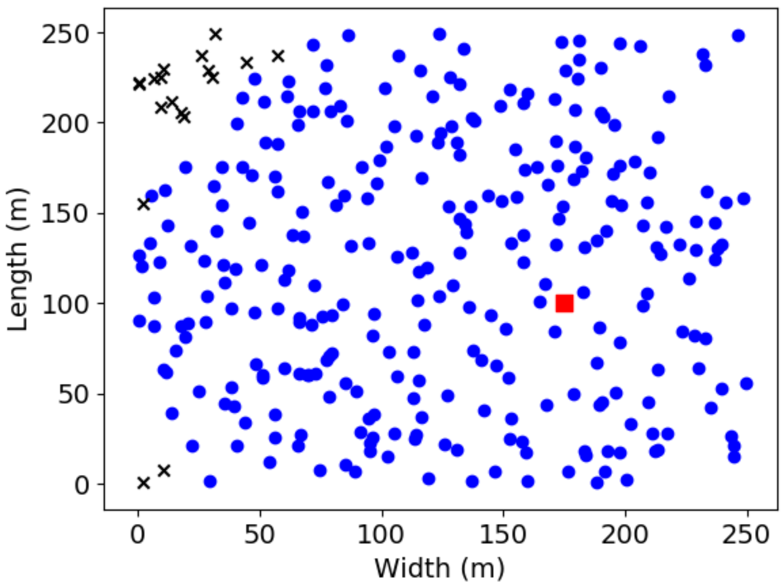

Figure 4.7: Distribution of dead nodes using DC with BS at (175,100)

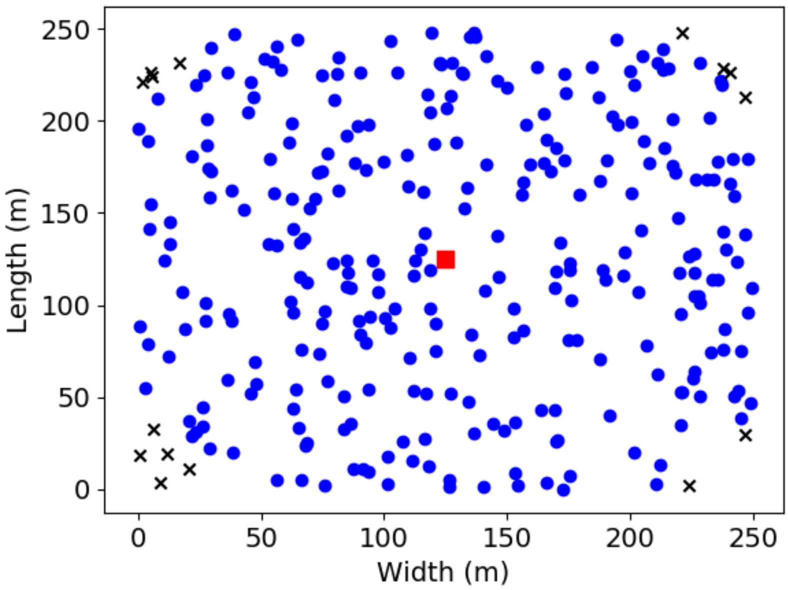

Figure 4.8: Distribution of dead nodes using DC with BS at (125,125)

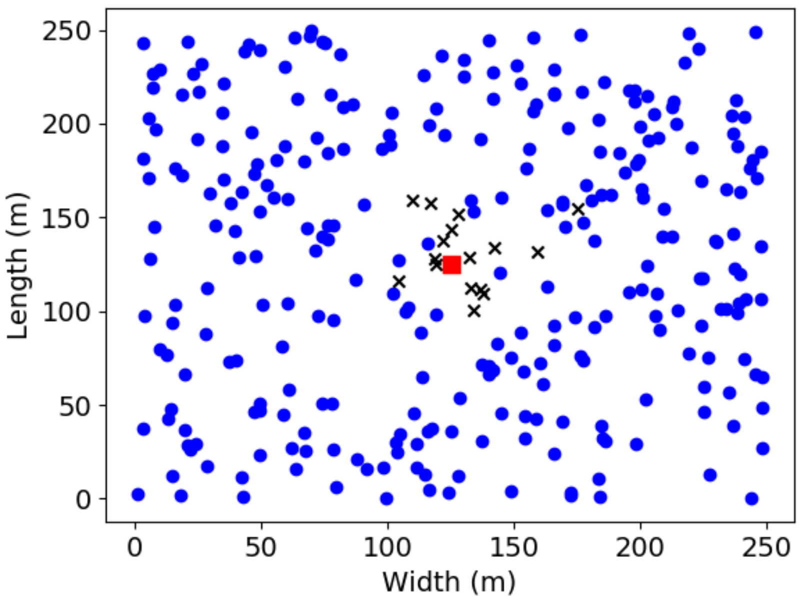

Figure 4.9: Distribution of dead nodes using MTE

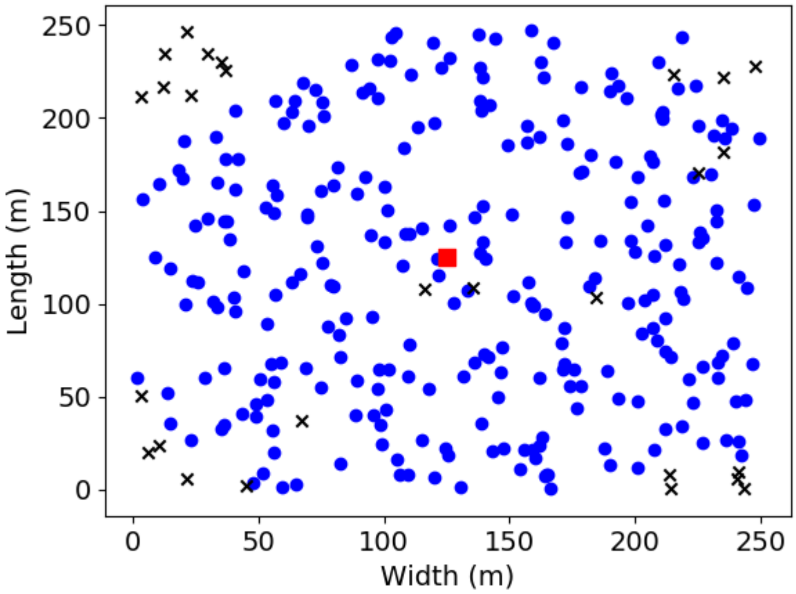

Figure 4.10: Distribution of dead nodes using LEACH

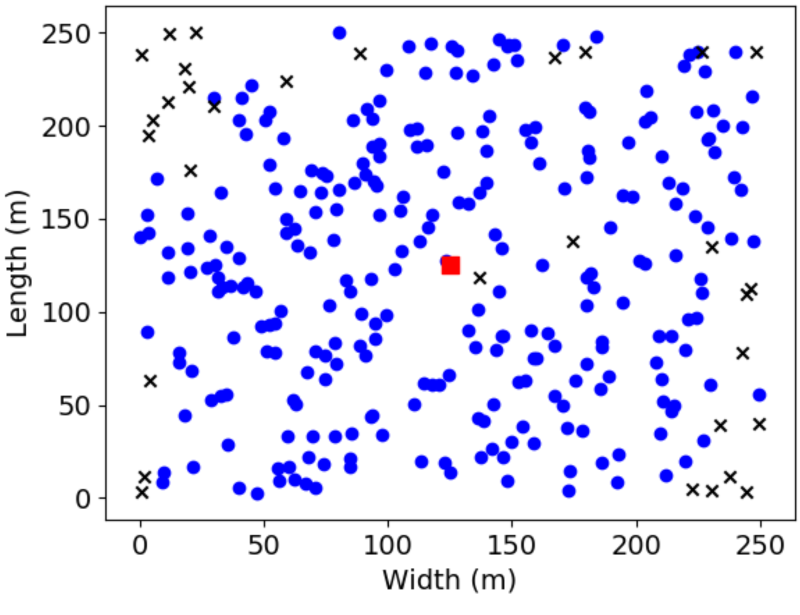

Figure 4.11: Distribution of dead nodes using FCM-PSO

The distribution of dead nodes is presented in Figure 4.7, Figure 4.8, Figure 4.9, Figure 4.10 and Figure 4.11. In case of DC, it can be seen that nodes which are further from the BS deplete energy faster as the transmitting distance is further. From Figure 4.7 and 4.8 it can be seen that how location of BS affects the energy depletion of the nodes and performance of the network. It can be seen that when BS is present at centre, the dead nodes is not distributed in a single area. In MTE, nodes which are closer to the BS run out of energy earlier because of forwarding a huge amount of data received from the further nodes. In LEACH, although the nodes further from the BS have higher chance to run out of energy first, the energy balance among the network assist LEACH network obtains a larger covered area after a longer time of operation, compared with Direct Communication and MTE. In case of this work, CH takes the responsibility of aggregating data from cluster nodes and sending it to BS instead of nodes directly communicating with the BS. After each round new cluster head is selected based on the largest residual energy which distributes the load of aggregating and distributing data to base station. So, the depletion of nodes energy doesn't always begin with furthest node and the network life time is increased.

- Remaining energy and number of node alive with time

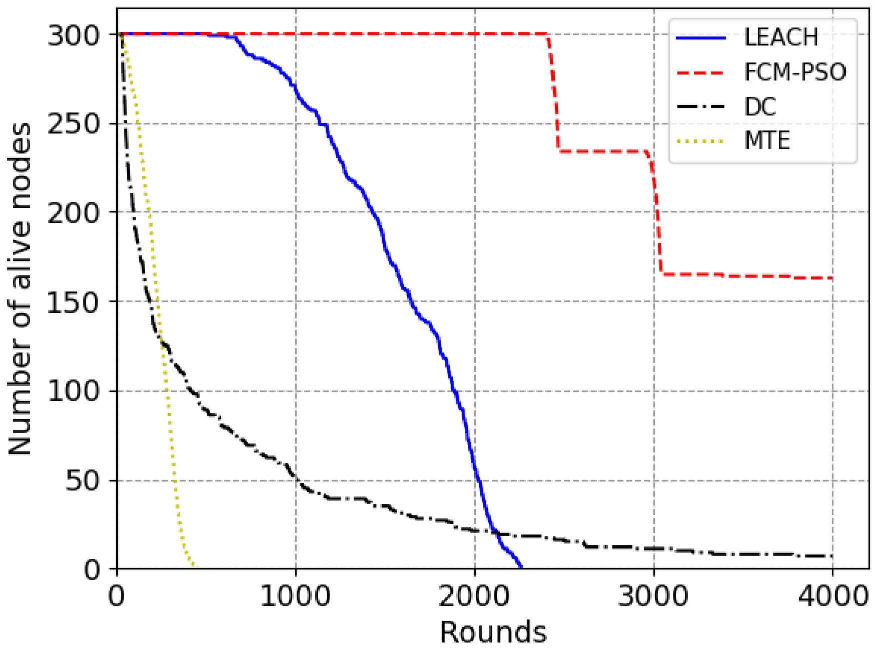

Figure 4.12: Number of node alive over the time with BS at (125, -75)

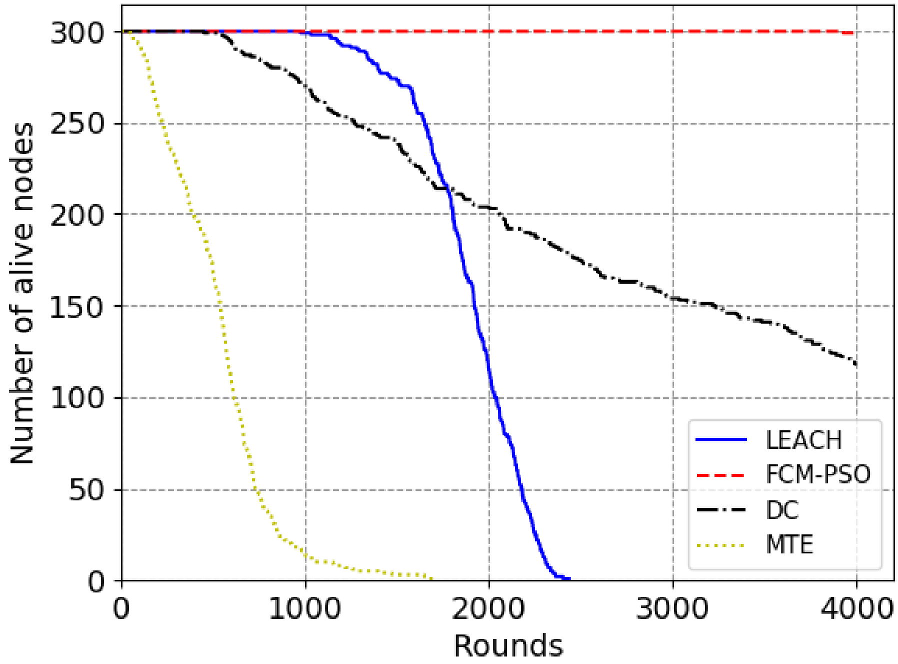

Figure 4.13: Number of node alive over the time with BS at (125,125)

Table 2: Energy remaining in the network

Protocols	1000 rounds		2000 rounds	
	BS at (125,-75)	BS at (125,125)	BS at (125,-75)	BS at (125,125)
DC	34.009J	10.182J	300.007J	149.380J
MTE	Depleted	Depleted	Depleted	Depleted
LEACH	144.918J	Depleted	203.018J	Depleted
FCM-PSO	415.036J	224.253J	497.233J	392.476J

In Figure 4.12 and Figure 4.13, the number of alive nodes over the operating time of the network by using different protocols is compared. In this work, the performance of Direct Communication, MTE, LEACH and FCM-PSO are studied. From the Figure 4.12 and 4.13 it can be seen that the lifetime of network with 100% nodes alive is much longer than lifetime of network with other protocols. From Table 2, it can be seen that total remaining energy of the network is greater in case of this implementation in comparison to DC, MTE and LEACH. It can also be seen that positioning of BS affects the network lifetime. With proper positioning of the BS, energy spend in transmission of data from sensor nodes to the BS is reduced due to which the network lifetime can be increased.

Table 3: Lifetime of nodes in the network

Protocols	First dead node occurs (rounds)		30 percent depletion occurs (rounds)	
	BS at (125,-75)	BS at (125,125)	BS at (125,-75)	BS at (125,125)
DC	23	516	78	1271
MTE	10	37	137	300
LEACH	616	973	816	1609
FCM-PSO	2409	3886	2892	N/A

In Table 3, the lifetime up to which all nodes are alive and lifetime when 30 percent of nodes depletion occurs is shown. From the results obtained it can be seen that that by balancing the energy consumption among all nodes during routing and using energy sleeping schedule the duration up to which all nodes are alive in the network can be improved significantly. In case of DC and MTE it can be seen that energy depletion of nodes begins at early rounds whereas in case of LEACH and FCM-PSO it occurs in later rounds which improves the network performance.

CHAPTER FIVE: CONCLUSION AND LIMITATIONS

5.1 Conclusion

Duty cycle regulation via adaptive thresholding, Fuzzy C-means routing and sleeping schedule based on particle swarm optimization has been used to increase the lifetime of WSNs. By balancing energy consumption in all node by implementation of both Fuzzy C-means routing and particle swarm optimization in comparison to implementation of only LEACH and MTE the lifetime of the network is increased significantly. Also, by implementation of duty cycle regulation via adaptive thresholding it is found that the network lifetime is increased further by saving the energy used in continuous transmission of data.

For future work other techniques like efficient data communication protocol, network coding and Dynamic Voltage and Frequency Scaling can be implemented to further save the energy consumption to improve the network lifetime. Techniques of cluster head backup selection and round time estimation can be implemented. Other various routing and sleep scheduling algorithm can also be used to evaluate performance.

5.2 Limitations

Implementation of Duty cycle regulation via adaptive thresholding, Fuzzy C-means routing and sleeping schedule based on particle swarm optimization can reduce the energy consumption of the node and increase the lifetime of the network but still there are some limitations. The current implementation only considers the case when both base station and sensor nodes are stationary. The effects of climate and cases of nodes failure due to external environment or faulty hardware has not been taken into consideration while performing simulation.

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