Extending Self-configuration Algorithms of Energy Constraint Wireless Sensor Networks to Emergency Environment

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Abstract

Wireless Sensor Networks have recently gained interest in building monitoring applications as a low cost and easy to install alternative. Some examples are smart/green buildings and emergency/rescue operations. These types of networks require that a large number of sensors be positioned easily and that they configure themselves to perform the tasks needed without human intervention. This raises the issue of self-organization of sensor nodes.

In the recent past, many researchers have investigated this topic. However, there is a lack of suitable self-organization algorithms which can be used in emergency monitoring applications in an indoor environment. This thesis proposes a self-organization algorithm for Wireless Sensor Networks suitable for an emergency detection and monitoring application by considering emergency environment issues.

A distributed unequal clustering algorithm with a suitable node dying pattern for an emergency monitoring application is proposed and simulated. The proposed algorithm optimizes the energy usage of the network and prolongs the network lifetime by multi-hop communication. The simulation result shows that the proposed algorithms prolong the network lifetime while maintaining the coverage of the building with existing nodes in a 2D environment. EDCR-LGRUC algorithm prolong the lifetime of the network by 1000 rounds more than the EDCR algorithm. Additional, SCAE algorithm delayed and reduced the CH failures compared to EDCR. Also, the communication failure occurred due to the CH failure is reduced by 10% compared to EDCR. Moreover, 500 data rounds are optimized in the proposed multi-hop algorithm compared to EDCR-MH algorithm.

From the application point of view, the proposed algorithm is simulated in a 3D environment. The result shows that, it achieves the same outcome as in 2D environments and that the algorithm is suitable for a wireless sensor network deployed in a multi-story building.

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Contents

List of Figures

List of Tables

Nomenclature

$Bel(i,t)$	Severity of node i at time t
c_i	Dynamic re-clustering threshold
D_{ch-ch}	Average distance between two Cluster Heads
$dist_{i.j}$	Distance between node i and j
Δ	Re-clustering threshold
$e_{cpu-change}$	energy consumption of one time state transition
e_{off-on}	One time energy consumption of opening sensor operation
e_{on-off}	One time energy consumption of closing sensor operation
E_{const}	Constant Energy Level
E_{cpu}	Processor energy consumption
$E_{cpu-change}$	Sum of the state transition energy consumption
$E_{cpu-state}$	Sum of the state energy consumption
E_{DGR}	Total energy cost of data transmission in global re-clustering
E_{elec}	Energy at the transmitter or receiver circuitry
$E_{j,i,p}$	Residual energy of node p, at the beginning of node i Cluster Head period in the Epoch j
E_{OGR}	Total energy cost of transmitting overhead data in global re-clustering
E_{sensor}	Sensor energy consumption
E_{static}	Static re-clustering threshold
$E_{rel-max,i}$	Relative maximum energy of sensor i's neighborhood
$E_{res,i}$	Residual energy of sensor i
$E_{Rx,i}$	Energy consumption in receiving state of node i
E_{TLD-P}	Total energy cost in partial local delegation
$E_{Tx,i}$	Energy consumption in transmitting state of node i
ε_{amp}	Energy at the transmitter amplifier
h	Average hop count

J_{CH}	Energy cost in a Cluster Head
J_{CM}	Energy cost in a Cluster Member
J_{total}	Total data gathering cost of one data round
k_i, γ	Random numbers
l	Length of a message
n	The radio propagation path loss exponent
$N_{cpu-change}$	Frequency of state transition
N_d	Number of nodes in partial local delegation
$N_i^{R_{max}}$	Set of nodes within the neighborhood of radius R_{max} around node i
$P_{cpu-state}$	Power consumption in a CPU state
P_{end}	Power of end state
$P_{initial}$	Power of initial state
Pl	Plausibility function
$R_{comp,i}$	Maximum compatible radius of node i
$R_{d,i}$	Radius of partial local delegation
R_{max}	Maximum communication range od a sensor node
R_{min}	Minimum communication range od a sensor node
T	Limited time interval for CH candidacy
$T_{candi,i}$	Cluster Head candidacy time of node i
$T_{cpu-state}$	Time interval in a state
$T_{initial-end}$	Time interval for the state transition
$T_{local-candi,i}$	Local Cluster Head candidacy time of sensor i
$w_i, W_{i,j}$	Weight parameters
$X_{j,i}$	number of data transmission rounds that node i serves as a CH in the Epoch j
X_S_i	Number of data rounds that node i serves as a CH after triggering static re-clustering

Chapter 1

Introduction

Wireless sensor networks (WSNs) have found their way into a wide variety of applications in area such as health [1], military [2], environmental monitoring [3], habit monitoring [4] and emergency detection [5]. WSNs have recently gained interest in rescue operations in emergency detection and response applications [6, 7].

A WSN may contain hundreds or thousands of sensor nodes,monitoring specified parameters.These sensor nodes have the ability to communicate with each other or directly to an external base-station(BS)/sink [8]. Each sensor node comprises sensing, processing, transmission, position finding systems, and power units. However, WSNs have some restrictions such as limited energy, computational power, memory, band width of links connecting sensor nodes, etc.

Since sensor nodes have limited battery power, energy efficiency is a key issue in designing a topology for a sensor network, which affects the lifetime of it greatly. Most of the WSN based applications require periodic data collection from sensors distributed over the environment to one central location (the BS).The energy consumption of such a network can be reduced by compressing the traffic volume, multi-hop communication which will reduce required communication power, and decreasing wasteful energy consumption as a result of idle listening on the wireless channel, minimizing re-transmissions due to packet collisions, and protocol overhead for exchanging control packets [9]. However, in emergency response applications, there are some other issues that need to be addressed. Some of them are transmitting real time data reliably, adding new nodes to the network, continuing data transmission while existing nodes drop out from the network, etc. [10, 11].

This research considers a WSN deployed in an indoor environment for emergency detection, monitoring and rescue operations. For such an application, battery energy is a critical need [10]. Similarly, the sensor node dying pattern in the building, due battery exhaustion is also an important fact. Hence, this research focuses on the battery energy optimization while maintaining the coverage of the monitoring area with existing nodes.

Furthermore, in an emergency environment, sensor nodes drop out from the network. For example, in a fire emergency situation, nodes will burn and perish. Hence, data transmission in such a situation is crucial. There are many other factors which need to be considered in an emergency. However, this focuses on a way that network functionality can be prolonged while nodes drop out.

1.1 The Research Problem

Researchers have identified many unsolved issues and challenges in WSNs. Some of them are, lifetime, coverage, localization, data collection, security and architecture [12–14]. The current research attempt is to address the self-organization issue of WSN deployed in a multi-story building for emergency response applications.

For many applications, WSNs consist of hundreds, thousands or even millions of low power inexpensive sensor nodes that may be placed either regularly or irregularly. Also indoor emergency response applications need large scale deployment of sensor nodes in an ad-hoc fashion to monitor the environment and collect data. This research considers a uniform random distribution of sensor nodes.

Furthermore, most current research have considered the situation where all nodes in the network die at once due to energy exhaustion. However, emergency response applications need at least one node alive in the area to monitor the environment and transmit information, which is yet to be addressed.

There is lack of coherence in research especially when self-organization algorithms are used in emergency support applications. In such applications there are many issues such as, deployed nodes being destroyed, fire-fighters introducing new nodes to the network, link failures, etc. [10]. Hence, when proposing a self-organization algorithm for an emergency monitoring application, these issues need to be addressed.

In the current research context, existing radio communication protocols for

WSNs such as IEEE 802.11 fail to perform for the reason of not addressing unnecessary drain of energy due to over hearing, packet collisions and overhead of control [9]. WSN based emergency response applications require periodic data collection from the distributed sensor node to the BS. The energy key to optimizing of such a network is effective clustering algorithms. Hence the key issues addressed in this research can summarize as follows.

- Optimize the energy usage of the network
- Combine clustering algorithm with severity level of the emergency
- Propose a node dying pattern suitable for emergency response application
- Propose the algorithm for multi-storey building environment
- Propose architecture for emergency response sensor network

1.2 Challenges in Emergency Response

WSNs raise many exciting opportunities to minimize the impacts caused by emergencies [10, 15]. In the recent research, the potential of using sensor networks in indoor emergency detection and monitoring applications has been highlighted. One reason is, sensor network can be installed in a new building at the time of construction and also it can be easily installed in older buildings due to their wireless nature. The second reason is, that large number of sensors can be positioned easily and they can configure themselves to perform the needed task without human intervention. Additionally, installation and maintenance is convenient.

However, the nature of an emergency is highly dynamic and demanding. Also, real-time data retrieval, processing and management are required. Hence, when proposing an algorithm for emergency response, there are some challenges that need to be considered. Some of the basic challenges can be highlighted as,

- Highly dynamic and demanding environments.
- Real-time data retrieval, processing and management.
- WSN may lose its sensor nodes. For example in fire emergency nodes burned and destroyed.

- New sensor nodes may be added to the network, i.e. first responders may add stationary and mobile sensor nodes to the WSN.
- Communication link failures.
- Noise added to the multi-modality sensed data.
- Communication delays.

1.3 Organization of the Thesis

Chapter 2 will summarize the related research work in clustering algorithms suitable for ad-hoc deployed WSNs. Chapter 3 presents energy efficient unequal clustering algorithm named as EDCR-LGRUC (Energy Driven CH Rotation with Local and Global Re-clustering in Unequal Clusters) which addresses the drawbacks identified in the existing equivalent class of algorithms. Then Chapter 4 proposes an optimized self-organizing algorithm named as SCAE (Severity based Clustering Algorithm for Emergency) to prolong the network lifespan during an emergency. Chapter 5 proposes a self-organization algorithm for WSN emergency monitoring application by considering a suitable node dying pattern. The proposed EDCR-LGRUC algorithm is extended to use in muliti-storey building by using multi-hop communication is discussed in Chapter 6. Finally, Chapter 7 summarize the conclusion and future directions of the research.

Chapter 2

Related Work

This chapter will summarize the related research work in clustering algorithms suitable for ad-hoc deployed WSNs, which requires periodic data gathering.

2.1 Clustering

Clustering is a technique, which divides the network into small groups called clusters. Each cluster consists of a Cluster Head (CH) which acts as the leader of the cluster and multiple member nodes. These member nodes monitor the environment periodically and transmit the sensed data to its CH. In single-hop clustering algorithms, the CH directly transmits the data received by its member nodes to the BS. However, in multi-hop clustering algorithms, CHs transmit the data via the closest CH neighbor in the direction of the BS until the data reaches the final destination (BS). The Fig 2.1 and Fig 2.2 show an example of single-hop clustering and multi-hop clustering respectively.

When compared to other nodes, energy consumption in the CH is much larger than member nodes due to its functions such as collecting data from member nodes, data aggregation, and sending aggregated data to the BS. Hence to avoid rapid energy dissipation, clustering algorithms use CH role rotation mechanisms called as re-clustering. CH uses either global re-clustering or local re-clustering. In global re-clustering all the existing clusters are removed at once and a new cluster formation phase is carried [9, 16–18]. This method can distribute the CHs all over the environment and centralize each CH within its cluster area. With that the energy consumption of the network can be optimized. On the other hand, in local re-clustering, the CH is rotated within the cluster and other

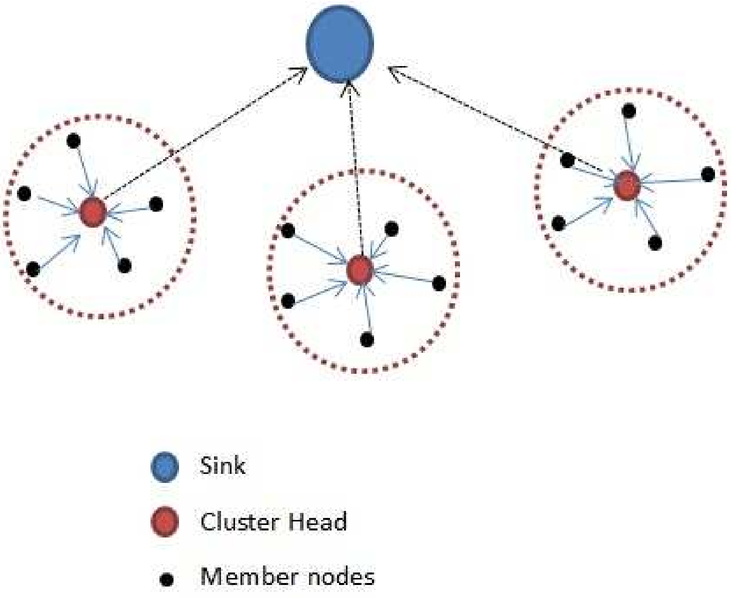


Fig. 2.1: Single-hop clustering

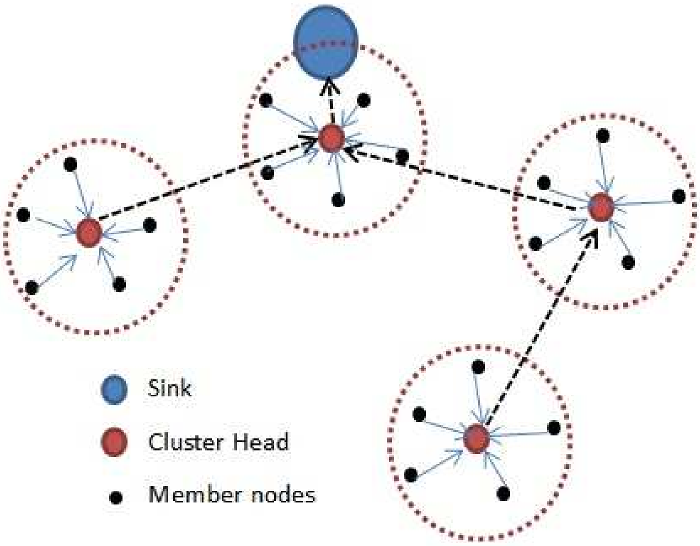


Fig. 2.2: Multi-hop clustering

clusters will remain as unchanged [19–21]. This method can reduce the overheads for exchanging packets needed for unwanted CH role rotation.

This research primarily concern with clustering and the protocols related to clustering, due to the following reasons [22, 23].

1. Clustering greatly reduces the distance that nodes need to transmit their data. The data transmission is proportional to the n^{th} power of the distance

between the source and destination nodes. Since the CH is closer to all member nodes in the cluster, it will effectively save member nodes energy by reducing transmission distance.

2. The Time Division Multiple Access (TDMA) protocol used in clustering algorithm. This will reduce data collision in the network and reduce energy needed in the re-transmission of data packets. Also, TDMA protocol can reduce the energy needed to keep the regular nodes on for idle listening [24].
3. CH data aggregation method it can reduce unwanted data transmission from CH to BS. In most situations, physically close sensors have highly correlated data and CH can perform a high data compression.

2.1.1 Challenges

Clustering algorithms in WSN faces several challenges such as computing the optimal cluster size, selecting the optimal frequency of CH rotation, how clusters form and node's duty cycle [25].

The optimal cluster size is the main factor which determines the expected number of clusters. If the cluster size is large, few clusters will cover the entire WSN. This results in member nodes having to communicate over long distances and each CH handling more nodes. On the other hand, if cluster size reduces, there would be more CHs which need to be alive all the time and most of them need to communicate with far away BSs. Hence, selecting a proper cluster size is a challenge.

To prolong the network lifetime, selecting an optimal frequency of CH rotation is essential. Existing clustering schemes, use time or a dynamic parameter to trigger the CH rotation. In time driven re-clustering, selecting the optimum time period (T) for triggering is crucial. Since T is fixed and found at the designing stage, re-clustering cannot be done adaptively to the environment changes. However, this issue has been addressed in dynamic parameter CH rotation mechanism. For an example, a CH triggers a new CH election when its battery level goes below a threshold value.

In a clustering algorithm, the main concern is how clusters should be formed. For this, how the CHs are selected and how member nodes are associated with a CH need to be considered. If the cluster formation phase is less complex and highly effective, it will optimize the energy usage of the network.

Another factor to prolong the battery lifetime is allowing sensors to sleep when not active. Idle listening consumes significant energy and battery discharge is nonlinear. Hence clustering techniques should incorporate the nodes duty cycle in their design.

In addition, there are some other issues that need to be considered while proposing a clustering algorithm.

1. Optimal distribution of CHs. If the cluster formation is non-uniform, member nodes need more energy to transmit sensed data.
2. Ability to perform in heterogeneous energy networks.
3. The suitability to be used in an emergency response system. Nowadays there is a trend of using WSN in emergency response applications due to its characteristics. Hence, in such applications, clustering algorithms need to consider emergency issues in their design.

2.2 Clustering Algorithms Proposed for Wireless Sensor Networks

A variety of clustering algorithms have been proposed for prolonging the lifetime of a WSN. This section gives a brief description of such WSN clustering algorithms in line with CH selection and rotation, and overall performance.

2.2.1 LEACH: Low Energy Adaptive Clustering Hierarchy

Heinzelman et. al. [16] introduced a hierarchical clustering algorithm for sensor networks, called Low Energy Adaptive Clustering Hierarchy (LEACH). The operation of LEACH is separated into two phases, the setup phase and the steady state phase. LEACH randomly selects a few sensor nodes as CHs in the setup phase. This decision is based on the suggested percentage of CHs for the network and the number of times the node has been a CH so far.

Each elected CH broadcasts an advertisement message to the rest of the nodes in the network that they are the new CHs. Hearing the advertisements, each sensor node chooses the closest CH and registers itself as a cluster member. After receiving all messages from the nodes that would like to be included in the cluster and based on the number of nodes in the cluster, the CH node creates a TDMA schedule and assigns each node a time slot when it can transmit. This schedule is broadcast to all the nodes in the cluster.

In LEACH, the CH nodes compress data arriving from nodes that belong to the respective cluster, and send an aggregated packet to the BS in order to reduce the amount of information that must be transmitted to the BS. LEACH uses a TDMA/CSMA MAC to reduce inter-cluster and intra-cluster collisions. However, data collection is centralized and is performed periodically. After a given interval of time, a randomized rotation of the role of the CH is conducted so that uniform energy dissipation in the sensor network is obtained.

However, LEACH algorithm suffers from the following drawbacks.

- LEACH clustering terminates after a finite number of iterations, but does not guarantee good CH distribution and assumes uniform energy consumption for CHs [26].
- The algorithm does not take into account any application-specific characteristics in the decision making process. The only global information that LEACH uses is the desired percentage of CHs in the network [27].
- Also, CHs are chosen in a probabilistic way. The predetermined optimal numbers of clusters are not necessarily organized and clusters are not well distributed in a region. Hence, there is a dramatic variation of energy consumption of the CHs [28, 29].
- In LEACH, every sensor has the same chance to become a CH. Hence, a sensor node with insufficient residual energy will occasionally becomes a CH and die due to battery depletion, while there may be a sensor node with rich battery power nearby [29].
- The LEACH algorithm does not perform well in heterogeneous energy sensor networks [30]
- CH broadcasting message has to cover the entire WSN. Hence this would requires a significant energy compared to covering a local neighborhood.

Modified LEACH Protocols

Due to the above mentioned drawbacks, many protocols have emerged to improve and enhance LEACH. In LEACH-B(Balanced) [31] ,there is a second stage for selecting CHs through considering the residual energy of candidate nodes to become CHs. This modifies the number of CHs at the set up phase considering the nodes residual energy.

In LEACH-C (Centralized) [32], authors have made an improvement over LEAH protocol such that, during the CH selection stage the BS should know the remaining energy of all nodes and their location. Accordingly, the BS selects the most suitable nodes to be CHs, and divides the rest of the nodes between CHs to form the clusters. Simulation results of LEACH-C shows an enhancement based on the first dead node compared to LEACH.

Authors in [33] introduced the LEACH-P (Performance) protocol which considers the probability selection of Energy Aware Multipath Routing into the LEACH algorithm and makes a better choice of selecting CHs and optimizing the chance of cluster rebuilding.

A new version of LEACH with a mobility factor has introduced in [34]. LEACH-M uses the same threshold formula of the original LEACH to calculate the threshold. However, it takes into consideration the mobility of nodes during the data transfer phase, which LEACH does not. The mobility itself is a challenge because a mobile node can leave cluster while it is transmitting data to a CH. LEACH-M solves this problem by confirming whether a mobile node is still able to communicate with CH or not according to the TDMA schedule. LEACH-ME [35] is an enhanced version of LEACH-M.

Furthermore, there are some other improved LEACH algorithms such as TL-LEACH [36], E-LEACH [37], FL-LEACH [38], etc. [39].

2.2.2 SEP: Stable Election Protocol

SEP [17] proposes the use of a small percentage of advanced nodes along with normal nodes. Then, it uses a technique to allocate these advanced nodes as CHs more often than normal nodes, and thus try to prolong the overall network lifetime. The randomized rotation of CHs is weighted by the proportion of extra initial battery energy of the nodes. This weighting is such that SEP selects advanced nodes $(1 + \alpha)$ times more often than a normal node, where α is the extra energy content incorporated into the advanced nodes. And also it defines two different threshold values for advanced and normal nodes. Rest of the SEP algorithm is identical to LEACH.

According to the simulation results presented in [17], SEP has taken full advantage of heterogeneity (i.e. extra energy of advance nodes). Thus, the life time of the WSN has increased by 26% compared to LEACH.

While SEP has a WSN lifetime increase compared to LEACH, still it inherits many drawbacks identified with LEACH such as, random CH election that cannot guarantee the desired number of CHs are elected or that the elected CHs are evenly positioned, and fixed time based CH role rotation. Also, SEP algorithms cannot be used in a true random heterogeneous energy sensor networks.

2.2.3 HEED: Hybrid Energy Efficient Distributed Clustering

HEED [18] periodically selects CHs according to their residual energy. It is a distributed clustering algorithm, which eliminates the non-uniform cluster forming problem observed in LEACH and its derivatives. HEED requires CH announcement to cover only a local neighborhood. Furthermore, this algorithm has the ability to perform in a heterogeneous energy networks as it considers node residual energy in CH election.

However, HEED uses a complex weight based cluster setup procedure, where a CH is selected with many round of iterations. This has adversely affected the communication and coordination energy overhead during cluster setup. Hence, it has a less network lifetime compared to LEACH. Furthermore, this too rotates CHs after a constant predetermined number of data gathering rounds. Hence, same problems faced by LEACH on fixed time based CH rotation are applicable to HEED.

2.2.4 An energy-efficient clustering algorithm for data gathering and aggregation in sensor networks: ANTCLUST

ANTCLUST [40], is an algorithm that considers the ant model of colonial closure to solve the distributed clustering problem in ad-hoc deployed WSN. It regards a sensor node (the object) as an ant and a cluster as a nest. In ANTCLUST, it is assumed that two randomly chosen objects meet. Based on their similarity threshold values, they create, merge, or delete clusters. By repeatedly conducting random meetings, clusters are appropriately organized, so that objects in the same cluster become more similar with one another than those in different clusters.

ANTCLUST algorithm elects a node with the highest residual energy in a given neighborhood as the CH. Further, the algorithm guarantees no two nodes in a given neighborhood are CHs. Non-CH nodes select their clusters based on the residual energy of the neighboring CHs, its distance to the neighboring CHs, and an estimation of the cluster size based on the information gathered from local meetings. Eventually, energy efficient clusters are formed, that result in an extension of the lifetime of the sensor network.

This algorithm does not have non uniform cluster forming issue as with LEACH and its derivatives. Further, this algorithm can be applied to heterogeneous energy networks. According to the simulation results presented in [40], the number of rounds in which more than 80% of the sensor nodes are alive with ANTCLUST is, 25% to 55% higher than that with LEACH.

However, this algorithm too go for CH rotation after a predetermined period of time in normal operation similar to LEACH and HEED and does not define how to identify optimal point to do so. Furthermore, the ANTCLUST based clustering algorithms requires prior knowledge of the location information of all sensor nodes.

2.2.5 EDAC: Energy Driven Adaptive Clustering

EDAC [19] has energy based CH selection and rotation mechanisms. A selected CH will function until its residual energy falls below a threshold and then CH rotation take place. Then a node with the highest residual energy in this CH's member base will take over the new CH role. Hence there will not be a change of cluster boundaries.

EDAC uses the approach outlined in LEACH to determine the first set of CHs. This can lead to the creation of non-uniform clusters, especially since two or more close by nodes may now become CHs similar to the situation that occurred in the LEACH algorithm. Further, there can be situations where the number of clusters produced in the first round is far apart from what is expected as mentioned in the drawbacks of LEACH. If the initial cluster setup phase has these problems, it can propagate to subsequent rounds with non-uniform clusters and non optimal number of clusters. Additionally, EDAC also expects nodes to know their position.

Simulation results presented in [19] shows that EDAC has about 10% better lifetime performance compared to LEACH in a homogeneous energy WSN. This performance improvement in EDAC is a direct result of energy based CH role rotation. Whereas in LEACH, performance is low, due to the predetermined fixed time duration of the CH role rotation. However, here, they do not provide a method to find a suitable value for the CH rotation triggering threshold.

2.2.6 EEUC: Energy Efficient Unequal Clustering

The CHs closer to the BS are burdened with heavy relay traffic and tend to die early, leaving areas of the network uncovered and causing network partition. EEUC [41] tries to address this issue. This is a distributed competitive algorithm where CHs are elected by localized competition i.e. a node's competition range decreases as its distance to the BS decreases. The BS broadcasts a hello message to all nodes at a certain power level. By this way each node can compute the approximate distance to the BS based on the received signal strength. Several tentative CHs are selected to compete for final CHs. Suppose that tentative CH has a competition range, which is a function of its distance to the BS. The organization of intra-cluster data transmission is identical with LEACH after clusters have been formed.

Also, they have proposed an Energy-aware multihop routing protocol for inter-cluster communication where the CH chooses a relay node from an adjacent CH based on residual energy and distance to the BS. Here it is assumed that nodes are homogeneous and all are stationary after deployment.

Simulation results presented in [41] shows that the number of clusters in EEUC is more steady than that in LEACH and it clearly improves the network lifetime (both the time until the first node dies and the time until the last node dies) over LEACH and HEED.

2.2.7 EDUC: Energy-Driven Unequal Clustering

Jiguo YU et al. [20], have proposed an Energy Driven Unequal Clustering (EDUC) protocol for heterogeneous WSNs. It includes an unequal clustering algorithm and an energy driven adaptive CH rotation. The major assumptions made by this algorithm are, that the nodes are randomly distributed over the sensing area, that nodes are stationary after deployment and that nodes are heterogeneous.

The cluster construction phase is similar to EEUC and cluster re-construction happens when CHs residual energy drops below a threshold value.

The simulation results for dense and sparse networks in [20] show that EDUC can prolong the network life time compared to LEACH and HEED, and also that the lifetime of a dense network is a little longer than that of a sparse network.

2.2.8 ECRA: Energy-Aware Cluster Based Routing Algorithm

Jyh-Huei Chang has proposed an Energy-Aware Cluster Based Routing Algorithm (ECRA) [21] to maximize the lifetime of the network. Clustering, data transmission, intra-CH rotations are the three phases in this algorithm.

In the clustering phase, it constructs the Voronoi diagrams and mass centroid. Then it chooses the set of node closest to the mass centroid and advertises itself as the CH. Data transmission phase is similar to LEACH and CH rotation happens within the cluster after each round. The new CH is choose based on communication cost and residual energy.

Jyh-Huei Chang proposed a two-tier architecture (ECRA-2T) to enhance the performance of ECRA.

Simulation results presented in [21] show that, these two algorithms outperform direct communication, static routing and LEACH.

2.2.9 Energy Efficient Homogenous Clustering Algorithm for Wireless Sensor Networks

Shio Kumar Singh et al [26] have proposed an Energy Efficient Homogeneous Clustering Algorithm in which the lifespan of the network is increased by ensuring a homogeneous distribution of nodes in the clusters. In this algorithm, energy efficiency is distributed and network performance is improved by selecting CHs on the basis of the residual energy of existing CHs, holdback value, and the nearest hop distance of the node. The cluster members are uniformly distributed and the life of the network is further extended.

This algorithm assumes that all nodes in the network are homogeneous and energy-constrained, that all nodes are able to send data to BS and that the BS has the information about the location of each node.

In the first round, the BS collects information regarding the location of all the nodes in the network and depending on the density and geographical layout of the network, it virtually divides the network into zones. Nodes in each zone have the same probability to become a CH. Therefore randomly selects one node as

CH and cluster joining same is as in LEACH. Re-clustering happens when CHs residual energy drops below a threshold value.

Simulations in [26] compare the performance of the proposed homogeneous clustering algorithm against the normal random selection method in terms of energy consumption. It shows that the battery power consumption for different size of message transmission is less in the proposed algorithm compounded to the random selection method.

2.2.10 EDCR: Energy Driven Cluster-Head Rotation

EDCR [9] relaxes the assumptions of being homogenous energy nodes and location awareness of nodes. This uses the residual energy of sensor nodes for selection and rotation of CHs and has observed that CH selection is completely distributed.

The CHs are selected based on the residual energy of the nodes. Non-CH nodes select their CHs based on the residual energy of the CH, and distance between CH and the node. Data transmission is similar as LEACH. CH rotation takes place when the residual energy of the CH drops below a threshold value.

Simulation results presented in [9] show that it outperforms LEACH, HEED, SEP and ANTCLUST algorithms in both homogeneous and heterogeneous energy WSN scenarios under free space and multi path radio propagation models. The reasons for EDCR to perform much better are its low overhead, energy based CH selection and rotation resulting in even local energy balancing. Therefore I have improved some of the basic methods used in EDCR algorithm in my research.

2.3 Sensor Network Model

This section presents a WSN model to be used in the rest of this research. This model has been derived from related literature. First, the assumptions that have been considered in the research are discussed. Then, presents the energy consumption model of a wireless sensor node is presented. Finally, different WSN lifetime measurement matrices are discussed.

2.3.1 Assumptions

Since, actual WSN are complex, researches have looked at different aspects of WSN with appropriate assumptions. Following preliminary assumptions are made to make the sensor network model mathematically tractable and these assumptions are in line with previous literature [9, 42].

1. The BS does not have any energy limitations.
2. All sensor nodes are identical and stationary after deployment.
3. A Contention based MAC protocol is used during cluster setup.
4. TDMA based data transmission is used for intra cluster communication.
5. There is no adjoining cluster interference.
6. A Symmetric radio communication model is used i.e. if a particular node can reach another node then the second can reach the first using same amount of energy.
7. Nodes can use transmit power control.
8. The required transmit power is calculated based on the received signal strength, i.e. the availability of Received Signal Strength Indicators in the nodes.
9. Sensor nodes are uniformly and randomly distributed in a rectangular region.
10. Sensor nodes can aggregate or fuse multiple data packets into one packet.

2.3.2 Energy Consumption Model

Previous cluster based sensor network algorithms consider only the transceiver energy consumption. However, node's different functional modules : Microprocessor, Transceiver and Sensor, consumes energy in different component states and state transitions. H.Y. Zhou et al. [43], have proposed an energy consumption model for a sensor node by considering the processor module, communication module and sensing module of a sensor node as shown in Fig. 2.3.

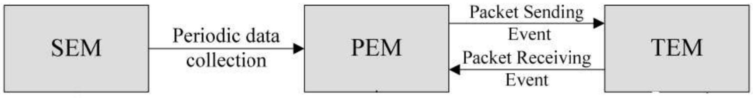


Fig. 2.3: Node Energy Model

Sensor Energy Model (SEM)

The sensor module is responsible for information collection and digital conversion. In this paper, the sensing module is supposed to operate in the periodic mode, in which sensors are opened and closed periodically.

The sensor energy consumption (E_{sensor}) can be expressed as in (2.1).

$$\begin{aligned} E_{sensor} &= E_{sensor-on} + E_{on-off} + E_{off-on} \\ &= N(V_s I_s T_s + e_{on-off} + e_{off-on}) \end{aligned} \tag{2.1}$$

where, V_s, I_s and T_s are the working voltage, current and time interval of sensor respectively. e_{on-off} is the one time energy consumption of closing sensor operation, e_{off-on} is the one time energy consumption of opening sensor operation. N is the number of sensor opening and closing operation.

Processor Energy Model (PEM)

The processor module is responsible for node control and data processing tasks. The microprocessor normally supports three operational states; sleep, idle, and run. Since this research consider a continuous monitoring application, processor module has two states (idle and run) and two state transitions.

Processor energy consumption E_{cpu} can be expressed as in equation (2.2).

$$\begin{aligned} E_{cpu} &= E_{cpu-state} + E_{cpu-change} \\ &= \sum_{i=1}^{m} P_{cpu-state}(i) T_{cpu-state}(i) + \sum_{j=1}^{n} N_{cpu-change}(j) e_{cpu-change}(j) \end{aligned} \tag{2.2}$$

where $E_{cpu-state}$ is the sum of the state energy consumption, $E_{cpu-change}$ is the sum of the state-transition energy consumption, $P_{cpu-state}$ is the power of state i, $T_{cpu-state}$ is the time interval in state i, $N_{cpu-change}$ is the frequency of state transition j, $e_{cpu-change}$ is the energy consumption of a single state transition j, which can be calculated as in equation (2.3), m is the number of the processor state (m=2)and n is the number of the state-transitions (n=2).

$$e_{cpu-change}(j) = T_{initial-end}(j) \frac{P_{initial}(j) + P_{end}(j)}{2} \tag{2.3}$$

where $P_{initial}$ is the power of the initial state in the state transition j, P_{end} is the power of the end state in the state transition j, and $T_{initial-end}$ is the time interval for the state transition j from the initial state to the end state.

Transceiver Energy Model (TEM)

The transceiver module is responsible for data sending and receiving. Normally it has six states; Transmitting, Receiving, Off, Idle, Sleep, and CCA/ED (Clear Channel Assessment/Energy Detect). However, here we consider four states : Transmitting, Receiving, Idle, and CCA/ED.

Transceiver energy consumption E_{trans} is similar to processor energy consumption, which is the sum of state energy consumption $E_{trans-state}$ and state-transition energy consumption $E_{trans-change}$.

Since we assume, nodes can adjust their transmission power according to the transmitting distance, we use equation (2.4) and (2.5) to calculate the energy consumption in transmitting state $E_{Tx}(l,d)$ and receiving state $E_{Rx}(l)$.

$$E_{Tx}(l,d) = E_{elec}l \; + \; \mathcal{E}_{amp}ld^{n} \tag{2.4}$$

$$E_{Rx}(l) = E_{elec}l \tag{2.5}$$

where E_{elec} is the energy at the transmitter or receiver circuitry, $\mathcal{E}_{amp}$ is the energy at the transmitter amplifier, l is the length of the message, d is the distance between transmitter and receiver, and n is the radio propagation path loss exponent.

To calculate the energy consumption in idle and CCA/ED states, equation (2.6) is used.

$$\begin{aligned} E_x &= P_x T_x \\ &= V_{tr} I_x T_x \end{aligned} \tag{2.6}$$

where E_x, P_x, I_x and T_x are the energy consumption, power consumption, electric current and time interval in state x respectively. V_{tr} is the working voltage.

$E_{trans-change}$ can be calculated as equation (2.3) in processor module.

2.3.3 Lifetime of the Sensor Network

The definition of the lifetime of a WSN depends on the application where the sensors are deployed. There are three common definitions for the lifetime of sensor network. Those are,

1. First Node Dies (FND)
2. Percentage of Nodes Active (PNA)
3. Last Node Dies (LND)

The goal of any self organizing WSN protocol is to increase the lifetime of all sensors in the network. That is, the self organizing and communication algorithms should achieve both energy balance and energy efficiency [44].

Chapter 3

Proposed Energy Efficient Unequal Clustering Algorithm

This chapter presents energy efficient unequal clustering algorithm named as EDCR-LGRUC (Energy Driven CH Rotation with Local and Global Re-clustering in Unequal Clusters). This addresses the drawbacks identified in the existing equivalent class of algorithms in Chapter 2. The algorithm uses a combination of both re-clustering methods, global and local [45]. With this method the lifetime of the network can be prolonged with efficient energy consumption of the sensor nodes and reduction in overheads. Furthermore, unequal clusters are formed based on the relative position of the CHs residual energy with respect to the other nodes in its neighborhood to optimize energy usage in data transmission. The member nodes select their CHs by considering the residual energy of CH and distance; to ensure that data can be transmitted with minimum delay and errors. Additionally, the algorithm adopts an energy-driven CH rotation triggering method which can further reduce the overheads in the network [46, 47].

3.1 Details of the Algorithm

The proposed algorithm has five phases: CH Candidacy phase, Cluster formation phase, Creating local re-clustering table phase, Data gathering phase and CH rotation phase. Each phase is explained in detail in the following subsections.

3.1.1 Cluster Head Candidacy Phase

The objective of this phase is to select the most suitable sensor node as the CH and find the communication range of it. Since a CH node consumes more energy, the nodes with more residual energy are selected as CHs.

Every sensor node s_i transmit *JOIN_MSG* within it's neighborhood and calculates the relative maximum energy in neighborhood of node i, $E_{rel\_max,i}$ as,

$$E_{rel\_max,i} = \max\big\{ \max_{j \in N_i^{R_{max}}} E_{res,j},\ E_{res,i} \big\} \tag{3.1}$$

where $N_i^{R_{max}}$ corresponds to set of nodes within a neighborhood of maximum radius R_{max} around s_i.

After calculating the maximum energy by all nodes, each sensor node s_i finds out its compatible communication radius based on the relative position of its residual energy with respect to it's neighborhood maximum energy level. Current researches [20, 41, 48] define the maximum compatible radius for each sensor node based on the distance to the BS. However, our algorithm uses a novel technique to calculate the maximum compatible radius $R_{comp,i}$ which is given by equation (3.2).

$$R_{comp,i} = \max\{(\frac{E^t_{res,i}}{E_{rel\_max,i}})R_{max}, R_{min}\} \tag{3.2}$$

where $E^t_{res,i}$ represents the residual energy of s_i at time instance t, R_{max} represents the maximum communication range of sensor nodes and R_{min} represents the minimum communication range, i.e. at least one node exists in its coverage. The calculation of these values are described in section 3.4.

Then the sensor node s_i transmits its candidacy message, *HEAD_MSG* within a neighborhood of radius $R_{comp,i}$ at a time instance $T_{candi,i}$ given by equation 3.3. At first, all sensor nodes consider themselves as potential candidates of being a CH. When a sensor node receives a CH advertisement from any other sensor node, will abandon its quest to become a CH.

$$T_{candi,i} = T(1 - P_i)\ +\ k_i \tag{3.3}$$

where T is the limited time interval for CH candidacy phase, $P_i \in\ [0, 1]$ represents the relative position of the node s_i with respect to the other nodes in its neighborhood R in terms of its residual energy level and k_i is a random time unit. k_i is introduced to reduce the possibility of collision among sensor node advertisements with identical P_i in the same neighborhood.

Additionally, by introducing P_i to the candidacy time, it can be applied for a homogeneous energy network as well as for a heterogenous energy network. P_i value for sensor node s_i is given by equation (3.4).

$$P_i = \frac{E^t_{res,i}}{E^t_{rel\_max,i}} \tag{3.4}$$

Furthermore we define a set $\mathbb{H}$ where,

$$\mathbb{H} = \{i | set\; of\; all\; nodes\; i\; where\; node\; i\;\; is\; a\; CH\}$$

3.1.2 Cluster Formation Phase

Any node s_j which is not a CH will select its CH based on residual energy of the CH and the ratio of receiving power to transmitting power of the *HEAD_MSG*. By considering residual energy of the CH, sensor nodes can select the highest residual energy node as their CH. Also, the ratio of receiving to transmitting power will indicate the distance between two nodes and the quality of the link. Hence, energy required for data communication can be reduced by reducing communication distance and selecting a best quality path which reduce re-transmission of data packets. Therefore to choose its CH_j node s_j uses the equation (3.5)

$$CH_j = \{i | \max_{i \in\, H \cap N^R_j} E^t_{res,i} \frac{P_{rx_{i,j}}}{P_{tx,i}}\} \tag{3.5}$$

where $E^t_{res,i}$ represents the residual energy of CH s_i at time instance t, $P_{rx_{i,j}}$ represents the received signal power from node s_i to node s_j and $P_{tx,i}$ represents the transmitted power of the advertisement message of node s_i.

After the CH candidacy time interval, node s_j selects it's CH s_i and sends a *ACCEPTANCE_MSG* to CH s_i. Subsequently CH s_i calculates its TDMA schedule for the nodes who have joined its cluster and broadcasts the schedule among them. Each member node awakens in its allocated time slot and transmits data. During other time slots it goes in to idle mode. Apart from the slots allocated for each member node in its cluster, the TDMA schedule will have a separate time slot reserved for the CH to send any message to its members, if any. This slot will also be used to send control information if any. All the member nodes will keep awake during this time slot to identify if there are any control messages from the CH.

3.1.3 Creating Local Re-clustering Table Phase

This is a mechanism newly introduced in this algorithm. The CH rotation is a combination of global and local CH rotation methods [59]. The objective of this phase is to find the nodes which can take over the CH role in future local CH rotations. The algorithm goes to a local CH rotation only if a suitable node exists within the CH neighborhood $R_{d,i}$ where $R_{d,i} < R_{comp,i}$ as shown in Fig (3.1). Hence, $R_{d,i}$ can be stated as $R_{d,i} = \alpha R_{comp,i}$

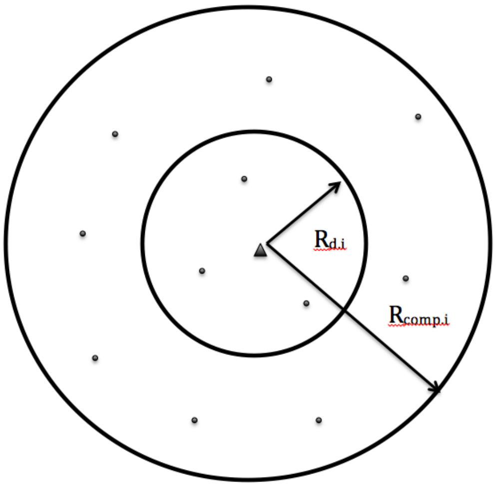


Fig. 3.1: Nodes for local re-clustering

After all member nodes join CH s_i, it creates a table called the Local_Re_Clustering table and makes entries if the following condition satisfied.

$$distance\, to\, the\, CH \;\leq\; R_{d,i} \;\; and \;\; E_{res,j} \;>\; 0$$

To find the nodes within the area of radius $R_{d,i}$, CH s_i sends a control message $REQUEST\_INFORMATION$ to nodes within neighborhood $R_{d,i}$ by changing the transmission power. The nodes which receive that message will then acknowledge with their residual energy $E^t_{res,j}$ and transmission power $P_{tx,j}$. The reason for sending the transmission power is to get an idea on how far it is located from the CH.

The Local_Re_Clustering table contains the columns; node ID, and ratio between $P_{rx_{i,j}}$ and $P_{tx,j}$ i.e as a indication of distance. This table is maintained until a global re-clustering occurs. Also, when the local CH rotation takes place, this table information is transferred to the new CH.

3.1.4 Data Gathering Phase

The next phase of the algorithm is data transmission where the nodes go into the normal routine operation of periodic data gathering. The nodes use single hop communication with their CHs, and the CHs communicate with the BS. Member nodes s_j send their data in the allocated time slot according to the TDMA schedule to their CH s_i . The CH uses a data aggregation algorithm to merge the received data from its cluster member nodes before sending to the BS to reduce the amount of unwanted or repetitive information transmitted to the BS.

3.1.5 CH Rotation Phase

The proposed algorithm uses a novel combining method of global and local re-clustering methods. When CH s_i identifies that its residual energy is falling below the threshold value c_i calculated by the algorithm, it triggers to a CH rotation phase by sending *TRIGGER_MSG* to its member nodes.

Since, EDCR [9] uses global re-clustering, it uses one threshold value for the whole network. However, with the novel method used in this algorithm, each CH has a different threshold value based on their residual energy and number of member nodes. With this, the unwanted CH rotations can be reduced. As a result, energy usage of the network can be further optimized and overheads in the network can be reduced.

The *TRIGGER_MSG* message requests residual energy levels of CH s_i's member nodes. Then, CH s_i finds three member nodes with the highest residual energy and checks whether at least one of those exists in the Local_Re_Clustering table. If one exists CH triggers to a local re-clustering, otherwise it triggers to a global re-clustering.

Local Re-clustering

CH s_i calculates time instances for local CH candidacy $T_{Local\_Candi,l}$ for the chosen nodes in the Local_Re_Clustering table as in equation (3.6). Then it transmits time instance values to the member nodes.

$$T_{Local\_Candi,l} = \gamma(1 - \frac{E_{res,l}}{E_{max,i}}) + (1-\gamma)(1 - \frac{P_{rx_{i,j}}}{P_{tx,j}}) \tag{3.6}$$

where $\gamma \in [0, 0.5]$ is random number introduced to reduce the possibility of having same time instance for member nodes s_l.

When node s_l received it time instance $T_{Local\_Candi,l}$ from its CH s_i, it sets the timer and send a CH candidacy message to all the nodes in the cluster. If any sensor node chosen as a new CH receives a CH advertisement message from any other sensor node, it will abandon its quest to become a CH. Also, after the candidacy message, the previous CH s_i sends the information in the Local_Re_Clustering table to the new CH s_l.

Furthermore, it is not necessary to recreate a TDMA frame. Since all the nodes can communicate in the same time slot and the previous CH s_i can communicate in the time slot allocated to present CH s_l. Hence after this phase it can directly go to the data gathering phase.

Global Re-clustering

If any node can not find a node in the same cluster to handover the CH role, CH s_i sends *TRIGGER_CH_MSG* to the BS asking for a global re-clustering. When the BS receives the message, it sends a *Re_CLUSTER_MSG* to all CHs in the network. Then all CHs in the network sends a *TRIGGER_MSG* to its member nodes requesting their residual energy level. After receiving residual energy levels from member nodes, each CH s_i finds the maximum residual energy in the cluster $E_{max,i}$ and transmits it to the CHs in the neighborhood $2R_{max}$.

The highest relative residual energy level is computed by each CH s_i using the equation (3.7) and transmit it to their member nodes. Then member nodes set their $E_{rel\_max,j}$ as $E_{relative\_res,i}$ and go for the CH candidacy phase.

$$E_{relative\_res,i} = \max\left\{\left\{\max_{j \in H \cap N_j^{2R+\varepsilon}} E_{max,j}\right\}, E_{max,i}\right\} \tag{3.7}$$

3.2 Algorithm Pseudo Code

```
if Initial Round then
    Broadcast $Join\_Msg(ID, E_{res,i})$
```

```
    Compute $P_i, R_{comp,i}$
end if
All nodes $potentialCH \leftarrow TRUE$ and $finalCH \leftarrow FALSE$
$k_i \leftarrow rand(0, 1)$
Compute $T_i$ from equation 3.3
while $t < T$ do
    if $T_i == t$ & $S_i.potentialCH == TRUE$ then
        Broadcast $Candidacy\_Msg(ID, R_{comp,i}, E_{res,i}, E_{tx})$
        $S_i.finalCH \leftarrow TRUE$
    end if
    if $S_j.potentialCH == TRUE$ & $hear\ a\ Candidacy\_Msg from\ i \in N_j^{R_{max}}$ then
        $S_j.potentialCH \leftarrow FALSE$
    end if
end while
if $j \notin H$ then
    Select $s_j.CH$ using equation 3.5
    Send a $Join\_Request\_Msg(ID, E_{res,j}, P_{tx})$
end if
if $i \in H$ then
    Collect all $Join\_Request\_Msg$
    Prepare the TDMA schedule and broadcast to members
    Calculate dynamic re-clustering threshold
    Prepare local re-clustering table
end if
if $i \in H$ & $E^t_{res,i} < c_i$ then
    Request residual energy levels of it's member nodes
    $nextCH \leftarrow$first three nodes having maximum residual energy
    if At least one node is in local re-clustering table then
        Broadcast $T_{Local\_Candi,l}$
        while New CH selected do
            if $t == T_{Local\_Candi,l}$ then
                Broadcast $Candidacy\_Msg$
                $s_l.finalCH \leftarrow TRUE$
                $s_i.finalCH \leftarrow FALSE$
```

```
                Clear timers
            end if
        end while
    else
        Send $Trigger\_Msg$ to BS
        Broadcast $E_{max}$ for $2R_{max}$ neighborhood
        Initiate CH selection phase
    end if
end if
```

3.3 Accuracy of the Algorithm

Observation 1. The proposed algorithm is completely distributed. A node s_i can be elected as a CH based on locally calculated candidacy announcement time T_i and if any node receives a CH candidacy announcement from other sensor node will abandon their quest to become a CH. Also, in local re-clustering, the new CH selection is limited to a area with a radius of R_d to locate the CH closest to the centroid of the cluster.

Observation 2. The algorithm effectively balances the energy level of all nodes. This is achieved by selecting the highest residual energy node as the CH, calculating the communication range of the CH based on it's second degree neighborhood's maximum energy and energy-driven CH rotation. Further, energy based cluster formation and selecting communication range helps to balance the local energy of heterogeneous energy sensor networks.

Observation 3. At the end of the CH candidacy phase, a node will either become a CH or a member node. At first, all sensor nodes consider themselves as potential candidates of being a CH. However, if a sensor nodes s_j receives a CH advertisement from any other sensor node s_i it will abandon its quest to become a CH and join to a cluster within its neighborhood.

3.4 Optimization of Control Parameters

The performance of the algorithm is mainly determined by the proper selection of three parameters, namely:

1. Maximum communication range of a CH (R_{max})
2. Radius of the partial local delegation area (α)
3. Dynamic re-clustering constant of each CH (c_i)

Thus, this section presents suitable techniques for finding the optimum values of the above parameters in achieving the desired objectives.

3.4.1 Optimum Maximum Communication Range of a CH

The selection of optimum communication range is crucial for the energy optimization of the network. Even though this is an unequal clustering algorithm, we assume that all the CH's broadcasting radius is R_{max} for the simplicity of the calculation. The CH's broadcasting radius is the main factor which determines the expected number of clusters. Hence, if R_{max} increases, few clusters will cover the entire WSN and this results in member nodes having to communicate over large distances and each CH handles more nodes. On the other hand, if R_{max} reduces, there would be more CHs which need to be alive all the time and most of them need to communicate with the far away BS. Therefore, the proper selection of R_{max} is important.

First we need to find the CH density by using the probability density function (PDF) of cluster area Ω. For that we used the method proposed in EDCR [9] algorithm with some changes. In [9] , the author assume that a single cluster consists of a large number of sensor nodes, which cannot apply for our application. Hence this assumption is released in our calculation.

To find the PDF of Ω, the following equation is used.

$$P(A.B)(\delta_1 \leq \Omega \leq \delta_2) \ = \ P(A/B)(\delta_1 \leq \Omega \leq \delta_2) \ \times \ P(B)(\delta_1 \leq \Omega \leq \delta)_2 \quad (3.8)$$

where $0 \leq \delta_1 \leq \delta_2 \leq \Pi R^2$, $P(B)$ is the probability that no uncovered nodes exist in a given cluster neighborhood and $P(A/B)$ is probability of the cluster area given no uncovered nodes exist in a given cluster neighborhood.

The smallest possible cluster size ($\frac{\sqrt{3}}{2}R^2$) exist when a given CH's neighboring CHs sit on the circumference of its CH broadcasting coverage area with radius R and largest possible cluster size with no uncovered area is $\frac{3\sqrt{3}}{2}R^2$ [9]. If A_Ω is the uncovered area formed by cluster setup, $P(B)$ and $P(A/B)$ can be stated as follows.

$$P(B) = \begin{cases} e^{-\lambda A_\Omega}, & \text{for } \Omega > \frac{3\sqrt{3}}{2}R^2 \\ 1, & Otherwise \end{cases}$$

$$P(A/B) = \begin{cases} e^{-\lambda A_\Omega}, & \text{for } \frac{3\sqrt{3}}{2}R^2 < \Omega < \Pi R^2 \\ 1, & \text{for } \frac{\sqrt{3}}{2}R^2 \leq \Omega \leq \frac{3\sqrt{3}}{2}R^2 \\ 0, & Otherwise \end{cases}$$

Form equation (3.8),

$$P(A.B) = \begin{cases} e^{-2\lambda A_\Omega}, & \text{for } \frac{3\sqrt{3}}{2}R^2 < \Omega < \Pi R^2 \\ 1, & \text{for } \frac{\sqrt{3}}{2}R^2 \leq \Omega \leq \frac{3\sqrt{3}}{2}R^2 \\ 0, & Otherwise \end{cases}$$

Therefore,

$$PDFofP(A.B) = \begin{cases} e^{-2\lambda(\Omega - \frac{3\sqrt{3}}{2}R^2)}, & \text{for } \frac{3\sqrt{3}}{2}R^2 < \Omega < \Pi R^2 \\ \dfrac{1}{\sqrt{3}R^2}, & \text{for } \frac{\sqrt{3}}{2}R^2 \leq \Omega \leq \frac{3\sqrt{3}}{2}R^2 \\ 0, & Otherwise \end{cases} \tag{3.9}$$

Furthermore, the probability that a randomly chosen node is a CH, y, is the ratio between number of CHs in a given area and the number of nodes in the same given area. It can be further simplified as,

$$\begin{aligned} y &= \frac{Number\ of\ CHs\ in\ a\ given\ area}{Number\ of\ nodes\ in\ the\ same\ given\ area} \\ &= \frac{1}{Number\ of\ nodes\ in\ a\ random\ cluster} \\ &= \frac{1}{\Omega\lambda} \end{aligned} \tag{3.10}$$

Therefore the PDF of y can obtain from equation (3.9) and (3.10)

$$PDFofy = \begin{cases} e^{-2\lambda(\frac{1}{y\lambda}-\frac{3\sqrt{3}}{2}R^2)}, & \text{for } \frac{1}{\Pi\lambda R^2} < y < \frac{2}{3\sqrt{3}\lambda R^2} \\ \dfrac{1}{\sqrt{3}y^2\lambda R^2}, & \text{for } \frac{2}{3\sqrt{3}\lambda R^2} \leq y \leq \frac{2}{\sqrt{3}\lambda R^2} \\ 0, & Otherwise \end{cases} \tag{3.11}$$

According to equation (3.10), y can be further represented by,

$$y = \frac{k}{N}$$

where, k is the number of CHs at a given instant and N is the total number of nodes. Hence $E[y]$, the expected probability that a given node is a CH can be denoted as,

$$E[y] = E[k/N] = E[k]/N = \lambda_c/\lambda \tag{3.12}$$

where, λ_c is the CH density.

$$\begin{aligned} E[y] &= \int_{-\infty}^{+\infty} y(PDFofy)\mathrm{d}y \\ &= \frac{e^{-3\sqrt{3}\lambda R^2}}{\lambda}[0.19 + \sum_{n=1}^{\infty} |\frac{(2\Pi R^2\lambda)^n|}{n.n!} - \frac{(-3\sqrt{3}R^2\lambda)^n|}{n.n!}|] \\ &\quad + \frac{1}{0.5018\Pi\lambda R^2} \end{aligned} \tag{3.13}$$

From equation (3.12) and (3.13), we can find the CH density.

The total data gathering cost of one round J_{total} can be written as follows,

$$J_{total} = \sum_{i \in H}(J_{CH}(i) + \sum_{j \in memeber\ nodes\ of\ s_i} J_{CM}(j,i)) \tag{3.14}$$

where $J_{CH}(i)$ is the amount of energy to transfer one bit of information originated from the CH s_i and $J_{CM}(j,i)$ is the amount of energy to transfer one bit of information originated from a cluster member s_j belonging to the CH s_i. These values can be calculated using the equation described in section 2.3.2.

However, for this analysis we need the expected value of J_{total} denoted by $\widehat{J}_{total}$. Therefore, Campbell's Theorem was used [9].

$$\widehat{J}_{total} = (\lambda_c A)\widehat{J}_{CH}(i) + (N - \lambda_c A)\widehat{J}_{CM}(j,i) \tag{3.15}$$

Note : Here, $\widehat{f}(x) = \int_A \frac{f(x)}{A} dx$.

Since, $\widehat{J}_{total} = f(R)$, it is possible to identify the optimum $R = R_{max}$ by solving $\frac{\partial \widehat{J}_{total}}{\partial R}$. Due to the complexity of these equations, we use computer aided mathematical tool Matlab for calculation.

3.4.2 Optimum Radius of the Partial Local Delegation Area

To find the optimum R_d value, we used the same objective function proposed in [45].

$$\begin{aligned} Cost\ of\ global\ re-clustering &\geq Opportunity\ cost\ of\ local\ delegation \\ N_d E_{OGR} &\geq E_{TLD-P} - x N_d E_{DGR} \end{aligned}$$

where N_d is the number of nodes in the partial local delegation area, E_{OGR} is the total energy cost of transmitting overhead data in global re-clustering, E_{TLD-P} is total energy cost in partial local delegation, E_{DGR} is the total energy cost of data transmission in global re-clustering and x is the number of data rounds which triggers a new CH candidacy.

To find the energy cost in each case, we consider only the transmission and receiving energy of the transceiver. Since the objective function is a comparison between two scenarios, CPU and sensor energy cost will cancel out.

E_{OGR} can be calculated by adding the energy required for CH candidacy (broadcast CH candidacy and TDMA schedule), cluster formation (join member nodes to CH) and CH rotation (CH rotation triggering message to BS and secondary neighborhood). E_{TLD-P} and E_{DGR} can be calculated by adding energy required to transmit data from a single sensor node to BS.

3.4.3 Optimum Dynamic Re-clustering Threshold of each CH

To find the dynamic re-clustering threshold, we assume that CH is at the center of the cluster. Since local re-clustering is limited to a radius of R_d, we can consider that the CH is very much closer to the center of the cluster. Also, each node in a cluster gets an opportunity to become a CH in a round robin fashion [49].

Let $X_{j,i}$ is the number of data transmission that node i serves as a CH in the

j^{th} Epoch. Epoch can be defined as the number of data transmission rounds that allows all nodes in a cluster serve to as a CH once. $E_{j,i,p}$ is the residual energy level of a node p, at the beginning of node i CH period, in the Epoch j. E_{CH} is the total energy spent by a node as a CH, in a given data transmission round. E_{CH} consists of energy required for receiving data packets from all member nodes, transmitting control messages to member nodes, and transmitting and receiving aggregated data from second neighbourhood. Then, $X_{j,i}$ can be defined as,

$$X_{j,i} = \frac{(1 - c_i)E_{j,i,i}}{E_{CH}} \tag{3.16}$$

Next, τ is denoted as the total number of data transmission rounds that node 0 completes before its total energy depletes. Let, τ_1 represents the total number of data transmission rounds that node 0 is alive, excluding the data transmission rounds it spends with the last CH, before it dies. τ_2 is the number of data transmission rounds that node 0 spends with its last CH, before it dies. Then it can be noted that, $\tau = \tau_1 + \tau_2$.

$$\tau_1 = \begin{cases} \displaystyle\sum_{p=0}^{j-1} \sum_{q=0}^{N/E[k]-1} X_{p,q} + \sum_{q=0}^{i-1} X_{j,q}, & \text{for } j \geq 1 \\ \displaystyle\sum_{q=0}^{i-1} X_{0,q}, & \text{for } j = 0 \end{cases} \tag{3.17}$$

$$\tau_2 = \begin{cases} \dfrac{E_{j,i,0}}{E_{nonCH}}, & \text{for } i \neq 0 \\ \dfrac{E_{j,0,0}}{E_{CH}}, & \text{for } i = 0 \end{cases} \tag{3.18}$$

Thus,

$$\tau = \tau_1 + \tau_2 = f(c) \tag{3.19}$$

The objective is to maximize τ. Hence, when $\tau \to \max(\tau)$, then $c_i \to c_{i,opt}$. In order to find this, computer aided mathematical software can be used. In this thesis Matlab simulation software is used.

3.5 Simulation results

In this section, the performance of the proposed algorithm was evaluated via simulations. For the simulation, the MATLAB simulation platform was used. For

Table 3.1: State Power and Transition Time of Strong ARM SA-1100

	Parameter	Value
State Power	Run	400mw
	Idle	50mw
State Transition Time	Run-Idle	$10\mu s$
	Idle-Run	$10\mu s$

Table 3.2: State Current and Transition Time of CC2420

	Parameter	Value
State Current	Idle	$426\mu A$
	CCA/CD	17.4mA
State Transition Time	Tx/Rx-Idle	$2\mu s$
	Idle-Tx/Rx	$192\mu s$
	CCA/CD-Idle	$2\mu s$
	Idle-CCA/CD	$192\mu s$

Table 3.3: State Transition Power and Work Voltage and Current of DS18B20

	Parameter	Value
State Transition Power	Off-On	0.0002J
	On-Off	0.0001
Working	Voltage	5V
	Current	1mA

the simulation of the node energy model, we suppose a WSN node that consists of a Intel Strong ARM SA-1100 Microprocessor, a Chipcon CC2420 transceiver and a Dallas digital temperature DS18B20. Table 3.1, 3.2 and 3.3 presents the parameter values of microprocessor, transceiver and temperature sensor respectively. The other simulation parameters are shown in Table 3.4. [20]

3.5.1 Cluster Head Distribution of the Algorithm

CH distribution of the algorithm is shown in the Figure 3.2. The BS is located at the center of the network. According to the figure, CHs are distributed all over the network to reduce the transmission energy in data collection. Also, Table 3.5 illustrate the effect of unequal clustering used in this algorithm. For example,

Table 3.4: Simulation Parameters

Parameter	Value
E_{elec}	50 nJ/bit
$\mathcal{E}_{amp\_fs}$	100 pJ/bit/m^2
$\mathcal{E}_{amp\_mp}$	0. 0013 pJ/bit/m^4
Setup packet size	60 bits
Data packet size	2000 bits
Area of network	50 m × 50 m
Number of nodes	200

Cluster 1's CH distance to the BS is 23m, but it has a communication range of 13m because it's residual energy is high compared to others. However cluster 12's CH distance to the BS is 14m, but it has a communication range of 9.8m. Hence with this, proposed algorithm has been able calculate the best communication range for CHs to optimize the energy usage.

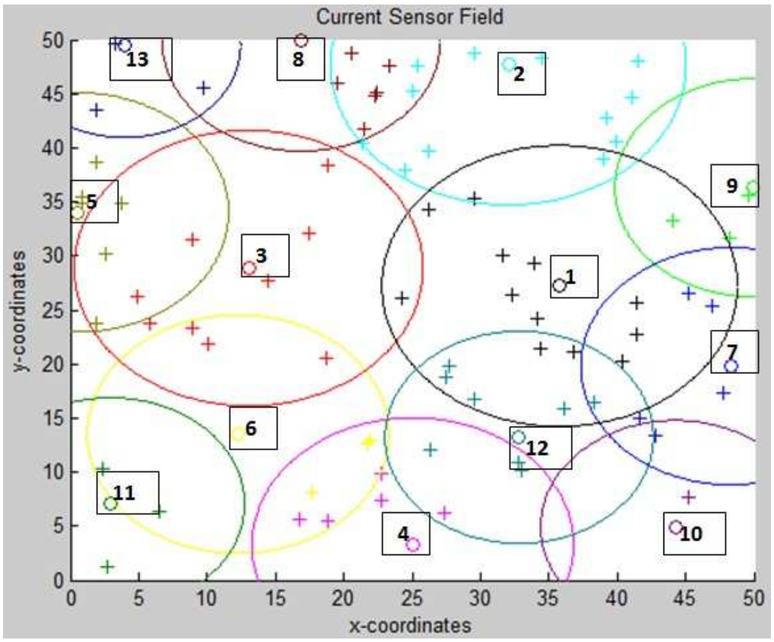


Fig. 3.2: CH distribution over the network

3.5.2 Stability of the Algorithm

Here the stability of the algorithm was calculated by the distribution of CH in each round. Fig 3.3 shows the distribution of clusters in LEACH, SEP, HEED, EDCR

Table 3.5: CH Communication Range Variation with Energy

Cluster Number	Communication Radius	Residual Energy	Distance to the BS
1	13m	0.3382J	23.79m
2	13m	0.3395J	11.01m
3	12.75m	0.334J	12.57m
4	11.76m	0.3163J	21.73m
5	11.07m	0.2850J	26.11m
6	11.03m	0.2996J	17.15m
7	10.98m	0.3062J	23.89m
8	10.17m	0.2767J	26.15m
9	10.08m	0.2876J	27.36m
10	9.84m	0.2876J	27.80m
11	9.82m	0.2621J	28.45m
12	9.81m	0.2662J	14.14m
13	8.46m	0.2331J	32.21m

and the proposed algorithm. Randomly selected 100 rounds of the simulation were used for the calculation.

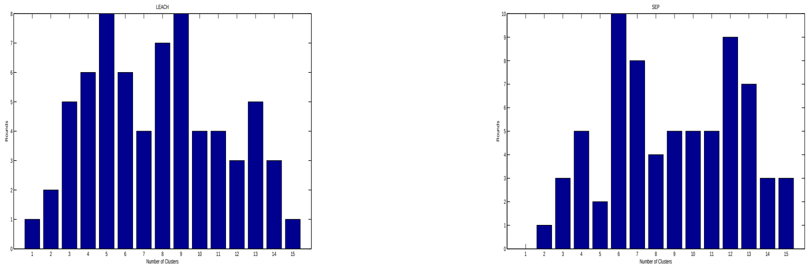
In LEACH and SEP number of clusters fluctuates with number of rounds. The reason is, those two algorithms use a fully random approach to elect CHs. As a result cluster size variation is high, although the expected number of CHs per round is deterministic. As in the figure, a situation like one CH covers the whole network also might occur. Therefore the stability of these two algorithms is very less. But HEED, EDCR and the proposed algorithm have a more steady distribution of clusters which lead to higher stability.

3.5.3 Energy Efficiency of the Algorithm

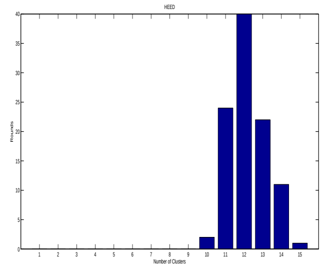
The performance of the proposed algorithm is compared with existing WSN clustering algorithms, LEACH, SEP, HEED and EDCR. For the simulation both homogeneous and heterogeneous energy networks were considered.

In implementation of LEACH, the predetermined number of CHs in the network is used as 5% and every node can cover the whole network. In SEP, 20% of nodes have 4 times the extra energy as in [9].

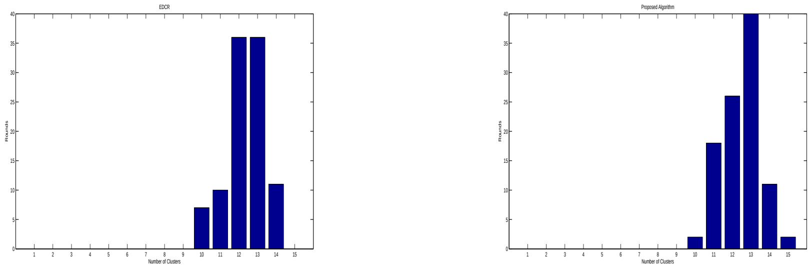
In order to present the comparison of the proposed algorithm with LEACH, SEP, HEED, and EDCR, following four cases under free space propagation model and multipath fading propagation model were considered by selecting a value for n between 2-4.



(a) LEACH (b) SEP



(c) HEED



(d) EDCR (e) PROPOSED

Fig. 3.3: Cluster distribution in each round (Rounds vs Number of clusters)

Case I : Homogeneous Network of 200 nodes each with 0.5J energy randomly distributed in a 50 × 50 region with BS located at (25,25)

Case II : Homogeneous Network of 200 nodes each with 0.5J energy randomly distributed in a 50 × 50 region with BS located at (75,25)

Case III : Heterogeneous Network of 200 nodes with energies 0.3J to 0.8J (randomly assigned) randomly dispersed in a 50 × 50 region with BS located at (25,25).

Case IV : Heterogeneous Network of 200 nodes with energies 0.3J to 0.8J (randomly assigned) randomly dispersed in a 50 × 50 region with BS located at (75,25).

Note 1: Case I and III refers to free space propagation model and Case II and

IV refer to multipath fading propagation model.

Note 2: SEP algorithm cannot consider as complete homogenous or heterogenous network, due to two types of energy nodes it uses. To overcome this problem we used 20% of nodes having 4 times (0.5J 4 = 2J) extra energy [9].

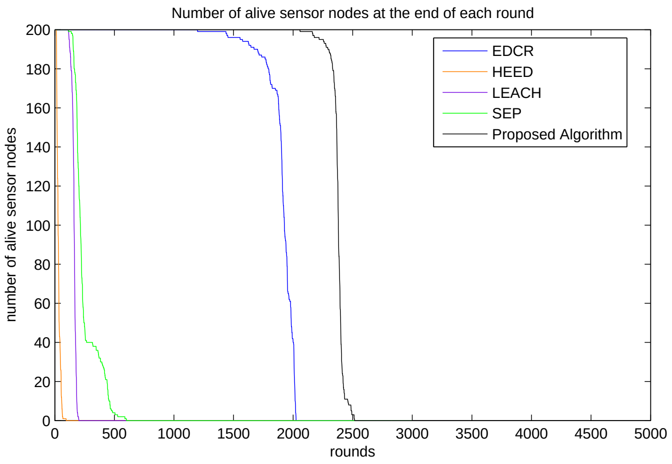


Fig. 3.4: Energy Efficiency - Case I

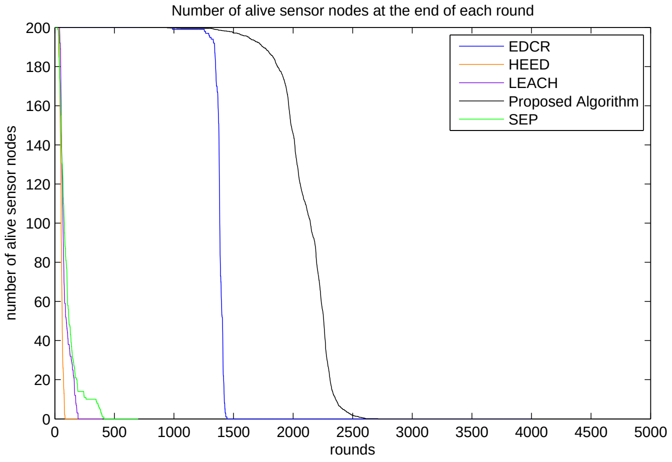


Fig. 3.5: Energy Efficiency - Case II

Fig. 3.4 to Fig. 3.7 shows the number of sensor nodes remaining alive with respect to the number of data transmission rounds for all four cases. From the results obtained, the proposed algorithm has nearly ten times larger network lifetime compared to LEACH, HEED and SEP. Therefore the future comparison, we are not going to use these three algorithms. Also the proposed algorithm optimized the energy usage in the network better than EDCR in all three lifetime measurements listed in Chapter 2. There is nearly 1000 data round optimization

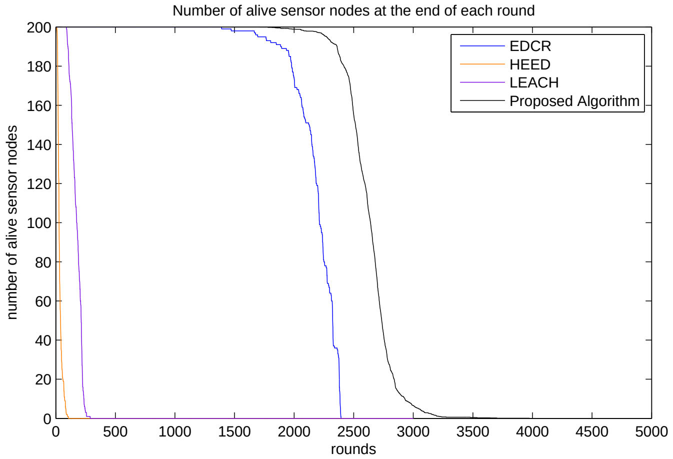


Fig. 3.6: Energy Efficiency - Case III

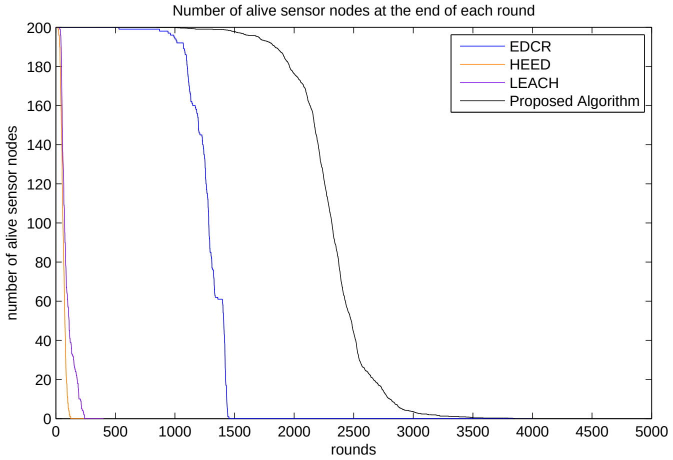


Fig. 3.7: Energy Efficiency - Case IV

with our proposed algorithm. This has been achieved by using the proposed unequal clustering and combination of global and local re-clustering. In EDCR, the global re-clustering is always used and as a result overheads in the network increase.

Finally, from all the results obtained the proposed algorithm has outperformed LEACH, HEED, SEP, and EDCR algorithms in homogeneous and heterogeneous networks. The reason for the outperforming is, the equation used in calculating compatible communication range and the method used in re-clustering. Moreover, when calculating the optimum values, some of the assumptions used in previous research were released.

Chapter 4

Self-Organization of Wireless Sensor Networks Based on Severity of an Emergency Environment

This chapter proposes an optimized self-organizing algorithm named as SCAE (Severity based Clustering Algorithm for Emergency) to prolong the network lifespan during an emergency [50]. A WSN deployed in multi-story building to detect and monitor emergency situations, by using smoke, temperature, and color sensors is considered. The sensor nodes monitor the status of the emergency situation, transmit relevant information to relevant parties (e.g. Firefighters).

urrent clustering algorithms focus on energy usage of the node and some other parameters such as bandwidth and packet synchronization. Unfortunately there is a lack of coherence in research when it comes to self-organizing algorithms for emergency support. Hence, the severity status of the emergency is used with the residual energy of the nodes during the self-organization of the network . The estimation of the severity is obtained by filtering the Dempster-Shafer (DS) belief values which are generated from multi-modality sensor data.

4.1 Preliminaries

4.1.1 Dempster-Shafer(DS) Theory

DS theory [51] can be interpreted as a generalization of Bayesian probability theory. The probabilities are assigned to sets as opposed to mutually exclusive singletons. The underline notions and the definitions are briefly discussed in this section.

Let $\Theta = \{\theta_1, \theta_2, ...\theta_n\}$ denote the total set of mutually exclusive and exhaustive propositions referred to as the frame of discernment (FOD). Elements in the power set form all propositions of interest. A proposition is referred to as a singleton and represents the lowest level of discernible information. Other propositions are referred to as composites, e.g.,$(\theta_1, \theta_2) \subseteq \Theta$. A-B denotes all propositions in A after removal of those propositions that may imply B.

There are three important functions in DS theory, the basic probability assignment function (bpa or m), the Belief function (Bel), and the Plausibility function (Pl).

Definition 1

The bpa (m) defines a mapping of the power set to the interval between 0 and 1, where the bpa of the null set is 0, and the summation of the bpas of all the subsets of the power set is equals to 1.
$m : 2^\theta \Rightarrow [0, 1]$
$m(\phi) = 0$; and $\Sigma_{A \subseteq \Theta} m(A) = 1$ The mass of a composite proposition is free to move into its singletons. This is how the notion of ignorance, the main feature in DS theory is modeled.
A proposition that possesses a nonzero mass is referred to as a focal element. The set of focal elements is denoted by $\Im$ and the triple $\{\Theta, \Im, m\}$ is referred to as the body of evidence (BOE).

Definition 2

The upper and lower bounds of an interval is defined from the basic probability assignment (bpa).
The lower bound is referred as Belief (Bel) for a set A defined as the sum of all the basic probability assignments of the proper subsets (B) of the set of interest (A) (B $\subseteq$ A).

The upper bound Plausibility (Pl), is the sum of all the basic probability assignments of the sets (B) that intersect the set of interest (A) (B $\cap$ A $\neq \emptyset$).
Given a BOE $\{\Theta, \Im, m\}, m(A) \subseteq \Theta$

$$Bel(A) = \Sigma_{B \subseteq A} m(B) \tag{4.1}$$

$$Pl(A) = 1 - Bel(\bar{A}) = \Sigma_{B \cap A \neq \emptyset} m(B) \tag{4.2}$$

Definition 3

Dempsters rule combines multiple evidence functions through their basic probability assignments (m). These belief functions are defined on the same frame of discernment (FOD) based on independent arguments or bodies of evidence (BOE). Note that Dempster's rule of combination is purely a conjunctive operation (AND).

$$m(A)_{\Theta} = \frac{\Sigma_{C,D:C \cap D = A} m(C)_{\theta 1} m(D)_{\theta 2}}{K} \tag{4.3}$$

where $K = (1 - \Sigma_{C,D:C \cap D = \phi} m(C)_{\theta 1} m(D)_{\theta 2}), \forall A \subseteq \Theta$

4.2 Description of the Algorithm

The main objective of SCAE is to minimize the communication loss due to node failures in an emergency environment. This is achieved by delaying the CH failures in the network and allocating less priority to non-CH nodes to select their CH who might get dropped from the network quickly. In this chapter, a measurement called severity is used to find out the level of the emergency and this is incorporated with the clustering algorithm to make decisions.

SCAE consists of five phases: Estimating the severity level of an emergency phase, CH candidacy phase, Cluster formation phase, Data gathering phase and CH rotation phase. Detailed descriptions of each phase are discussed in the following subsections.

4.2.1 Estimating the Severity Level of an Emergency Phase

The main objective of this part of the algorithm is to accurately estimate the emergency level. In [52], the authors propose a framework to estimate the severity level of an emergency situation using Dampster-Shafer formalism and Evidence Filtering. WSNs with multiple sensor modalities are considered to increase the accuracy of the results. The proposed DS belief filtering framework is capable of extracting useful information buried in the raw data gathered from multiple sensor modalities. If the state of the environment under observation is defined as x_i, time instances as t_i, space coordinates as θ_i, and modalities as s_i, then the Dempster-Shafer Frame of Discernment (FOD) is defined over states under observation,

DS FOD=$\{x_1, ...x_n\}$

Firstly DS belief and/or plausibility values should be generated according to the data obtained from each sensor modality. Each sensor-modality generates a separate evidence signal by obtaining evidences according to 4.4.

$$\lambda_{t_k} = f(\zeta_{s_i,t_k}) \tag{4.4}$$

Where function f can be any evidence combination method.

Then Multiple Input Single Output (MISO) Evidence Filter will be used to filter out important signal components from unwanted noise in the raw sensor data.

$$Bel(B)(t) = \Sigma_{k=1}^{M}\alpha_k Bel(B)(t-k) + \Sigma_{i=1,k=0}^{N,M}\beta_{s_i,k}Bel_{s_i,k}(B|A)(t-k) \tag{4.5}$$

$$Pl(B)(t) = \Sigma_{k=1}^{M}\alpha_k Pl(B)(t-k) + \Sigma_{i=1,k=0}^{N,M}\beta_{s_i,k}Pl_{s_i,k}(B|A)(t-k) \tag{4.6}$$

$$\alpha_k \geq 0; \beta_{s_i,k} \geq 0 \tag{4.7}$$

$$\Sigma_{k=1}^{M}\alpha_k + \Sigma_{i=1,k=0}^{N,M}\beta_{s_i,k} = 1 \tag{4.8}$$

The conditions in 4.7 and 4.8 are to ensure that the belief and plausibility functions constitute valid DS functions.

During the information filtering, filter updates the existing knowledge base with the new evidence while taking into account the inertia and integrity of its already available knowledge. Coefficient α is the weight given to the available knowledge while β is the weight given to incoming evidence.

The output of the MISO Evidence Filter provides a reasonable indication on the severity of the emergency. Each sensor node in the network runs this MISO filtering and sends the output at each time step to the cluster head.

4.2.2 Cluster Head Candidacy Phase

The most suitable CHs are selected in this phase. Current studies are concerned only with the residual energy of the node while selecting the CHs. However in an emergency the key parameter is not necessarily the energy of the node. The parameter, severity of the node, also need to be considered. In clustering algorithm most crucial role is CH. Hence, in SCAE, a node with highest energy and least severity is selected as the CH.

Initially, all sensor nodes consider themselves as potential candidates of being a CH. The sensor nodes receive a CH advertisement from any other sensor node will abandon their quest to become a CH. Each node i transmit its residual energy $E_{res,i}$ to its neighborhood. Then node i calculates the maximum energy $E_{rel\_max,i}$ as

$$E_{rel\_max,i} = \max\left\{ \max_{j \in N_i^R} E_{res,j},\ E_{res,i} \right\} \tag{4.9}$$

where N_i^R corresponds to set of nodes within a neighborhood of maximum radius R from node i. Then the sensor node i transmit its candidacy message within a neighborhood of radius R at a time instance $T_{candi,i}$ given by equation (4.10)

$$T_{candi}(i,t) = T((1 - P(i,t))(1-\gamma) + \gamma Bel(i,t)) \ + \ K_i \tag{4.10}$$

where T is the limited time interval for CH candidacy phase, $\gamma \in \ [0, 0.5]$ is a random time unit, $P(i,t) \in \ [0,1]$ represents the relative position of the node i with respect to the other nodes in it's neighborhood R in terms of its residual energy level, $Bel(i,t)$ represents the severity of the CH at time instance t and K_i is a random time unit. K_i is introduced to reduce the possibility of collision among sensor node advertisements with identical $P(i,t)$ and $Bel(i,t)$ in the same neighborhood. $P(i,t)$ value for sensor node i is given by equation (4.11).

$$P(i,t) = \frac{E^t_{res,i}}{E^t_{rel\_max,i}} \tag{4.11}$$

4.2.3 Cluster Formation Phase

In this phase, node j which is not a CH selects the most suitable CH i as its CH. For the CH selection, non-CH nodes consider three things; residual energy of the CH, distance to the CH, and severity of the CH. Hence, to select its CH_j node j uses the equation (4.12)

$$CH_j = \{i| \max_{i \in H \cap N^R_j} CHPriorityValue(i,j)\} \tag{4.12}$$

$$CHPriorityValue(i,j) = \begin{cases} \frac{E^t_{res,i}}{(1+Bel(i,t))} \frac{P_{rx_{i,j}}}{P_{tx,i}} & Bel(i,t) > 0 \\ E^t_{res,i} \frac{P_{rx_{i,j}}}{P_{tx,i}} & Bel(i,t) = 0 \end{cases} \tag{4.13}$$

where H represents the entire set of CHs, $E^t_{res,i}$ represents the residual energy of CH i at time instance t, $P_{rx_{i,j}}$ represents the received signal power from node i to node j, $P_{tx,i}$ represents the transmitted power of the advertisement message for node j and $Bel(i,t)$ represents the severity of CH i at time instance t.

After the CH candidacy time interval, node j selects its CH, CH_j. Subsequently, CHs calculate the TDMA schedule for the nodes who joined its cluster and broadcast the schedule among them. Apart from the slots allocated for each member node in its cluster, the TDMA schedule will have a separate time slot reserved for the CH to send any messages to its members such as control messages, acknowledgement messages, etc. All the member nodes will keep awake during this time slot to identify if there are any control messages from the CH.

4.2.4 Data Gathering Phase

The next phase of the algorithm is the data gathering phase. The nodes use single hop communication with their CHs, and the CHs communicate with the BS. Each member node awakes in its allocated time slot and transmit data. During other time slots it goes to idle mode. The CH uses a data aggregation algorithm to merge the received data from its cluster member nodes before sending to the BS to reduce the amount of unwanted or repetitive information transmitted to the BS.

4.2.5 CH Rotation Phase

Energy usage of CH is comparatively higher than the non CH nodes and they die very quickly. Hence rotation of CH role is needed to balance the energy usage of the network. In addition to that in an emergency, nodes might be dropped from the network due to physical damage etc. If a CH drops from the network, all its member nodes are not able to communicate further until re-clustering occurs. Therefore number of CHs dropping from the network need to be minimized or delay. By concerning those factors, SCAE consider two things in CH rotation. One is whether the residual energy drops below a threshold value and the second one is whether the CH's severity value go beyond a predefined threshold value. However there is a restriction on severity based CH rotation to avoid occurrence of continuous re-clustering i.e. if CH i goes for a severity based CH rotation, and after sometime the same node i is chosen as a CH, it will not consider the severity based CH rotation. The reason is that in CH candidacy and cluster formation phases, the severity value of the node has been considered and less priority is given to such nodes of high severity to become a CHs. If a node with high severity value has elected as CH, it implies that, all its neighbor nodes also have a higher value for severity.

If a CH identifies it needs to go for a CH rotation phase, it transmits a triggering message to the BS. Subsequently the BS will inform this to all other CHs. Then all CHs use their immediate next chance in the TDMA slot to communicate this fact to its neighborhood, and further request nodes to send their residual energy along with the data in its allotted slot. Finally CH i computes the maximum residual energy component of its cluster and transmits to its neighbors.

4.3 Simulation Results

The performance of SCAE was evaluated using MATLAB. First, Fire Dynamic Simulator was used to develop a fire scenario and DS information filtering was applied to estimate the severity of the fire. Then, we examine the CH selection and the performance of SCAE in an emergency situation. Finally, illustrate how SCAE prolong the network lifetime.

The simulation parameters are set as in section 3.5. The total number of nodes was considered as 73. For the simulation, it assumes that the severity calculation frequency and data transmitting frequency are same. Furthermore, transmission range of each CH was chosen to be 13m.

4.3.1 Simulation Setup

Fire scenario is developed using Fire Dynamic Simulator (FDS) which is developed by National Institute of Standard and Technology (NIST), United States [53]. In the simulation set-up which is shown in Fig 4.1, the sensor nodes were deployed at the ceiling. Each sensor node is equipped with three sensors, to sense temperature, smoke, and optical density. At t=0, ignition starts and reading were taken for 1000s.

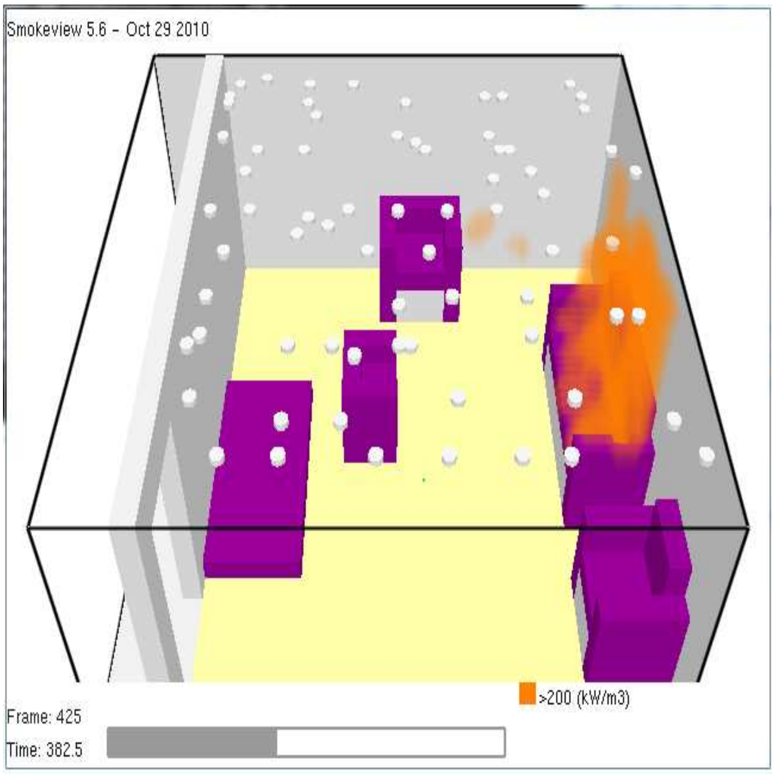


Fig. 4.1: Simulation setup: Living room, Sensor nodes are deployed at the ceiling

4.3.2 Applying DS Information Filtering to Estimate the Severity of the Fire

In order to detect an emergency and determine the growth stage of the fire or the severity level, the DS Frame of Discernment (FOD) is defined as,
DS FOD(Θ)=$\{no\ emergency$, $low_1, low_2.., low_n, medium_1,$

$medium_2, ..\ medium_m, high\}$
If $m = n = 1$, number of hypothesis is $2^4 = 16$.
At each time instance, each sensor node takes measurements for temperature, smoke, optical density and assigns masses to respective DS hypothesis.

Gathered evidences for multiple modalities are separately ordered over time and separate input evidence signals are generated. Multiple signals are passed through first order MISO LTI Filter.

$$Bel(B)(t) = \alpha_t Bel(B)(t-1) + \Sigma_{i=1}^{n} \beta_{t,s_i} Bel_{s_i}(B|A)(t) \tag{4.14}$$

$$Pl(B)(t) = \alpha_t Pl(B)(t-1) + \Sigma_{i=1}^{n} \beta_{t,s_i} Pl_{s_i}(B|A)(t) \tag{4.15}$$

Same weights were given to existing knowledgebase and new evidences from multiple sensor modalities by assigning α_t= 0.5, and β_{t,s_1}= β_{t,s_2}= β_{t,s_3}= $\frac{1-\alpha_t}{3}$. In both cases A is taken as the DS FOD (Θ).

4.3.3 Cluster Head Selection of the Algorithm

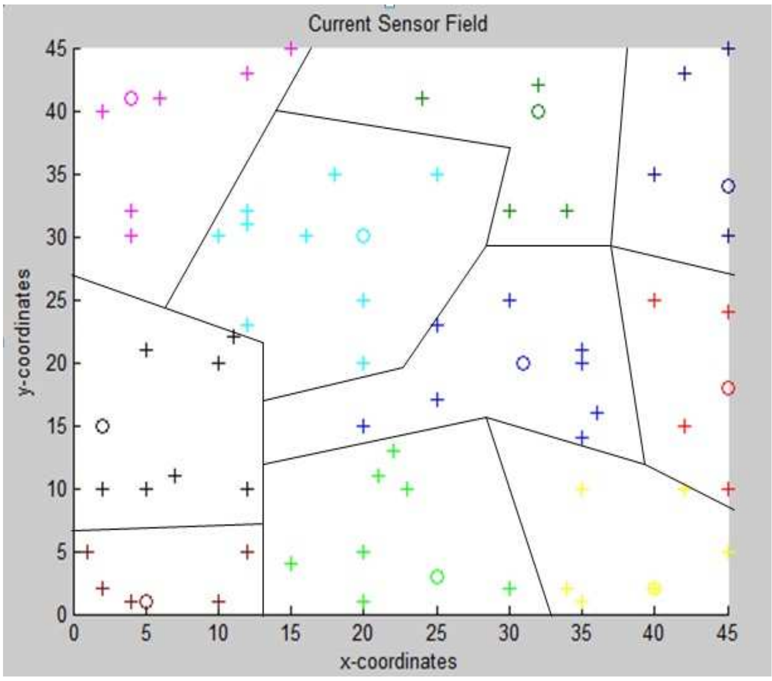
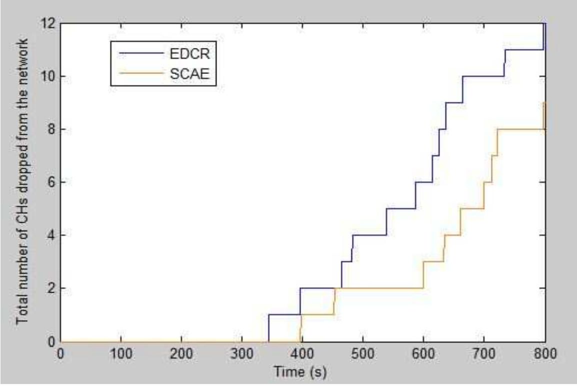


Fig. 4.2: CH distribution over the network

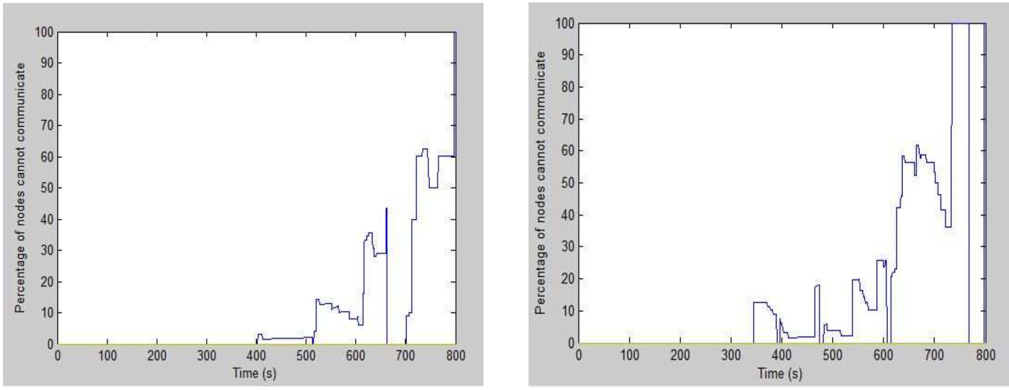
To optimize the energy usage of the network, CHs need to be distributed all over the network. Figure 4.2 shows the CH distribution of SCAE. According

Table 4.1: Selected CH's Residual Energy and Belief Values

Time = 1s		Time = 300s		Time = 500s		Time = 700s	
SCAE	EDCR	SCAE	EDCR	SCAE	EDCR	SCAE	EDCR
01(0.0000/0.4987)	01(0.0000/0.4987)	03(0.6345/0.3544)	06(0.1326/0.4453)	15(0.6345/0.3705)	15(0.6345/0.4213)	09(1.0000/0.4003)	23(1.0000/0.3073)
04(0.0000/0.4991)	04(0.0000/0.4991)	14(0.1226/0.3852)	11(0.1377/0.4474)	19(1.0000/0.3069)	29(0.9999/0.4202)	18(1.0000/0.3596)	36(1.0000/0.3692)
07(0.0000/0.4983)	07(0.0000/0.4983)	24(0.1040/0.3670)	25(0.0000/0.4489)	31(0.6563/0.3671)	48(0.1000/0.4248)	32(1.0000/0.3431)	58(1.0000/0.3630)
18(0.0000/0.4994)	18(0.0000/0.4994)	26(0.0000/0.3849)	35(0.0000/0.4554)	35(0.1219/0.3595)	50(0.1690/0.4181)	68(0.5925/0.3989)	69(1.0000/0.3532)
19(0.0000/0.4987)	19(0.0000/0.4987)	34(0.0000/0.3840)	37(0.9948/0.4408)	46(0.1350/0.3508)	51(1.0000/0.3740)	-	72(1.0000/0.3945)
23(0.0000/0.4989)	23(0.0000/0.4989)	41(0.1000/0.4093)	45(0.0000/0.4522)	65(0.1213/0.3948)	65(0.1213/0.4267)	-	-
51(0.0000/0.4992)	51(0.0000/0.4992)	67(0.0000/0.3799)	46(0.0000/0.4379)	70(0.1000/0.3964)	70(0.1000/0.3652)	-	-
71(0.0000/0.4996)	71(0.0000/0.4996)	71(0.0000/0.3979)	73(0.1000/0.4529)	72(0.1523/0.3984)	71(0.1728/0.4013)	-	-
*Format of data : CH ID(Belief Value/Residual Energy)							



(a) Number of CHs failed with SCAE & EDCR algorithms



(b) SCAE algorithm's percentage of communication failure

(c) EDCR algorithm's percentage of communication failure

Fig. 4.3: Performance of the algorithm in an emergency

to the figure, SCAE has been able to distribute the CHs all over the network. Also, Table 4.1 illustrate the effect of CH selection in this algorithm. For the comparison, EDCR algorithm [9] was selected because of its good CH distribution.

According to the data in Table 4.1, SCAE has given a higher priority value for the nodes with less severity to be elected as CHs compared to EDCR. Initially, both algorithms have chosen the same nodes as CHs because at that stage there was no emergency and belief values were zero. However when time passes, the severity values of nodes increases and CH selection is different. For example, at time=300s SCAE has selected CH with higher energy and less severity. But EDCR has selected CH with higher severity i.e. node CH_ID=37. Therefore this CH drops from the network very quickly and its member nodes fail to communicate further. Furthermore, at time=700s, EDCR has selected CHs with higher severity values, but SCAE has selected CH with less severity where ever possible (CH_ID=68).

Finally, with the CH selection equation used in SCAE, it has been able to select the best CH with highest residual energy and less severity value.

4.3.4 Performance of the Algorithm in an emergency environment

To examine the performance of SCAE, one assumption was made in this section, that the sensor node drops from the network when its severity value reaches one. With this assumption, number of CHs dropped from the network was calculated with the time. Then due to those CH failures, number of alive nodes that can not communicate further was calculated as a percentage of nodes in the network. The simulation results are shown in Figure 4.3

According to Figure 4.3a, SCAE's CHs start to fail 56s later than EDCR. Eventhough it starts at 400s, at 600s only two CH has dropped, but in EDCR it was five CHs. Also in Figure 4.3b and Figure 4.3c illustrate the percentage of nodes loss their communication due to CH failure. In SCAE it was negligible until 500s, but in EDCR it was 10% at time 344s. Furthermore, in EDCR algorithm 100% communication failure can see from time 741s to 767s, but at that time there was nearly 55% communication failure with SCAE.

Finally, because of the CH selection and CH rotation mechanism used in SCAE, it has been able to reduce and delay the failures of CHs in the network. Due to the cluster formation equation, the percentage of nodes that cannot continue to communicate has reduced in SCAE.

4.3.5 Energy Efficiency of the Algorithm

This section assumes that nodes will not drop from the network until nodes energy goes to zero. In order to present the comparison of SCAE with EDCR, free space propagation model were considered with a network of 73 nodes. Each node contains 0.5J energy and randomly distributed over a region of 50×50 with BS located at (25,25).

Fig. 4.4 shows number of sensor nodes remaining alive with respect to the time. From the results obtained, SCAE has optimized the energy usage in the network than EDCR in all three lifetime measurements. There is more than 400 data rounds optimization in the proposed method.

Finally, from all the results obtained SCAE has outperformed EDCR algo-

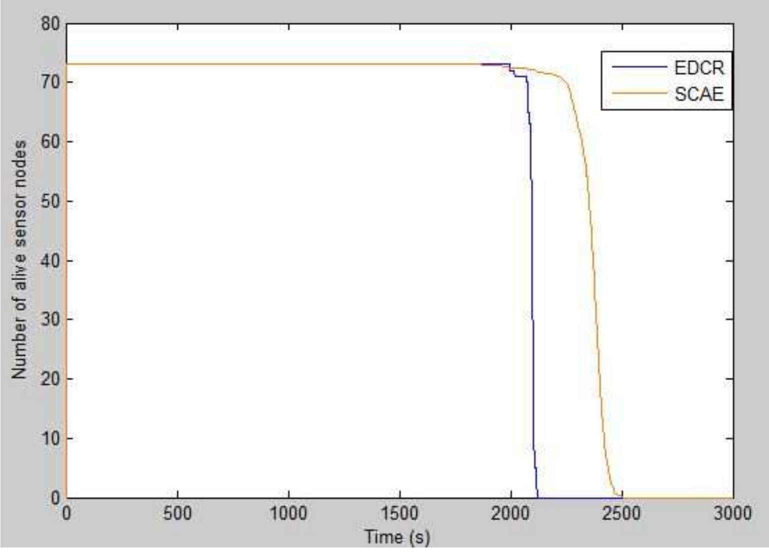


Fig. 4.4: Energy efficiency of the algorithm

rithms. The reason for the outperforming is the novel methods used in CH selection, Cluster forming and CH rotation.

Chapter 5

Suitable Node Dying Pattern for Emergency Applications

In the recent past, many researches have investigated several self-organization algorithms for WSNs. However, there are many shortcomings in their applicability for emergency monitoring application in indoor environments. This chapter proposes a self-organization algorithm for WSN emergency monitoring application by considering a suitable node dying pattern.

5.1 Node Dying Pattern Suitable for Emergency Monitoring Applications

Previous clustering algorithms have considered an all together dying pattern, i.e. all the nodes in the network die at once. In contrast, in an emergency monitoring application, at least one node to be kept alive to monitor the environment would be of more interest than dropping all the nodes at once as shown in Fig. 5.1. Fig. 5.2 illustrates, how nodes should be dropped from the network, while maintaining the coverage.

This chapter, considers an office building with cubicles and corridors. If the self-organization algorithm can keep at least one node alive in each cubicle, the decision maker can make correct decisions about the environment for a longer period.

For an example, as in Fig. 5.1, with all together dying pattern the decision maker can make the decisions up to 2000 rounds. In the node dying pattern suitable for emergency, first node dies earlier than in the all together dying pattern

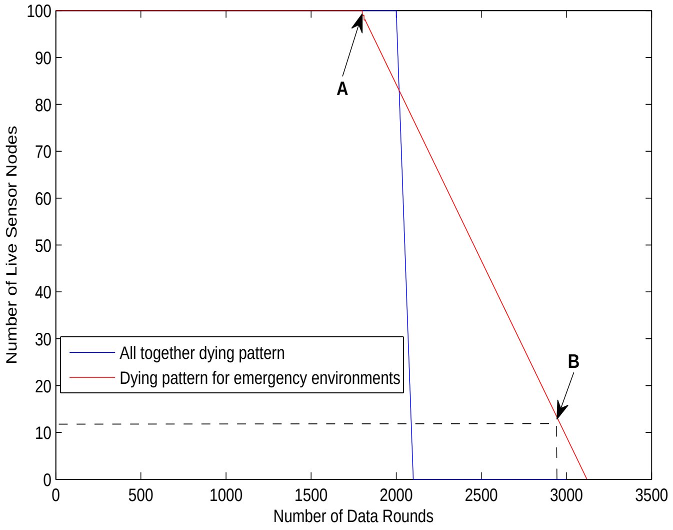


Fig. 5.1: Number of Live Sensor Nodes at the End of Each Round

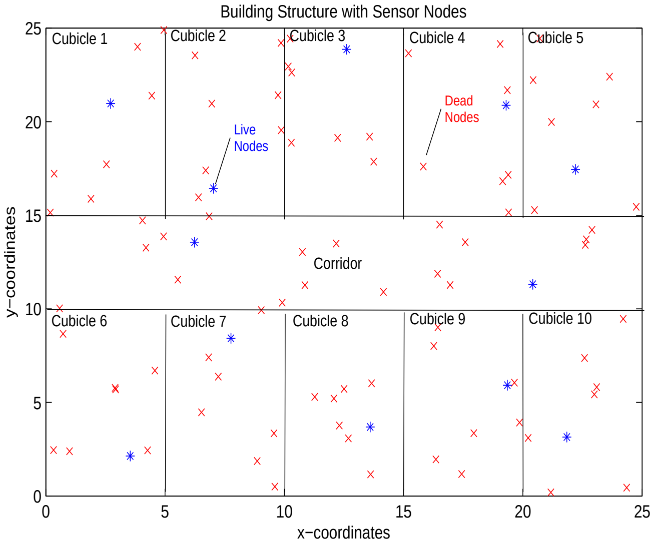


Fig. 5.2: Alive and Dead Nodes in the Environment

(refer point A). However, the decision maker can make decision about the building environment until 2700 rounds (refer point B), because network can cover the building and transmit data to the BS, if at least 12 nodes are alive in the network as shown in Fig. 5.2.

In an emergency situation, dropping nodes at different time instances while maintaining the coverage is more interest than dropping all the nodes at once.

5.2 Description of the Algorithm

The algorithm proposed in Chapter 3, has five phases as given below.

1. CH Candidacy phase
2. Cluster formation phase
3. Creating local re-clustering table phase
4. Data gathering phase
5. CH rotation phase

The proposed modification changes the CH rotation phase in the previous algorithm. The algorithm uses a dynamic re-clustering threshold until CH's energy drops below a specific energy level E_{const} and thereafter a static re-clustering threshold is used. However, previous energy driven re-clustering methods use a single dynamic threshold for re-clustering. With that, we cannot achieve the desired node dying pattern described in Section 5.1.

5.2.1 Modified CH Rotation Phase

This algorithm uses the same method used in Chapter 3, which is a combination of global and local re-clustering. In addition to that, it uses both dynamic and static re-clustering thresholds to trigger a CH role rotation. CH calculates it re-clustering threshold Δ as follows.

$$\Delta = \begin{cases} c_i E^t_{res,i}, & \text{for } x > E_{const} \quad (5.1a) \\ E_{static}, & Otherwise \quad (5.1b) \end{cases}$$

where c_i is the dynamic re-clustering constant of s_i, $E^t_{res,i}$ is the residual energy of CH s_i at cluster formation time and E_{static} is the static re-clustering threshold value which is equal to energy need for the global re-clustering phase.

After a data transmission round, if a CH identifies that its residual energy is below the threshold value, it triggers a CH rotation by broadcasting *Local_Trigger_Msg* to its member nodes. Then, CH s_i finds three member nodes with highest residual energy and checks whether at least one of those nodes exists in the Local Re-clustering Table. If so, CH s_i triggers to a local re-clustering, otherwise it triggers to a global re-clustering as described in Chapter 4.

5.2.2 Determination of Optimum Static Re-clustering Triggering Energy Level

To get the desired node dying pattern, finding the optimum static re-clustering triggering energy level is crucial. If it is closer to zero, sensor nodes drop from the network at once. Also, if it is a larger value, the coverage cannot be maintained. Hence a proper selection of E_{const} is important.

For the calculation, we assume that when one CH triggers to static re-clustering, all future CHs in that cluster must trigger to static re-clustering. The reason is, in the proposed algorithm CHs are chosen based on their residual energy i.e. highest residual energy node is elected as the CH.

Let τ_d be the total number of data rounds with dynamic re-clustering, which can be calculated as in sub section 3.4.3. For τ_2 equation (3.18) should be changed as,

$$\tau_2 = \begin{cases} \dfrac{E_{j,i,0} - E_{const}}{E_{nonCH}}, & \text{for } i \neq 0 \\ \dfrac{E_{j,0,0} - E_{const}}{E_{CH}}, & \text{for } i = 0 \end{cases} \tag{5.2}$$

X_S_i is the number of data rounds that node i serves as a CH after triggering static re-clustering.

$$X\_S_i = \frac{E_{i,i}}{E_{CH}} \tag{5.3}$$

Initially, $E_{i,i} = E_{const}$.

Here main objective is to optimize the energy usage of the network while maintaining the coverage. Hence we consider the smallest room area in the building and assume node 0 CH is at the center of the area. Then ρ is the total number of data rounds that the last node in the selected area can complete before the coverage drops.

$$\rho = \sum_{k=0}^{i-1} X\_S_k \tag{5.4}$$

where, i is the CH of last node in the selected area.

Then,

$$\rho + \tau_d = f(E_{const}) \tag{5.5}$$

The objective is to maximize $\rho + \tau_d$. Hence, when $\rho + \tau_d \to \max(\tau)$, then $E_{const} \to E_{const,opt}$. In order to find this. computer aided mathematical software can be used.

5.3 Simulation Results

The performance of the proposed algorithm was evaluated using MATLAB simulation software and the parameters are chosen as described in Section 3.5.

5.3.1 Sensor Distribution

An office environment with 20 cubicles were considered for the simulation as shown in Fig. 5.3. Since it's an indoor environment, path losses due to obstacles need to be considered. In this thesis path losses due to walls are considered. Wireless Insite software is used to find out the path loss values of the signal when transmitting through a brick wall and a concrete wall. The values are 1.13dBm and 5dBm respectively.

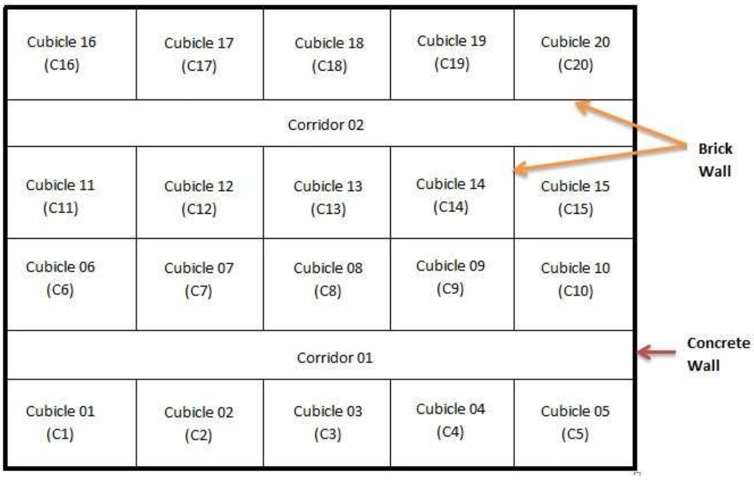


Fig. 5.3: Simulation Environment

5.3.2 Energy Efficiency of the Algorithm

The energy efficiency of the proposed algorithm is compared with EDCR-MH [54] algorithm and the algorithm proposed in Chapter 04 [47]. For the simulation four cases were considered.

Case I : Homogeneous Network of 200 nodes each with 0.5J energy randomly distributed in a 50 × 50 region with BS located at (25,25)

Case II : Homogeneous Network of 200 nodes each with 0.5J energy randomly distributed in a 50 × 50 region with BS located at (75,25)

Case III : Heterogeneous Network of 200 nodes with energies 0.3J to 0.8J (randomly assigned) randomly dispersed in a 50 × 50 region with BS located at (25,25).

Case IV : Heterogeneous Network of 200 nodes with energies 0.3J to 0.8J (randomly assigned) randomly dispersed in a 50 × 50 region with BS located at (75,25).

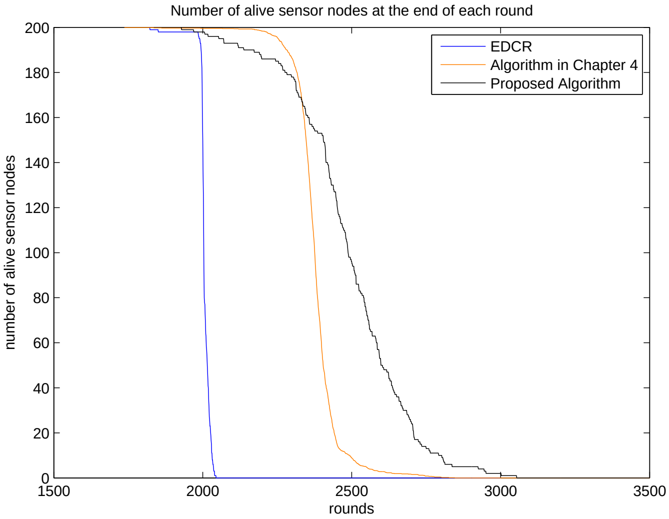


Fig. 5.4: Energy Efficiency - Case I

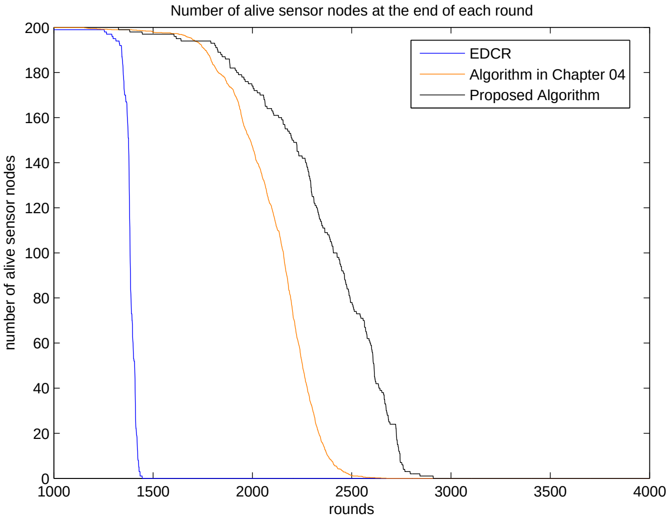


Fig. 5.5: Energy Efficiency - Case II

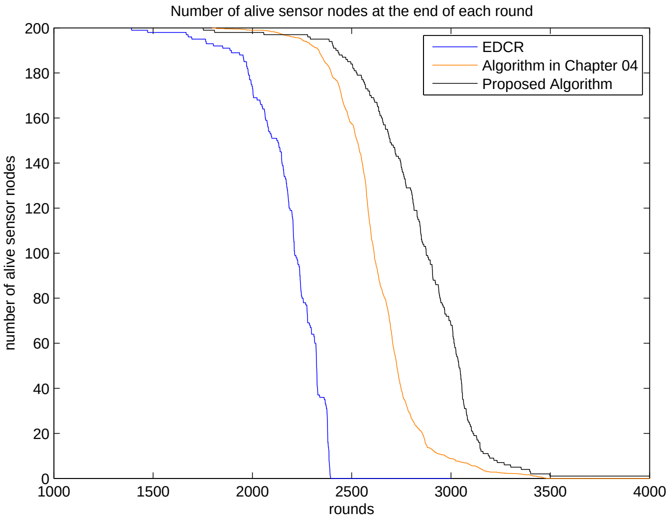


Fig. 5.6: Energy Efficiency - Case III

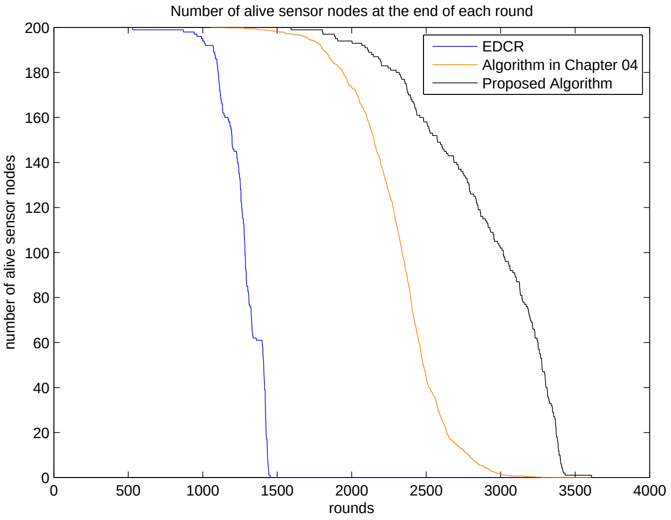


Fig. 5.7: Energy Efficiency - Case IV

Fig. 5.4 to Fig. 5.7 show number of sensor nodes remaining alive with respect to the number of data transmission rounds for above four cases. According to the Fig. 5.4, with the proposed algorithm the first node dies quickly than the EDCR. However, the other nodes remain alive for a longer time than the EDCR, which is an advantage in an emergency environment. In Fig. 5.5 to Fig. 5.7, the proposed algorithm outperforms the other two algorithm. The reason is, with the unequal clustering method we were been able to balance the energy usage of the network.

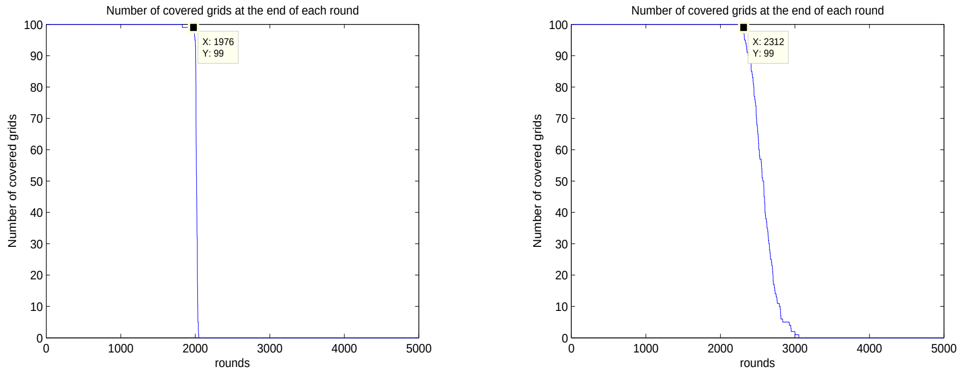
From the obtained results, it can be seen that the shape of the energy curve is as desired. However with these results, we cannot conclude that the coverage of the network(building) is maintained. Therefore, another simulation was carried out to check the coverage of the building with time as described in following section.

5.3.3 Node Dying Pattern

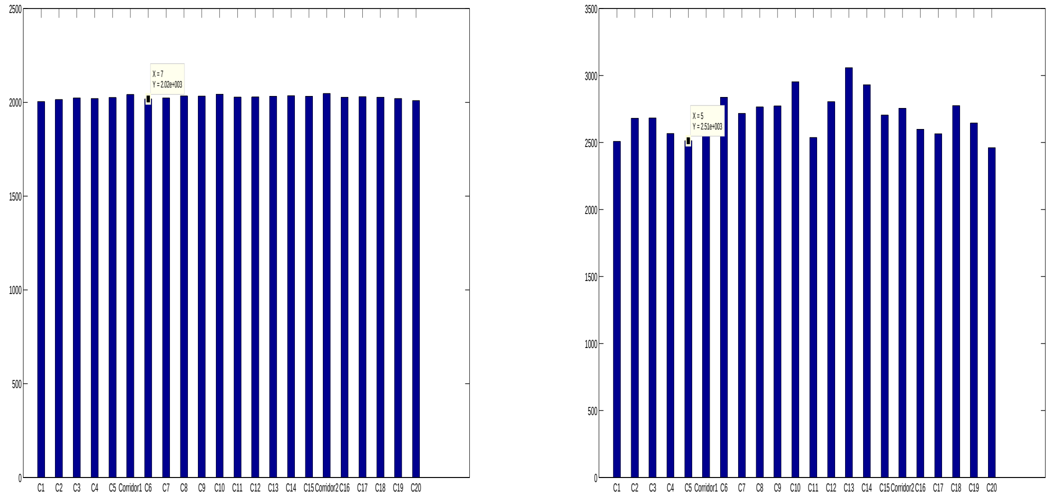
To check the average of the building, it was divided in to small grids of 5×5 area. Then we considered two parameters. First is, in which data transmission round, the first grid's coverage drops i.e. all the nodes in that grid will die due to energy exhaust. Second is, when the first cubicle's coverage drops(In future these two parameters are referred as point P and Q).

Hence, until Point P, decision maker can make decisions about the building environment more accurately. However in the Point P to Point Q region, there is at least one node alive in all the cubicles to monitor it and send data to the decision maker. After Point B, coverage is not maintained. Therefore with this algorithm, we try to increase the value of Point B and maintain the coverage of the building.

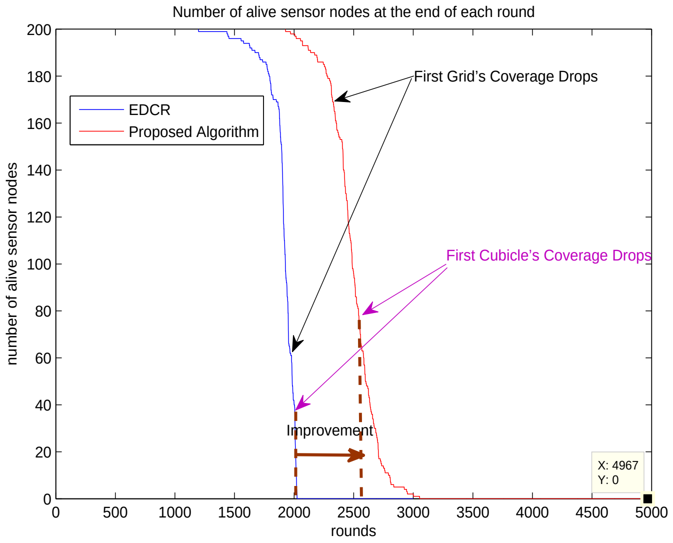
Fig. 5.8 to Fig. 5.11 illustrates the improved node dying patten for all the four cases listed above. In all four figures Point P and Q values are improved than EDCR and being able to maintain the coverage of the network. There is more the 500 data round optimization with the proposed method compared to EDCR algorithm. Hence, in rescue operations, WSN can guide firefighters for a longer period than the EDCR.



(a) EDCR - Grid Coverage Drop (b) Proposed - Grid Coverage Drop

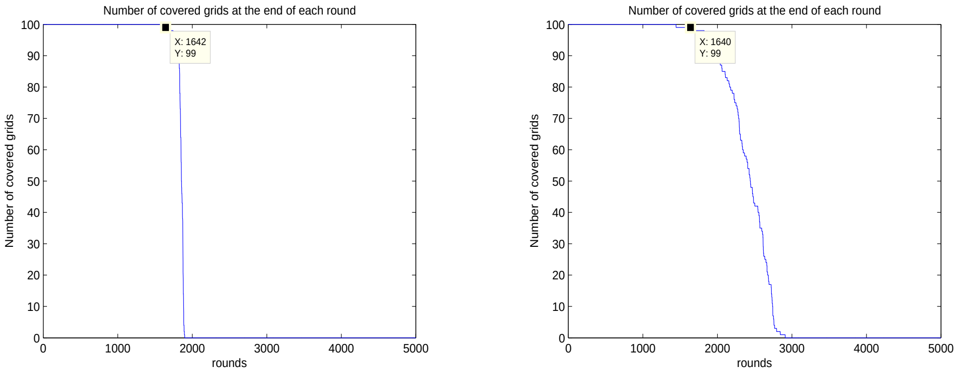


(c) EDCR - Cubicles Coverage Drop (Number of rounds vs Cubicle) (d) Proposed - Cubicles Coverage Drop (Number of rounds vs Cubicle)



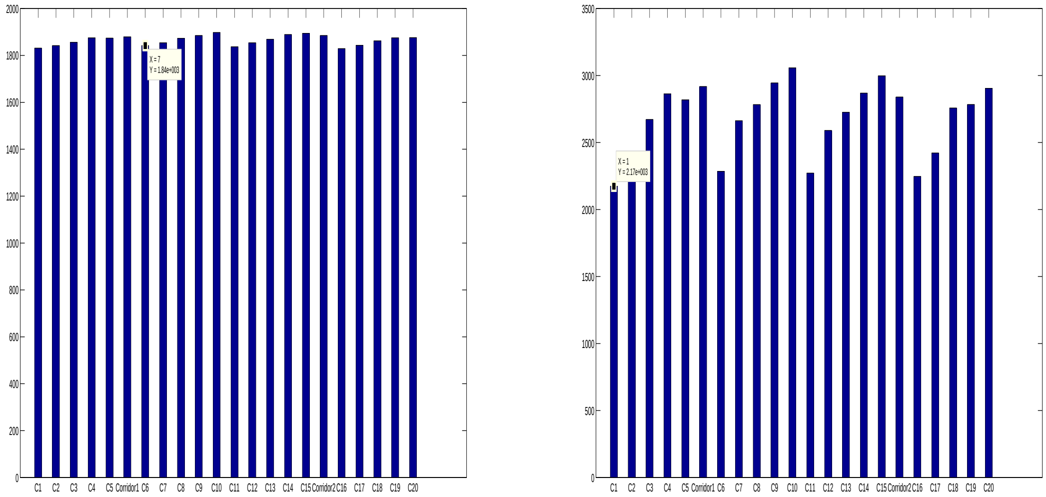
(e) Comparison of Node Dying Pattern

Fig. 5.8: Improvements in Node Dying Pattern - Case I



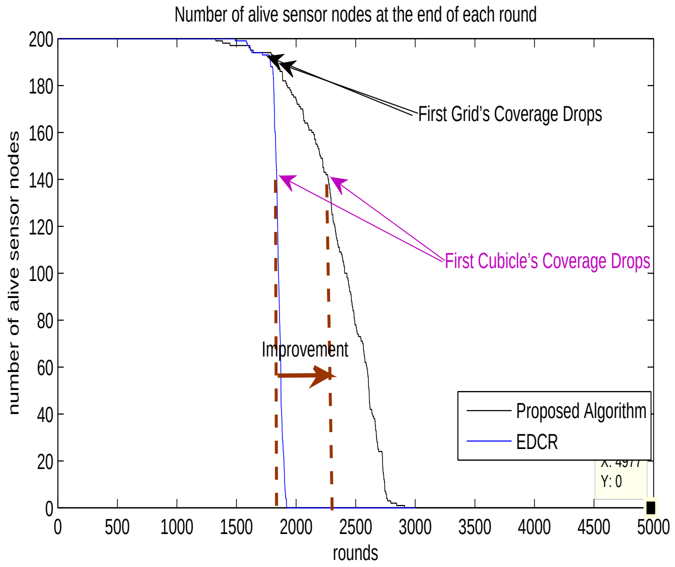
(a) EDCR - Grid Coverage Drop

(b) Proposed - Grid Coverage Drop



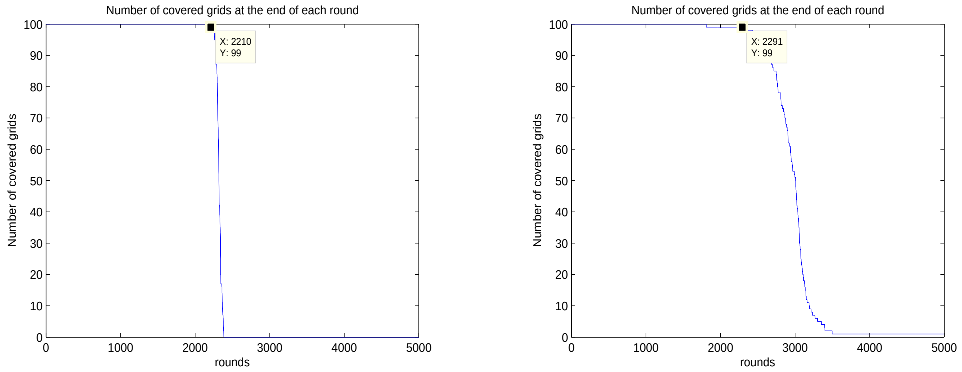
(c) EDCR - Cubicles Coverage Drop (Number of rounds vs Cubicle)

(d) Proposed - Cubicles Coverage Drop (Number of rounds vs Cubicle)



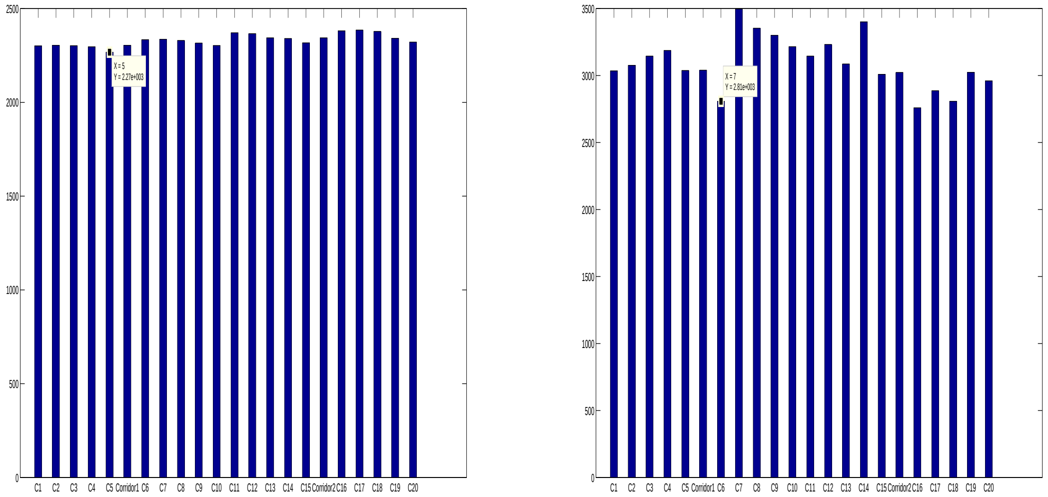
(e) Comparison of Node Dying Pattern

Fig. 5.9: Improvements in Node Dying Pattern - Case II



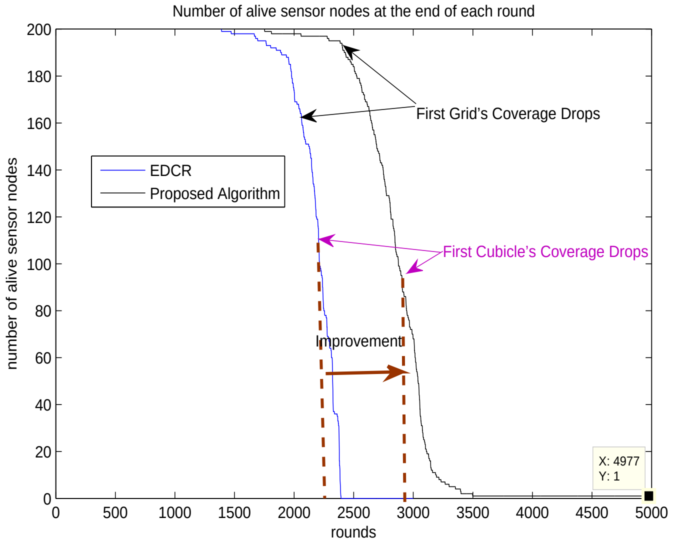
(a) EDCR - Grid Coverage Drop

(b) Proposed - Grid Coverage Drop



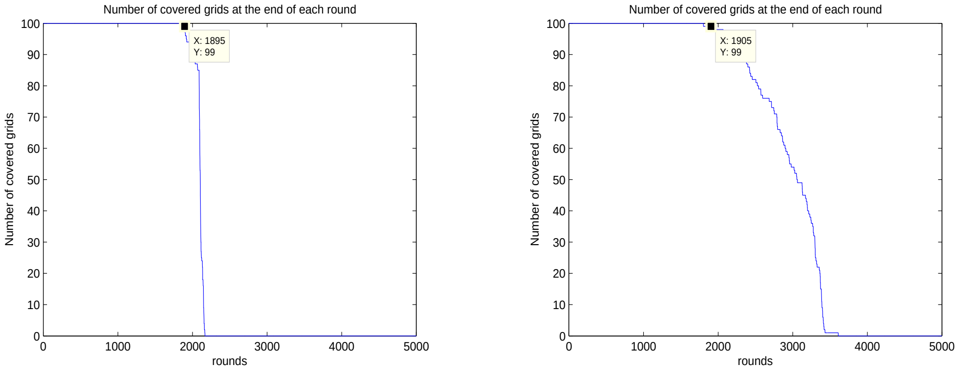
(c) EDCR - Cubicles Coverage Drop (Number of rounds vs Cubicle)

(d) Proposed - Cubicles Coverage Drop (Number of rounds vs Cubicle)

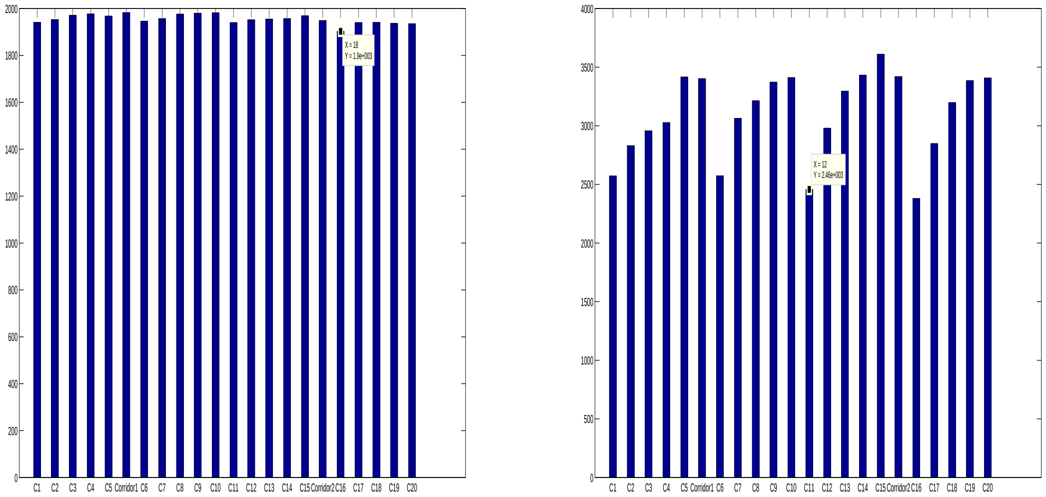


(e) Comparison of Node Dying Pattern

Fig. 5.10: Improvements in Node Dying Pattern - Case III

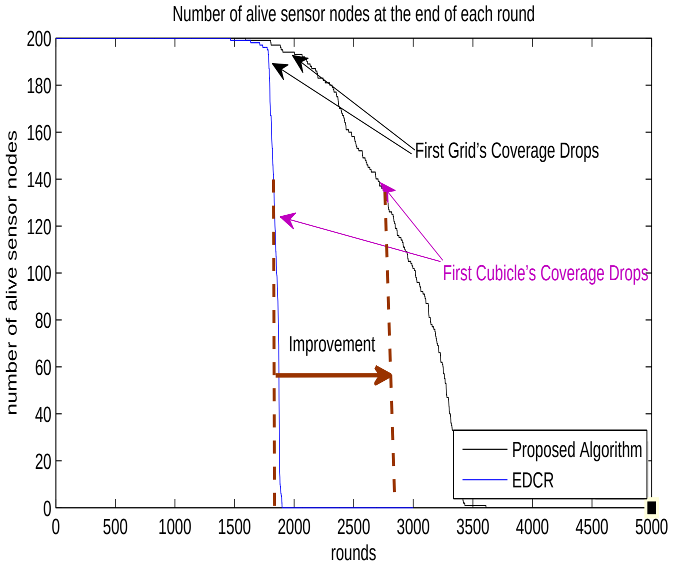


(a) EDCR - Grid Coverage Drop (b) Proposed - Grid Coverage Drop



(c) EDCR - Cubicles Coverage Drop (Number of rounds vs Cubicle)

(d) Proposed - Cubicles Coverage Drop (Number of rounds vs Cubicle)



(e) Comparison of Node Dying Pattern

Fig. 5.11: Improvements in Node Dying Pattern - Case IV

Chapter 6

The Proposed Algorithm in Multi-hop Network Setup

The applicability of the proposed algorithms in single-hop communication i.e. CHs directly transmit to BS, was discussed in the previous chapters. However, this mechanism has a negative impact on the nodes which are far away from the BS, as they die rapidly due to the long distance communication. This effect is significant for the WSN considered in this thesis, since here we consider a multi-story building environment where the dimensions of the deployment is large. Also, the BS can be located within the same building or in a separate one.

Hence, use of multi-hop communication between CH and BS can save the energy of nodes located at a distance by eliminating long distance communication. This will realized by, transmitting the aggregated data from each CH to close by CH, which is located in the direction towards the BS. Further, in [55], it is shown that multi-hop communication requires lesser total communication energy than the single-hop communication.

A variety of multi-hop clustering algorithms have been proposed for prolonging the lifetime of WSN. In EDCR-MH [54] algorithm, next hop CH is determined based on the distance between two CHs and the next hop CH to BS. However EEUC [41], considers only the distance to the next CH, which is towards the BS. In [56], uses a directed weighted graph $G = \{V, E\}$, where V is a set of nodes and E is a set of edges. The weight of each edge is calculated based on the communication energy need for the data transmission. Then the minimum weighted path is selected.

6.1 Multi-hop Network Setup

The algorithm proposed in Chapter 5 has five phases as given below.

1. CH Candidacy phase
2. Cluster formation phase
3. Creating local re-clustering table phase
4. Data gathering phase
5. CH rotation phase

The proposed modification to the algorithm will add a new phase between phase 3 and phase 4. In this phase, each CH will identify its next-hop CH towards the BS. CHs will forward their aggregated data to the identified next-hop CH.

6.1.1 Selecting Next-Hop CH Phase

CHs choose their most cost effective next-hop CH in this phase. First, CHs check whether the most cost effective way is to transmit directly to BS or to another CH closer to BS. For that, CH S_i calculates it's w_i parameters as shown in equation (6.1) and transmitted to its $2R_{max}$ neighborhood. After receiving all w_i values from neighbor CHs in $2R_{max}$, CH s_i chooses BS as its next-hop neighbour if the condition (6.2) satisfied.

$$w_i = \frac{E_{res,i}}{dist_{i,bs}^2} \tag{6.1}$$

where, $dist_{i,bs}$ is the distance between node s_i and the BS.

$$w_i = \max\big\{ \max_{j \in H \bigcap N_i^{R_{max}}} w_j,\ w_i \big\} \tag{6.2}$$

Note : When the BS is located within the network, CHs can check whether the BS is located within its communication range and decide to transmit directly to BS. However, in some applications the BS is located outside the network, in which case, CHs cannot make a decision at once. Hence calculating w_i value is important.

If any CH decides to transmit to another CH closer to the BS, it calculates $W_{j,l}$ parameter as in equation (6.3) and chooses the next hop neighbor using the condition in (6.4).

$$W_{j,l} = \frac{E_{res,l}}{dist_{j,l}^2 + dist_{l,bs}^2} \frac{P_{rx_{l,j}}}{P_{tx,l}} \tag{6.3}$$

$$W_{j,l} = \{ \max_{k \in H \bigcap N_k^{R_{max}}} W_{j,k} \} \tag{6.4}$$

6.1.2 Determination of Optimum Parameters for the Algorithm

For the determination of optimum parameters of the algorithm, the same method described in Chapter 4 and Chapter 6 can be used except for the data transmission energy calculation. Since we are considering multi-hop communication model, the energy needed to transmit a message from CH to BS can be calculated as the energy cost of one hop communication multiplied by the average number of hops. Therefore, we need to find average distance between two neighboring CH D_{ch-ch} and average number of hops $\widehat{h}$. The shape of a typical cluster area produced by a distributed clustering algorithm is a Voronoi polygon, with CH as the nucleus [57]. Based on observation, it is a polygon with six sides on average. Then,

$$D_{ch-ch} = \frac{2}{\sqrt{3}\lambda_c} \tag{6.5}$$

Since the random orientation of the next hop CH, data originating CH and BS do not lie on straight line, $\widehat{h}$ can be stated as,

$$\widehat{h} = \frac{1}{\cos(\Pi/12)} \frac{d_{CH_BS}}{D_{ch-ch}} \tag{6.6}$$

where d_{CH_BS} is the distance between data originating CH and the BS.

Then using equation 3.14, the total transmitting energy can be calculated.

6.2 Simulation Results

The performance of the proposed algorithm was evaluated using MATLAB simulation software and the parameters are chosen as described in Section 3.5.

6.2.1 Sensor Distribution

The same environment used in Chapter 6 was considered. Sensors are located within the environment in a uniform random distribution. The next-hop neighbour selection with respect to the BS location is shown in Fig. 6.1 and Fig. 6.2. Fig. 6.1 shows when the BS located at the center of the sensor bed and Fig. 6.2 shows when the BS is located outside of the network. As in the figures, CHs are distributed all over the network, which will lead to reduction in the transmission energy cost in data collection.

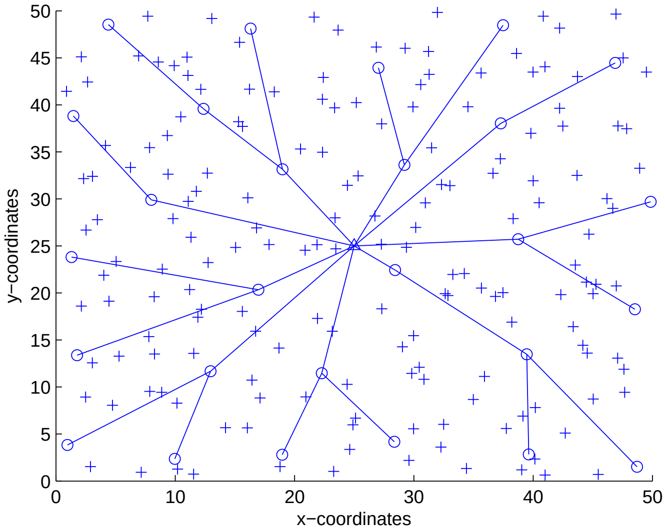


Fig. 6.1: Next Hop selection - BS at the Center

6.2.2 Energy Efficiency of the Algorithm

The energy efficiency of the proposed algorithm is compared with EDCR-MH [54] algorithm and the proposed single-hop algorithm in Chapter 6. For the simulation four cases were considered.

Case I : Homogeneous Network of 200 nodes each with 0.5J energy randomly distributed in a 50 × 50 region with BS located at (25,25)

Case II : Homogeneous Network of 200 nodes each with 0.5J energy randomly distributed in a 50 × 50 region with BS located at (75,25)

Case III : Heterogeneous Network of 200 nodes with energies 0.3J to 0.8J (randomly assigned) randomly dispersed in a 50 × 50 region with BS located at (25,25).

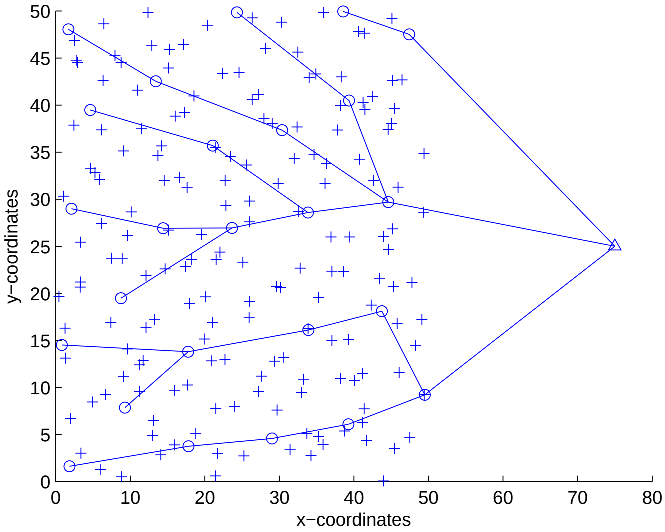


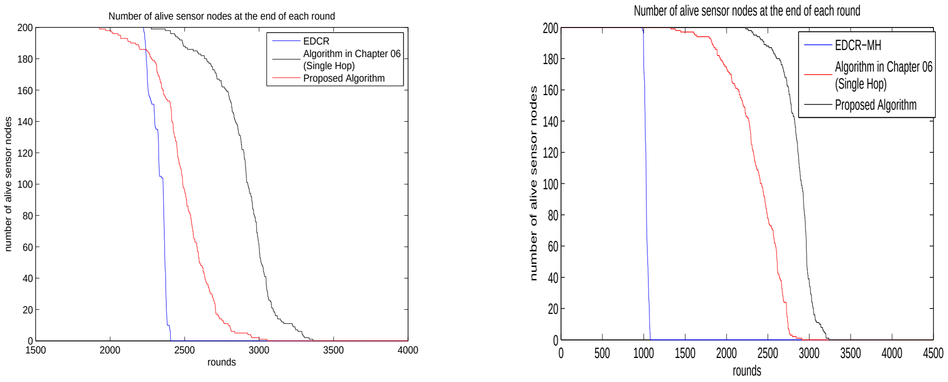
Fig. 6.2: Next Hop selection - BS Located Far Away

Case IV : Heterogeneous Network of 200 nodes with energies 0.3J to 0.8J (randomly assigned) randomly dispersed in a 50 × 50 region with BS located at (75,25).

Fig. 6.3 shows number of sensor nodes remaining alive with respect to the number of data transmission rounds for all four Cases. According to the Figure, the proposed algorithm outperform the other two algorithms in all four cases. Hence, it can conclude that, using multi-hop communication is more energy effective than using a single-hop communication in a large environment. Also, with all energy efficient methods used in the algorithm, it has outperformed the EDCR-MH algorithm as well.

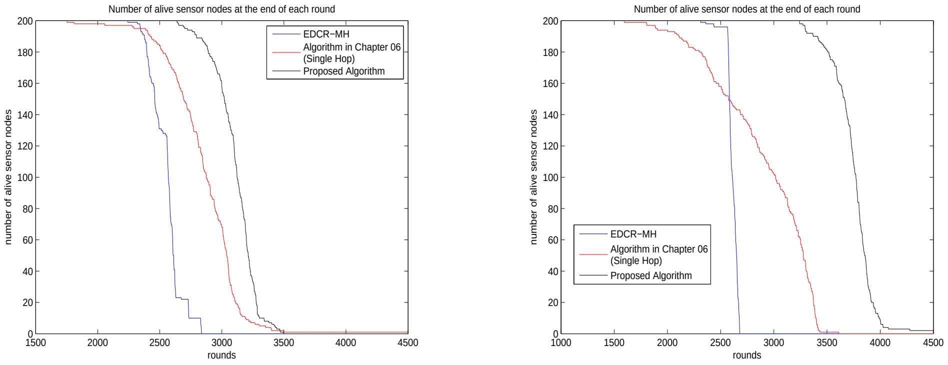
6.3 Suitability of the algorithm in 3D environment

The applicability of the proposed algorithm for 3D environment is discussed in this chapter. In previous chapters, the algorithm was evaluated in 2D environment, However in real world applications, sensor networks are deployed in 3D environment. Hence, the suitability of the algorithm in such a environment need to be considered.



(a) Case I

(b) Case II



(c) Case III

(d) Case IV

Fig. 6.3: Energy Efficiency of the Algorithm

6.3.1 Sensor Distribution

Matlab simulation software with same network parameters stated in previous chapters were considered for the simulation. A multi-storey building with three floors ($50 \times 50 \times 5$) is chosen as the sensor network deployment area. Each floor consist with 20 cubicles as shown in Fig. 6.4.

For the simulation two sensor beds are used as stated below.

Sensor Bed A : Sensors are located randomly in the ceiling of each floor as shown in Fig. 6.5. [58]

Sensor Bed A : Sensors are located randomly throughout the building as shown in Fig. 6.6. This was simulated because, sensor nodes can be located in different places of the walls, ceiling, on tables etc. [59]

The path losses occurs when signals are transmitting through walls and the concrete slabs are considered. The initial CH distribution in a single floor is shown in Fig. 6.7.

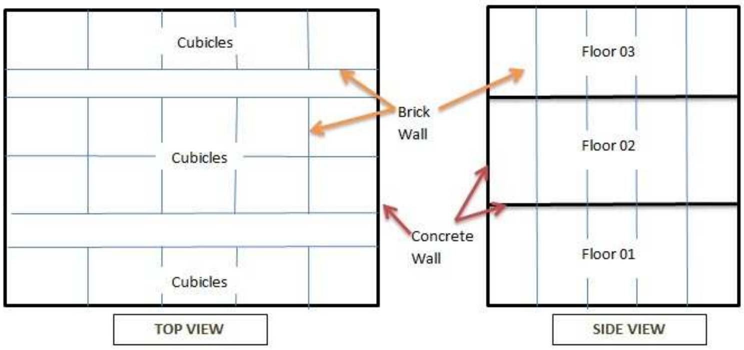


Fig. 6.4: Building Environment

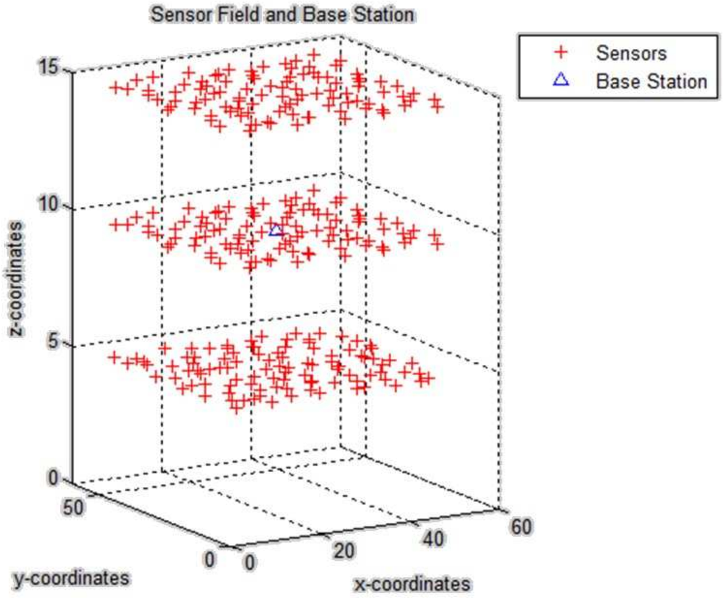


Fig. 6.5: Sensor Bed A

Next-hop selection of each CH is shown in Fig. 6.8 and Fig. 6.9 for sensor bed A and sensor bed B respectively. In each case first floor CHs are identified as in 'o' sign, second floor CHs are identified as in '+' sign and third floor CHs are shown in '△' sign. Since multi-hop selection equations (in Chapter 7) considered the received signal strength with respect to transmitting power, the next-hop CH with high quality was chosen. For example, CH s_i has two next-hop CHs; s_j in the same floor and s_k in another floor, with same distance towards the BS. Then CH s_i will select s_j as it's next-hop neighbour CH to transmit data, because when transmitting through a concrete wall path loss is high and link quality between those two nodes is poor.

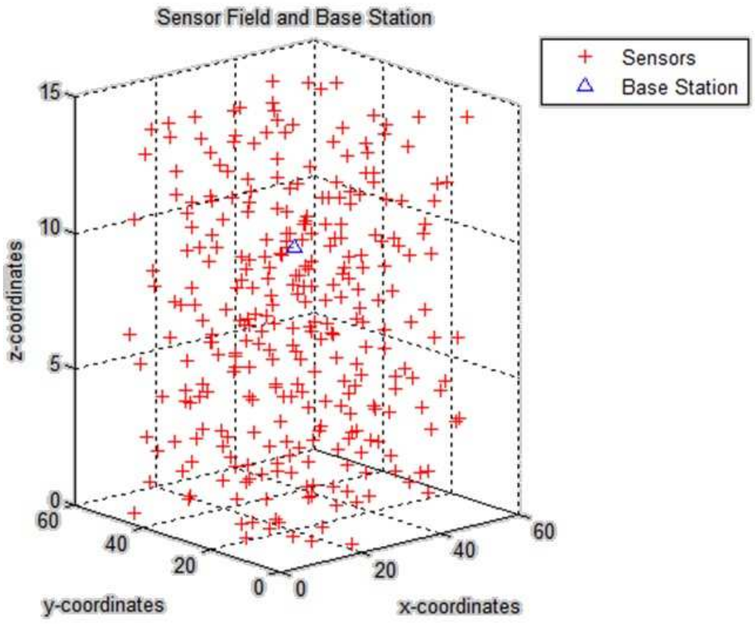


Fig. 6.6: Sensor Bed B

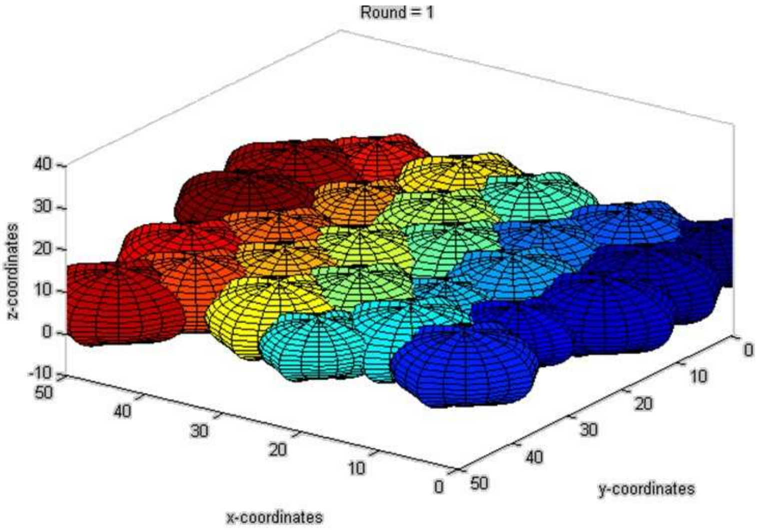


Fig. 6.7: CH Distribution in a Single Floor

6.3.2 Energy Efficiency and Coverage Control of the Algorithm

The energy efficiency of the algorithm is compared with the 2D algorithm proposed in Chapter 7. For the simulation following four cases were considered with two sensor beds.

Case I : Homogeneous Network of 900 nodes each with 0.5J energy randomly

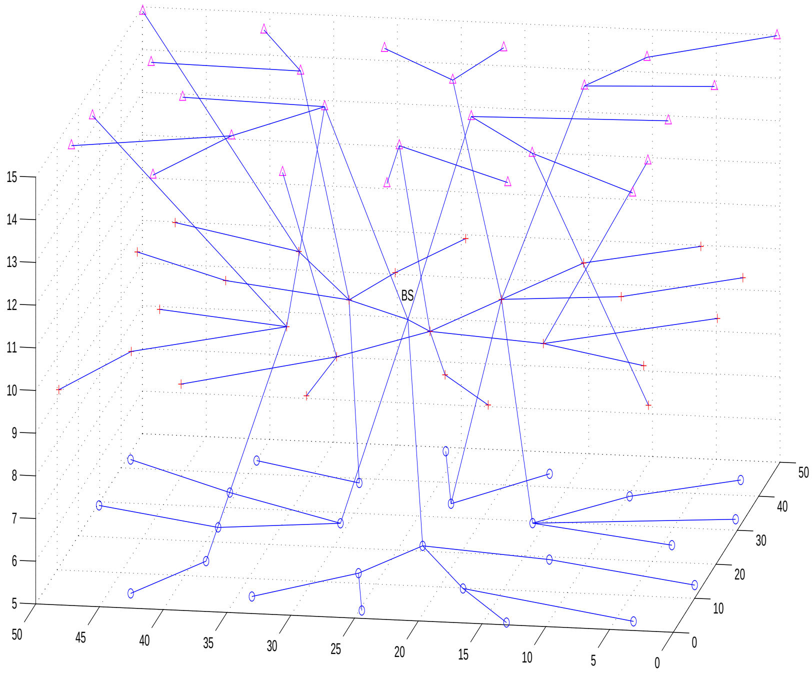


Fig. 6.8: Next Hop Neighbour Selection - Sensor Bed A

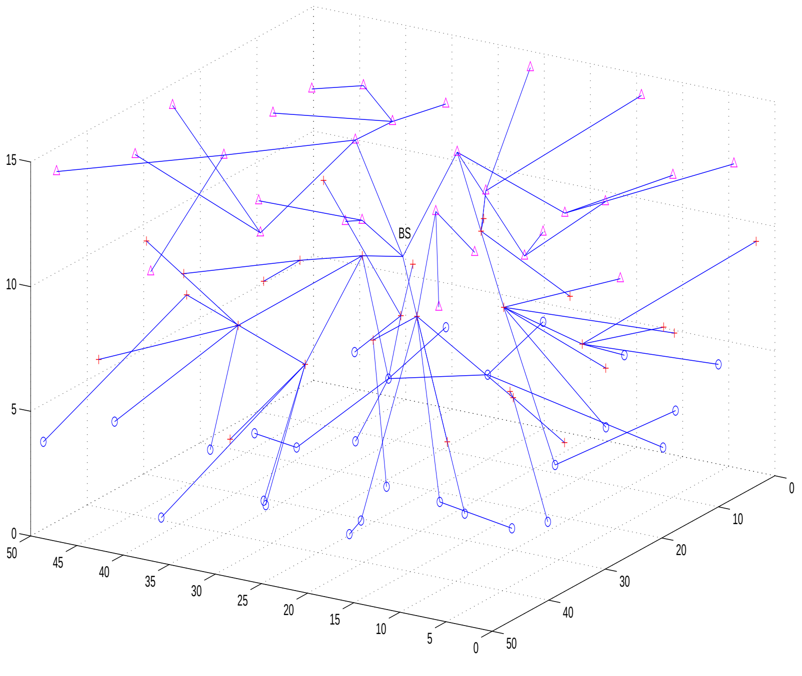


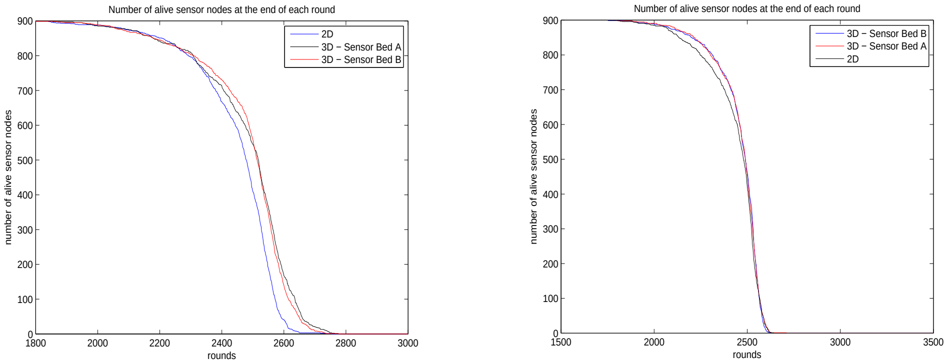
Fig. 6.9: Next Hop Neighbour Selection - Sensor Bed B

distributed in a 50 × 50 × 15 region with BS located at (25,25,10)

Case II : Homogeneous Network of 900 nodes each with 0.5J energy randomly distributed in a 50 × 50 × 15 region with BS located at (75,25,10)

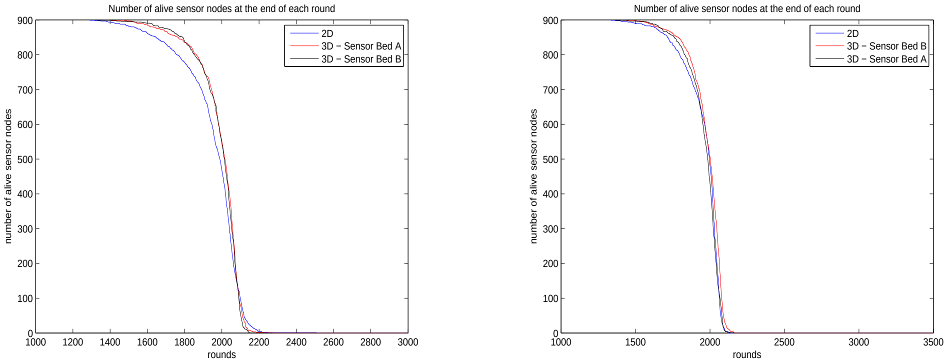
Case III : Heterogeneous Network of 900 nodes with energies 0.3J to 0.8J (randomly assigned) randomly dispersed in a 50 × 50 × 15 region with BS located at (25,25,10).

Case IV : Heterogeneous Network of 900 nodes with energies 0.3J to 0.8J (randomly assigned) randomly dispersed in a 50 × × 15 50 region with BS located at (75,25,10).



(a) Case I

(b) Case II



(c) Case III

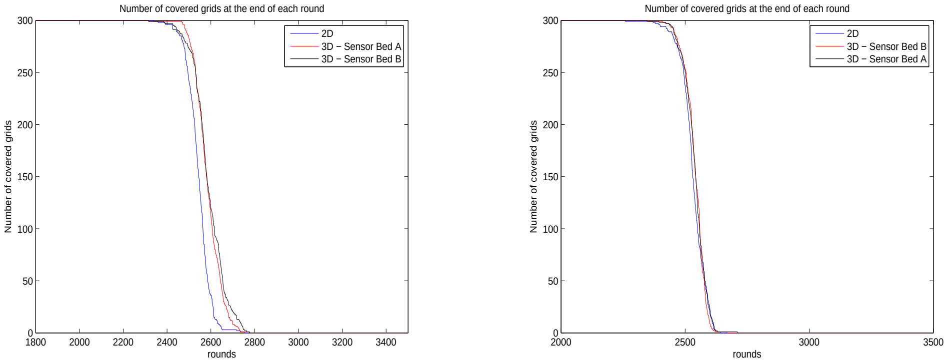
(d) Case IV

Fig. 6.10: Energy Efficiency of the Algorithm

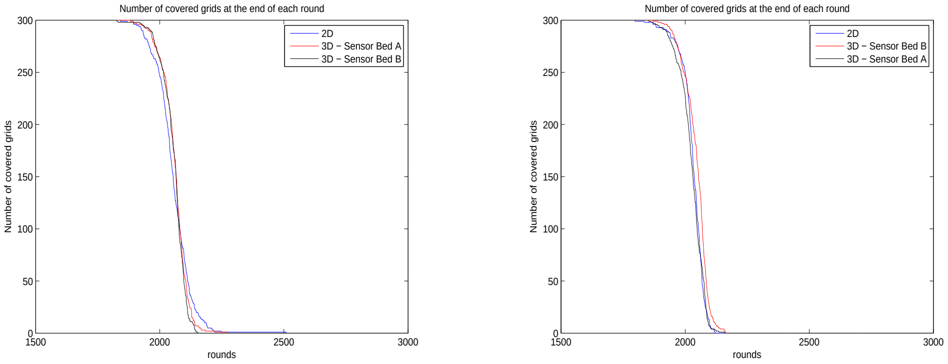
With the simulation results shown in Fig. 6.10, the algorithm performs in 3D environment as same as in the 2D environment. Hence, it can be conclude that, this algorithm can be applied to the 3D environment as well.

Finally, the coverage control of the algorithm is considered as same as in Chapter 6. For this, the environment is divided in to $5 \times 5 \times 5$ cubes and checked the coverage drop of each cube. The results are shown in Fig. 6.11 and it is the same as in 2D environment.

Hence, it can be concluded that the proposed algorithm is suitable for the 3D environment as well.



(a) Case I (b) Case II



(c) Case III (d) Case IV

Fig. 6.11: Grid Coverage Drop of the Algorithm

Chapter 7

Conclusion and Future Direction

This research proposes a energy efficient clustering algorithm for WSN emergency monitoring application.

The work reported in this thesis considers a WSN deployed in a multistorey building for emergency detection and monitoring purposes. Such a network consist of large number of sensor nodes deployed in a random manner. The main concern of this network is to gather useful information from the environment to BS as long as possible. In such a scenario, keeping at least one node alive to monitor the environment would be more effective, rather than keeping all the nodes alive.

For such periodic data gathering WSNs, previous researches have proposed the use of energy based distributed clustering techniques. This research has identified the strengths and weaknesses of these algorithms and proposes a new distributed clustering algorithm for emergency applications.

The proposed algorithm can achieve a perfect energy balancing through CH selection, communication range selection, cluster boundary determination and CH role rotation. The algorithm ensures that the node with most residual energy in a given neighborhood becomes the CH. Also, by forming unequal clusters a well energy balancing can observed. Non-CH join the closest CH with highest residual energy within its neighborhood. This reduces the burden on weaker CH as well as reducing the communication energy of all nodes. Furthermore, with the combination of local and global CH rotation, algorithm have been able to further optimized the energy usage and reduce the overheads in the network by reducing unwanted global re-clustering.

Since, in this research multistorey building was considered as the environment, the algorithm was extended to multi-hop communication. This realizes considerable improvement in performance. It chooses CH's next-hop neighbor based on the residual energy, distance and quality of the link.

According to the simulation results, the algorithm produces a fairly stable number of clusters. Further, these clusters are well distributed and CH tends to be close to the center of the cluster area. This is directly attributed to the improved lifetime performance of the algorithm. This research proposes an analytical formula for resultant cluster density of EDCR algorithm. Also proposes a analytical techniques to optimize the algorithm parameters such as maximum CH candidacy broadcasting range, radius of the partial local delegation area and CH role rotation trigger parameter.

This research also propose a severity based clustering algorithm for the use of the algorithm in an emergency monitoring application. This uses the node residual energy and the node severity for decision makings such as CH selection, cluster formation, and CH rotation. Severity is used to find out the level of the emergency. Due to parameters considered in decision making, the algorithm has been able to reduce the communication loss in the network. This is achieved by delaying the CH failures in the network and allocating less priority to non-CH nodes to select their CH who might get dropped from the network quickly.

Furthermore, a node dying pattern suitable for an emergency monitoring application is propose. This dying pattern was achieved by combining dynamic re-clustering threshold with a static re-clustering threshold. Also, an analytical formula was obtained to find out the threshold values.

7.1 Future Directions

As we have seen, the presented algorithm work well within the limits set by the objectives an assumptions therein. However, the proposed algorithms can be further redefined, improved and extended if the following aspects are taken into consideration.

Firstly, the applicability of the algorithm with a mobile sensor nodes. In emergency monitoring application, that would be another important aspect. In rescue operations, firefighters find the path by using the sensor nodes attached to their body. Hence there must be an reliable communication protocol to add these mobile node to existing sensor network and get the information.

Secondly, applicability of the algorithm with several BS. In an emergency applications, depending on a single BS would be crucial. Hence by deploying several BS station, the rescue operation can be done more securely. Therefore it would be another future area of study.

Thirdly, finding the nodes need to transmit data in a single data round within a cluster. In the proposed algorithm, we considered all the nodes are transmitting their data packets in one data round. However, there might be cases, where a single location can be monitored by two or three sensor nodes. Hence, if a CH can decide what are the nodes need to transmit data in a particular data round, that would be prolong the network life time further.

Finally, this thesis focuses on energy optimization of the clustering algorithm. Other than that there some other important parameters such as reliability, time synchronization, etc. need to be considered.

Publications

1. A. Guanathillake, D.M Weeraddana, K.S Walgama and K. Samarasinghe, "Self-Organization of Wireless Sensor Networks Based on Severity of an Emergency Environment", IEEE Eighth International Conference on Industrial and Information Systems , pp.483-488, December 2013.
2. Ashanie Gunathillake and Kithsiri Samarasinghe, "An Unequal Clustering Algorithm for an Emergency Response Wireless Sensor Network", IEEE Ninth International Conference on Mobile Ad-hoc and Sensor Networks, pp.383-388, December 2013.
3. H.H.S.Gayan, D.M.Weeraddana, A.Gunathillake,"Sensor Network Based Adaptable System Architecture for Emergency Situations", Third International Conference on Information Communication and Management,Lecture Notes on Information Theory Vol. 2, No. 1, pp.85-91, March 2014.
4. A. Gunathillake and K. Samarasinghe, "Energy Efficient Clustering Algorithm with Global & Local Re-clustering for Wireless Sensor Networks", World Academy of Science, Engineering and Technology, vol : 79, pp.52-59, July 2013.
5. D.M.Weeraddana, H.H.S.Gayan, A.Gunathillake,"Sensor Network based Emergency Response and Navigation Support Architecture", World Academy of Science, Engineering and Technology, vol : 79, pp.1-7, July 2013.

Appendix A

Proposed Sensor Network based Architecture

Objective of this section is to illustrate the novel sensor network based adaptive system architecture for emergency situations [60]. The system is highly adaptable in both non-emergency to emergency situations and vise versa.

Wireless sensor networks (WSNs) raise many exciting opportunities to minimize the impact caused by emergencies. [10, 61] these studies show the benefits of a sensor network to support Emergency Response (ER). Unfortunately there is a lack of coherence among research that has been reported for emergency support.

Correct decision making from the corrupted data gathered from the WSN, energy efficiency of sensor nodes [9], routing of data through sensor networks, localization of nodes [62] and self-configuration of sensor nodes in a network [63] are the most important aspects in emergency response, which are not properly addressed in a general WSN architecture. A proper architecture design for a WSN is crucial in the development of systems for complex and dynamic environments such as emergency response, especially when the WSN is deployed in a multistory building. Therefore, in such a domain, an architecture based on accurate design could prevent many disasters.

Work reported in [10] proposes a high-level conceptual architecture of the system that is capable of deploying the human computer interfaces suitable of supporting various fire fighter job roles during a fire ER. This research addresses only fire emergency situations, and also it is mainly concerned with data capturing, decision making and presentation. Localizing and optimizing the network parameters are not captured in the above research. Majority of the previous work [61, 64] that has been reported propose emergency architectures that do not capture all the above research aspects (i.e. Self-organizing) and the relationship among those, also the adaptability in the two modes (emergency and non-emergency) is not addressed.

The identified challenges in an emergency response and navigational support are,

- Real time information retrieval from various sources (i.e. WSN), processing, and managing information dynamically.
- Need for separate robust algorithms for victim navigation and first responder navigation.
- First responder and victim navigation algorithms require different types of information. Differentiate the gathered information among different types navigation algorithms is another challenge.
- A WSN deployed inside a building need an efficient communication protocol to optimize the energy usage, communication delay, packet retransmission, etc.
- First responders may add stationary and mobile sensor nodes (sensors attached to firefighters) to the WSN. Integrating and tracking the newly added nodes is also a challenge.
- Addition to the information from WSN, information about environmental conditions of the surrounding region i.e. wind speed, land marks should be acquired from separate data sources.
- Knowledge sharing mechanism among WSN and other data sources.

A.1 Proposed Architecture

The nature of an emergency is highly dynamic and demanding. Real-time data retrieval, processing and management is required. Sensor node failures, communication link failures and noise added to the multi-modality sensed data are common challenges in WSNs which introduce uncertainties in the overall system. Communication time delays directly impact real-time data retrieval and also introduce errors in the estimation of the dynamically varying environment.

Furthermore, during an emergency, first responders may add stationary and mobile sensor nodes to the WSN. Integrating and tracking the newly added nodes is also a challenge.

However, the resources for computation and communication may be limited at an incident site. Therefore, meeting the demanding performance requirements under resource constraints is a challenge. Considering all those challenges, a novel architecture is proposed to cope with emergency situations such as fires in a multi-story indoor environment using a WSN. The system will function in two main states; normal and emergency.

The proposed layered architecture shown in Fig. A.1 consists of three major layers namely, the communication layer, the core layer, and the presentation layer which will collaboratively function to create a complete WSN which can be adapted for emergency situations. Each layer consists of sub layers as described below.

A.1.1 Communication Layer

Physical and Medium Access Controller layers

These layers are responsible for the physical arrangements of sensor nodes and communication among them including medium access. Sensor nodes deployment topology, power levels, frame rates and antenna arrangements are some major aspects to be considered.

A.1.2 Core Layer

The output of the communication layer feeds as the input to the core layer and passes relevant fused and predicted messages to the presentation layer. The core layer consists of five sub layers, the localization layer, the perception layer, the self-organization layer, the data filtering and prediction layer, and the severity calculator layer.

Localization

This is the layer where the sensor nodes will be located with either absolute or relative coordinates. Most of the sensor nodes in an indoor WSN do not know their actual location due to unavoidable constraints on the cost and size of sensors, energy consumption, implementation environment (e.g., GPS is not

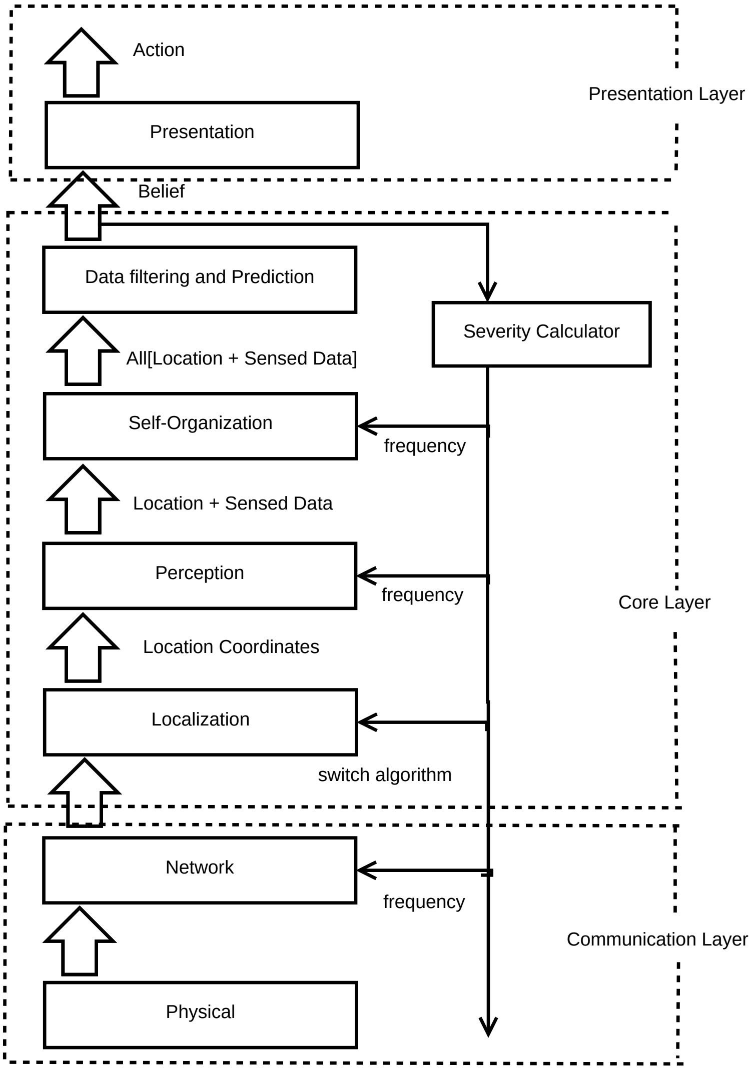


Fig. A.1: Proposed Architecture

accessible in indoor environments) and the deployment of sensors (e.g., sensors may be randomly scattered in the region). WSN localization techniques are used to estimate the locations of these nodes.

On the basis of mechanisms used to estimate the locations, WSN localization algorithms can be divided broadly into two categories; ranged-based and range-free. Range based techniques exploits either the distance or the angle information between neighbor nodes and then uses trilateral or multilateral localization methods to locate the unknown nodes, such as TOA, AOA, TDOA and RSSI [65]. Range-free algorithms uses estimated distances between nodes instead of measured distances locate the sensor nodes. Several such range-free localization algorithms are Centroid, DV-Hop, Amorphous, MDS-MAP and APIT [66]. Range-based approaches need more sophisticated ranging hardware to measure point to point distance or angles between nodes. Even though range-based localization can produce more accurate localization results, they are more expensive compared with range-free localization techniques. Therefor range-free algorithms attract more attention to overcome the high cost of hardware facilities and energy consumption required by range-based approaches

The main task of this layer is to locate the sensor nodes with minimum error under both normal and emergency situations. Then the location information will be passed to the upper layer Perceiving to be combined with environment sensed data as shown in Fig. A.2.

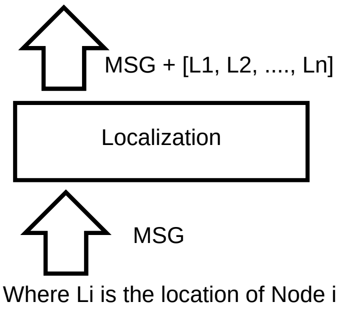


Fig. A.2: Function of Localization Layer

Perception

This layer will collect all the data generated at the sensor nodes. The data will be a collection of information such as temperature, humidity, air quality, smoke and so on of the monitoring environment. This perceived date will then be combined with location information and passed on to the upper layer for further processing. Fig. A.3 shows the functionality of the perception layer.

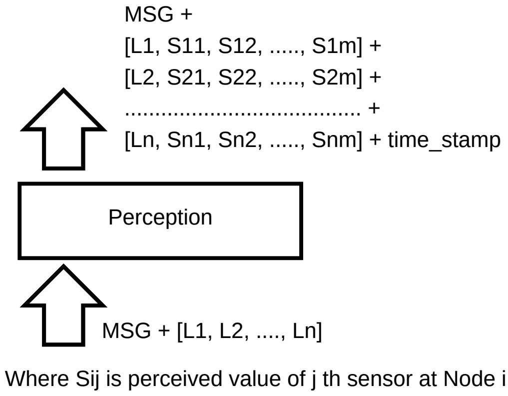


Fig. A.3: Function of Perceiving Layer

Self-organization

The ad-hoc deployment of the sensor nodes, prevent pre-planning of the network organization. Hence these networks need to self-organize themselves to interact with their environment, to monitor or sense physical parameters and to transmit those data to a central location.

This layer is concerned with organizing the ad-hoc deployed sensor nodes to collect the sensed data and transmit those to the application layers to make decisions. IEEE 802.15.4 standard is the most popular standard used in Wireless Sensor Networks, due to its characteristics. In this standard, Carrier Sense Multiple Access (CSMA) transmission method uses as the Medium Access Control (MAC) layer communication protocol. This transmission protocol need to be incorporate with self-organization algorithm to optimize the drawbacks of CSMA such as unnecessary drain of energy which can result due to over hearing on broadcast communication, overhead of control and redundant data packets.

Hence the main aim of this layer is, to enable nodes to configure by themselves to communicate with their neighbors by optimizing the network parameters such as energy consumption of the nodes, communication delay, re-transmission of packets and etc. In a WSN one of the most critical parameters is considered as energy usage, i.e. because in a sensor node one of the scarce resource is energy. Nodes use batteries that are intended to last for long period of time by careful duty cycling [61].

The self-organization layer receives the location of each sensor node from the location layer and these locations can be used in the self-organization algorithms. This is an advantage of the proposed architecture. It can reduce complexity of the computation as well as energy needed for those calculations. Then the the perceived data combined with location will then be passed to the upper layer for further processing. Fig. A.4 shows the functionality of this layer.

Data filtering and prediction

A WSN deployed in a multi-story building for collection of parameters related to emergency situations, energy consumption, building environment, human behavior inside the building etc. needs application layer protocols to filter the corrupted data and infer events of interest.

Data filtering and prediction techniques are needed for an application to ensure reliability and accuracy of information obtained from the WSN. Maintaining

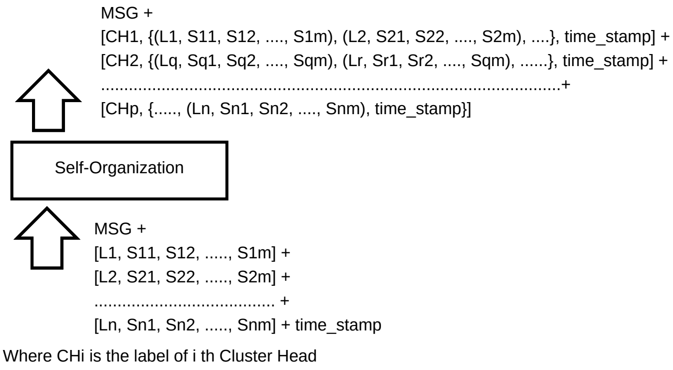


Fig. A.4: Function of Self-organization Layer

a knowledge base within the network with sophisticated machine learning techniques will reduce the risk at emergency. However, running such algorithms will also negatively impact the power consumption in sensor nodes, central nodes. Therefore the accuracy and the power should be traded off effectively.

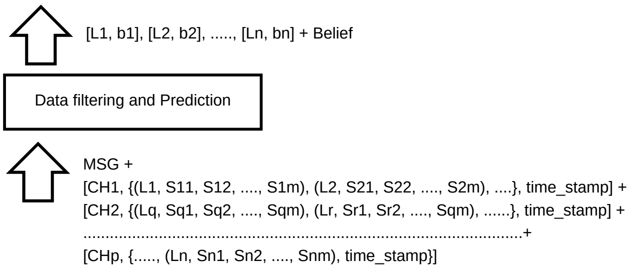
The approach of this layer is to develop a common knowledge based framework to predict emergencies for generating early warnings, effectively predict the emergency propagation (speed and direction of the emergency estimation) in the building.

The particular knowledge based approach proposed here basically achieved two tasks;

The first task is to detect an emergency and give early warnings to the presentation layer and to the lower layers (reporting the possible emergency emerging locations and the severity of the incident. Based on the severity of the warning;the presentation layer should decide whom to inform and the way to inform the emergency).

The second task of this layer is to predict the propagation of the emergency incident by estimating the speed and direction of the incident. Possibly building propagation maps (belief/plausibility or probability maps)will reveal certain important characteristics of an emergency.

Moreover, this is the layer where the data manipulation and calculations take place. It uses the received data from the lower layer as inputs and provides predictions on dynamically varying situations using knowledge based algorithms developed based on Dempster-Shafer formalism. Depending on the output of this layer several actions will be taken. The processed data will then be passed to both the presentation layer and the severity calculator. Fig. A.5 shows the functionality of data filtering and prediction layer.



Where bi is Dempster Shafer belief at Node i and Belief is the final prediction on whole system

Fig. A.5: Function of Data Filtering and Prediction Layer

Severity calculator

Severity Calculator layer provides feedbacks to the sub layers in order to adapt the system. In this layer most of the important parameters such as network refreshing rate, perceiving rate, clustering rate will be set. On the other hand it will switch the node localization algorithms if there is an emergency. Fig. A.6 shows the functionality of this layer.

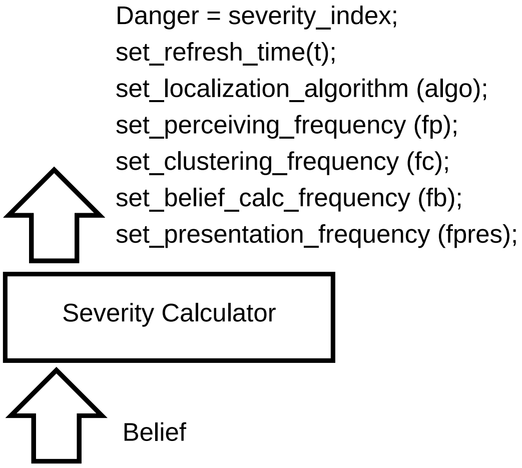


Fig. A.6: Function of Severity Calculator Layer

After calculating the severity index of the environment, the whole system will get reconfigured in the event of an emergency. For example if there is a medium strength fire, then the system will adapt to that by changing its refreshing rates, moving to a different localization algorithm and perceiving the environment more frequently until the environment become normal. This process will repeatedly run throughout the system.

A.1.3 Presentation Layer

Presentation

This layer is responsible for taking necessary action according to the output of the data filtering and prediction layer. Conditions of the environment could be presented as an easily readable map. On the other hand this layer could be used to inform the conditions of the environment to relevant parties (i.e.first responders) in the event of an emergency.

A.2 Example of Use: Sensor Network Based Emergency Response and Navigation Support Architecture

Navigation within WSNs has become the a much debated topic of research in recent times. This section illustrates the emergency response and navigation support architecture to cover key aspects during an emergency. The system caters to the navigation requirements of both the firefighters and victims, by integrating the knowledge gathered from various sources and distributing them to relevant parties efficiently. Furthermore this is a generic architecture. Even though any suitable algorithms, frameworks can be plugged into the architecture, some efficient methods that can be incorporated at each layer are proposed.

The majority of previous work on emergency navigation [67, 68] that has been reported, propose algorithms to eliminate key dangerous areas and save trapped people. However a high level architecture for emergency navigation targeting major roles involve in an emergency situation is not addressed.

To cater to the above mentioned challenges in an emergency response and navigational support, a layered architecture is proposed as in Fig. A.7 consists of three major layers. Namely, WSN Perceiving and Prediction layer, Navigation Support layer, and Knowledge Manipulation layer [69]. These will collaboratively function to create a complete WSN which is adaptable for emergency situations and support rescue and navigation operations. WSN Perceiving and Prediction layer consist of the architecture proposed in Section A.1. The main objective of this layer is to monitor the building environment and process sensed data to get meaningful information. Then the processed information is displayed on the presentation sub layer appears in navigation layer. After processing data, if it detects an emergency, it passes the required information to navigation decision maker, to perform first responder navigation information and victim navigation information. Objectives of the remaining two layers are described in the following sub sections.

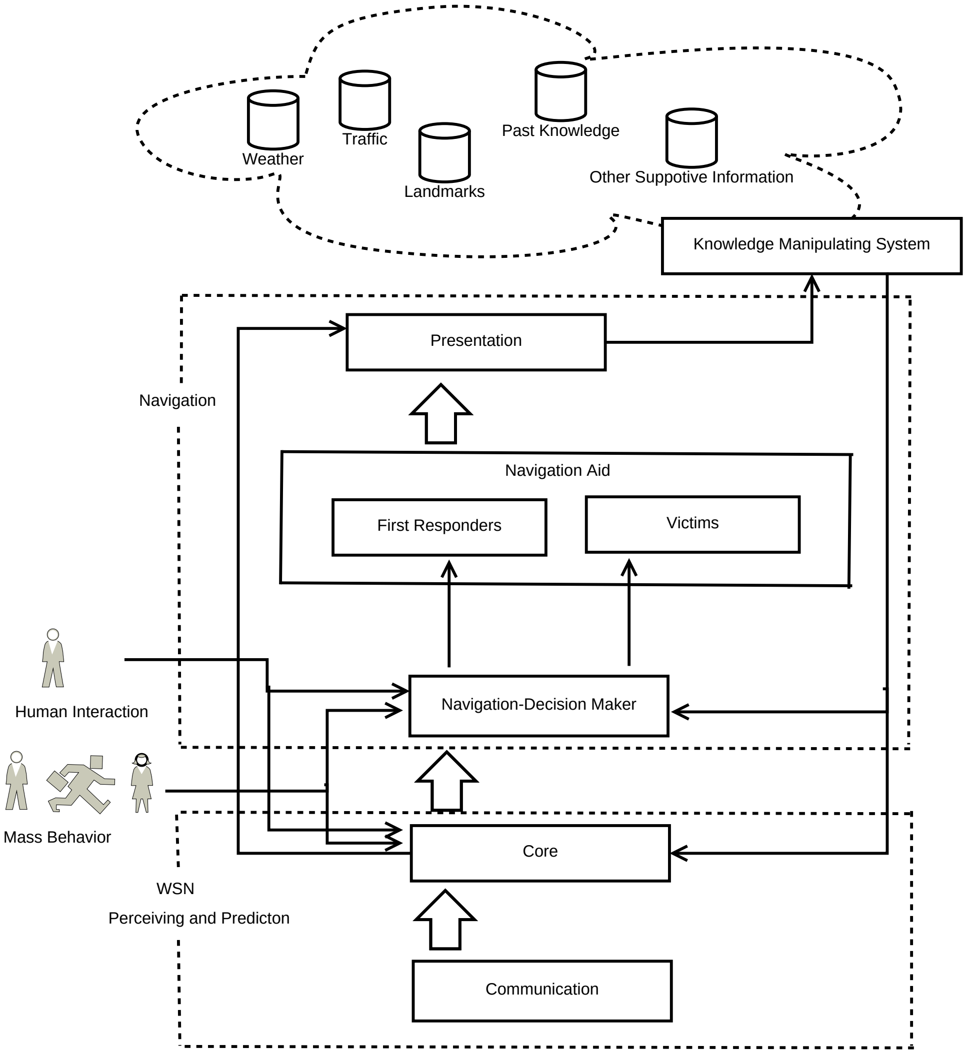


Fig. A.7: Proposed Emergency Response and Navigation Support Architecture

A.2.1 Navigation support layer

This application focuses on, an indoor emergency environment in which several dangerous areas can exist which are threats to human safety such as fire, smoke, obstacles, etc. Thus, people need to evacuate the building as quickly as possible while keeping away from those dangerous areas. Also first responders need to have an idea of emergency's spreading pattern in the building and the locations of trapped people. Hence, the main objective of this layer is supporting the victims to evacuate from the building and navigate responders through the building to find their way to save human lives and combat emergencies.

Navigation support layer consists of three sub layers. Navigation-Decision Maker, Navigation Aid, and Presentation. This layer gets the input from the WSN Perceiving and Prediction layer, knowledge manipulation layer and human behaviors. Then the output is displayed on a Graphical User Interface (GUI). Also, some of the decisions made in navigation aid sub layer are stored in the knowledge manipulation system.

Navigation-Decision Maker sub layer

The main role of this sub layer is dividing the processed data received from the WSN Perceiving and Prediction layer, knowledge manipulation layer, human interaction, and human mass behavior to, two navigation aid sub sections. Moreover, the data needed for the first responder navigation algorithm and the victim navigation algorithm are different. Therefore, the main objective of this sub layer is according to the rules specified, make decisions and separate the processed data into two categories. Then pass this information to two navigation sub layers respectively.

Navigation Aid sub layer

The main objective of this sub layer is providing navigation information to both first responders and victims. Navigation aid sub layer gets information from navigation-decision maker and output of its display in presentation sub layer. Also, decisions made on this layer stored in knowledge manipulation layer via the presentation sub layer. This sub layer consist of two sub sections namely first responders and victims.

First responder sub section Use of body area network (BAN) for first responder navigation has become more important in order to fight with the incident and save human lives. The dangers associated with this activity are the result of a number of factors, such as lack of information regarding first responders (i.e. location and health state), the environment surrounding (i.e. spread of emergency, temperature) and mental and physical stress in an emergency environment [70]. Indoor navigation of first responders deals with guiding them from its present location by avoiding obstacles and hazardous regions to save human lives and combat hazards. Hence, these navigation algorithms need information such as environment characteristics (heat, smoke, dust etc.), hazardous areas, locations, real-time map of the building, trapped people and etc. This information is fed to the first responder subsection from navigation-decision maker sub layer. With this information the navigation algorithms proposed in [70, 71] can be performed to guide the first responders. The decisions made by this layer, stored in the knowledge manipulation layer via presentation sub layer for future use. Also the output of navigation algorithm is passed onto the presentation sub layer to guide the first responders.

Victim sub section In an emergency, victims may find it difficult to find a way out from the building because of hazardous areas or other obstacles. As at any time, any spot may become dangerous. Therefore providing navigation information only for first responders to exit from hazardous areas is not enough. As a result, finding safe and efficient escape paths for victims under dynamically changing environmental is the main objective of this sub section. In this subsection, it takes the input from the navigation-decision maker sub layer which contains information on hazardous areas, emergency spreading, congestion areas etc. and can perform navigation algorithms proposed in [67, 68].The decisions made by this subsection, stored in the knowledge manipulation layer via presentation sub layer for future use. Also the output of navigation algorithm is passed onto the presentation sub layer to guide the victims.

Presentation sub layer

The presentation sub layer is responsible for displaying the processed information in a GUI and taking the necessary actions. In normal state without an emergency, the conditions of the building environment (temperature, humidity, color etc.) can be presented in an easily readable building map. If an emergency is taken place, this layer can be used to inform the conditions of the environment to relevant parties (i.e. first responders). Also during an emergency, presentation sub layer is responsible of displaying navigation information to victims through LCD displays or lighting bulbs and transferring navigation information to first responders through BAN or other relevant way.

Moreover all the outputs received from core sub layer and navigation aid sub layer (output of first responder and victim sub sections) are displayed in a meaningful manner to make the correct decision on the situation.

A.2.2 Knowledge Manipulation layer

Addition to the information from WSNs, the information gathered from various other data sources such as traffic data, atmospheric conditions, information regarding important locations etc. [10], can be used to make the whole emergency response system more accurate and efficient.

In this layer, we introduce several possible components to manipulate knowledge gathered from several sources. Dynamically varying results of this layer are sent back to the core layer and to the navigation layer to further refine the results at each layer. This layer will be deployed in a central location, to gain knowledge on disaster management of a particular geographical region. The connectivity between Knowledge Manipulation Layer and other layers in the architecture can be accomplished by using any suitable communication methods, via gateways.
The main objective and aim of this layer is to support emergency response and navigation by providing a rich collection of knowledge to the system.

Information of road traffic

Once an emergency alert is received and confirmed at the rescue operations center, the response time of the first responders towards the emergency situation is very critical. Providing real-time and forecasted road traffic related information appropriately to the firefighters would improve the response time effectively. By retrieving the real time and forecasted traffic information, fire fighters will be able to find the most suitable path to the emergency location and reach immediately. This information can be stored in a database and update dynamically.

Information of weather conditions

First responders can acquire valuable insight knowledge on the incident site by getting dynamic information related to atmospheric conditions in the vicinity of an incident. According to this information firefighter can capture nearly accurate surrounding environment of the emergency site, and take relevant equipment and human resources to the site immediately. Moreover, forecasting on the propagation of the emergency (i.e. spread of fire according to the wind speed) is possible and evacuating the relevant other surrounding crowds (who are not in the emergency site currently) is also possible.

Information of important surrounding locations

Information about the nearest hospitals, lakes and other water sources, dangerous locations (i.e. power plants, chemical storages) is very important to the first responders in order to make correct and immediate decisions on emergency response. Especially according to this information the resources they supply to the emergency site will be varied. This information will be stored in the database and most probably will be static.

Knowledge from past emergencies

Information about the past emergency incidents will be saved in a database. The perceived past knowledge can be used and combined with the current emergency information to further refine the knowledge of the incident. Forecasting on future emergencies and filtering current noisy information during an emergency can be achieved.

Information gathered from various websites

There may be important websites to get more information on the emergency environment. The websites can be previously identified as important websites or real time search results on the web. Web mining technologies can be incorporated into this part to extract meaningful information related to the incident.

Knowledge manipulating framework

The algorithm(s) run in this framework should be able to retrieve information from various sources and update the relevant databases. Moreover it will provide information to various layers and components in the system when needed. In a nutshell this framework adds following services to this layer,

- Retrieve information from various sources and update the databases.
- Distribute raw information to relevant layers when the raw information is needed.

- Manipulate, combine [72, 73] all the information gathered in real time and provide more detailed knowledge to relevant parties/layers when needed.
- Forecast on the event of interest and provide information to relevant parties/layers when needed.

Efficient maintenance of a large database system, saving, retrieving, managing large sets of data real time and off line is crucial to optimize the response time in an ER.

A.3 Future Work

An adaptable WSN based architecture was proposed for emergency situations which is capable of switching between emergency and non-emergency modes. Essentially, the architecture offers a way of minimizing the severity of the impact caused by the emergency using WSNs. The most crucial research aspects localization, self-organizing, energy consumption, multi-modality sensor fusion etc. are incorporated in an effective manner. To our knowledge, no architecture is able to address above research aspects in an emergency with the capability of switching between two states.

However, Each sub layer in the core layer should be further refined to make the behavior of the whole WSN architecture robust in emergency response.

Another important research aspect in WSN is security implications which have not been addressed in this paper. Additionally, it needs to be further explored on other aspects like, providing users the information on highest possible time lines and if a transmission failure occurred, notify it to the user/application as quickly as possible. Further a common data structure needs to be used with higher flexibility and proprietary formats. Furthermore, this architecture mainly focuses on building monitoring systems for emergency response. How can this architecture incorporate with green building applications, need to be investigated.

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