ENERGY EFFICIENT GRID BASED HYBRID NETWORK DEPLOYMENT APPROACH IN WIRELESS SENSOR NETWORKS

This Thesis is submitted to the Department of Computer Science University of Peshawar in Partial Fulfilment of the Requirements for the Degree of PhD in Computer Science

Submitted By
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Supervised By
DR. HUMA JAVED

DEPARTMENT OF COMPUTER SCIENCE
UNIVERSITY OF PESHAWAR, PAKISTAN
SESSION 2010-11
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FORWARD CERTIFICATE

The research entitled “Energy Efficient Grid Based Hybrid Network Deployment Approach in Wireless Sensor Networks” is conducted under my supervision and the thesis is submitted to University of Peshawar in partial fulfilment for the degree of PhD in Computer Science.

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ENERGY EFFICIENT GRID BASED HYBRID NETWORK DEPLOYMENT APPROACH IN WIRELESS SENSOR NETWORKS

APPROVAL

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I, Mr. Haleem Farman, hereby state that my PhD thesis titled “Energy Efficient Grid Based Hybrid Network Deployment Approach in Wireless Sensor Networks” is my own work and has not been submitted previously to claim any degree from University of Peshawar or anywhere else in the country/world.

At any time, if my statement is found to be incorrect even after my graduation the University has right to withdraw my PhD degree.

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Mr. Haleem Farman
Date: 16th March, 2018
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DEDICATED TO MY

Parents & Family
ACKNOWLEDGEMENTS

We cannot seek words at our command to express the deepest sense of gratitude to almighty ALLAH for his most merciful, beneficent and benign blessings which enabled me to complete the lengthy and enormous task for the talent, intellect and mental powers that he gifted. I cannot state expressions for my Parents as they are always available in my hard and soft times. There vital role laid a milestone in my academic career. Their continuous rally round enabled me to attain this ultimate goal of education in the form of this research. I am especially thankful to my wife for her unselfish support and encouragement. It is her tolerance and enthusiasm that let this effort turned in to reality.

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PUBLICATIONS

This research thesis is based on following publications.


ABSTRACT

Wireless Sensor Networks (WSNs) are becoming ubiquitous in everyday life due to their applications in weather forecasting, surveillance, implantable sensors for health monitoring, Internet of Things (IoT) and other plethora of applications. WSN is equipped with hundreds and thousands of small sensor nodes for monitoring and surveillance of a targeted region. As the size of a sensor node decreases, critical issues such as limited energy, computation time and limited memory become even more challenging. In such case, network lifetime mainly depends on efficient use of available resources. Organizing nearby nodes into clusters make it convenient to manage each cluster as well as the overall network efficiently. WSN empower applications for critical decision-making through collaborative computing, communication and distributed sensing. However, they face several challenges due to their peculiar use in a wide variety of applications. One of the inherent challenges with any battery operated sensor is the efficient consumption of energy and its effect on network lifetime.

The topology management becomes very important as nodes are often distributed randomly that leads to uneven distribution of load. In addition, cluster head selection plays an important role in enhancing network lifetime and improving energy efficiency. Inappropriate selection of Cluster Head (CH) may lead to high network overheads resulting in early battery depletion affecting overall network lifetime. The sensor node selected as CH is responsible for both inter and intra cluster communication, therefore, it consumes more energy as compared to other cluster nodes. Thus, it is very important to select an
optimal node as CH and to efficiently rotate the CH role periodically to avoid network partitioning problem.

In this research work, a novel Grid based Hybrid Network Deployment (GHND) approach for WSN is proposed to ensure energy efficiency and load balancing. The new merge and split technique that evenly distributes the nodes across the network for maximizing energy efficiency and network lifetime. The proposed method is compared with existing state-of-the-art energy efficient cluster and grid-based techniques on the basis of energy efficiency, scalability and network lifetime. An extensive set of simulations and experiments reveal that the proposed method outperforms existing state of the art techniques such as LEACH and PEGASIS in terms of load balancing, network lifetime, and energy consumption. Moreover, the cluster head selection problem is resolved with a multi-criteria decision modeling using the Analytical Network Process (ANP). A mathematical framework is developed that takes into account various parameters such as residual energy level, distance from neighboring nodes, centroid distance, number of times a nodes has been cluster head and whether a node is merged or not, for efficient selection of cluster head. In the ANP model, these mentioned parameters are pairwise compared to obtain the weights through the supermatrix. The supermatrix is transformed into a limit matrix that reports priority weights for all criteria parameters. These priority weights are further used to optimize the criteria list for efficient cluster head selection by eliminating low weight parameters ultimately minimizing computational complexity of the ANP process. The sensitivity analysis of the proposed ANP based scheme has been carried out to check the stability of parameters and relative importance in CH selection process.
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<td>ADC</td>
<td>Analog to Digital Converter</td>
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<tr>
<td>ADV</td>
<td>Average Distance Value</td>
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<td>ANP</td>
<td>Analytical Network Process</td>
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<tr>
<td>BS</td>
<td>Base Station</td>
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<td>CBDAS</td>
<td>Cycle Based Data Aggregation Scheme</td>
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<td>CH</td>
<td>Cluster Head</td>
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<td>CHEF</td>
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<td>CI</td>
<td>Consistency Index</td>
</tr>
<tr>
<td>CM</td>
<td>Consistency Measure</td>
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<tr>
<td>CP</td>
<td>Crossing Point</td>
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<td>CR</td>
<td>Consistency Ratio</td>
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<td>CV</td>
<td>Cumulative Value</td>
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<td>CZH</td>
<td>Candidate Zone Head</td>
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<td>DARPA</td>
<td>Defense Advanced Research Projects Agency</td>
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<td>DSNs</td>
<td>Distributed Sensor Networks</td>
</tr>
<tr>
<td>D45SR</td>
<td>Diagonal 45° Split Ratio</td>
</tr>
<tr>
<td>D135SR</td>
<td>Diagonal 135° Split Ratio</td>
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<td>DUCA</td>
<td>Distributed Uniform Clustering Algorithm</td>
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<tr>
<td>E&lt;sub&gt;0&lt;/sub&gt;</td>
<td>Initial Energy</td>
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<td>EADC</td>
<td>Energy Aware Distributed Clustering</td>
</tr>
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<td>EFP</td>
<td>Error Factor Percentage</td>
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<tr>
<td>EL</td>
<td>Energy Level</td>
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<tr>
<td>ER&lt;sub&gt;X&lt;/sub&gt;</td>
<td>Receiving Energy</td>
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<td>ET&lt;sub&gt;X&lt;/sub&gt;</td>
<td>Transmitting Energy</td>
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<tr>
<td>EV</td>
<td>Eigen Vector</td>
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<tr>
<td>FH</td>
<td>Field Height</td>
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<td>FW</td>
<td>Field Width</td>
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<tr>
<td>GBDD</td>
<td>Grid Based Data Dissemination</td>
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<td>GBRR</td>
<td>Grid Based Reliable Routing</td>
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<tr>
<td>GHND</td>
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<td>GPS</td>
<td>Global Positioning System</td>
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<td>GS</td>
<td>Grid Sectoring</td>
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<td>HDZ</td>
<td>High Dense Zone</td>
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<td>HSR</td>
<td>Horizontal Split Ratio</td>
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<td>IBG</td>
<td>Inter Bound Gap</td>
</tr>
<tr>
<td>ID</td>
<td>Identifier</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineering</td>
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<tr>
<td>IoT</td>
<td>Internet of Things</td>
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<tr>
<td>IZ</td>
<td>Interest Zone</td>
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<td>LB</td>
<td>Lower Bound</td>
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<td>LDZ</td>
<td>Low Dense Zone</td>
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<td>LEACH</td>
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<td>MCDM</td>
<td>Multi-Criteria Decision Making</td>
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<td>MN</td>
<td>Merged Node</td>
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<td>NUDND</td>
<td>Non-Uniform Deterministic Node Distribution</td>
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<td>ORR</td>
<td>Optimal Range Ratio</td>
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<td>PBDAS</td>
<td>Path Base Data Aggregation Scheme</td>
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<tr>
<td>PDA</td>
<td>Personal Digital Assistance</td>
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<td>PEGASIS</td>
<td>Power Efficient Gathering in Sensor Information System</td>
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<td>REL</td>
<td>Residual Energy Level</td>
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<td>Random Index</td>
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<td>SPIN</td>
<td>Sensor Protocols for Information via Negotiation</td>
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<td>TCH</td>
<td>Number of Times Cluster Head</td>
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<td>TV</td>
<td>Threshold Value</td>
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<td>Upper Bound</td>
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<td>Unequal Clustering Size</td>
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<td>WSN</td>
<td>Wireless Sensor Network</td>
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<tr>
<td>ZH</td>
<td>Zone Head</td>
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<td>Z_H</td>
<td>Zone Height</td>
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<td>Z_W</td>
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CHAPTER 01

INTRODUCTION

1.1 Motivation

Wireless sensor network (WSN) is a network of small sensor nodes which are deployed in large numbers, over a targeted area to sense the physical environment. A sensor node is capable of sensing the physical environment, processing the sensed data and then forwarding it to the base station (BS) or sink node. Sensor nodes are usually battery operated having inherent energy limitations. They are often deployed in hard environments where battery replacement or recharging is very difficult [1]. It becomes necessary to use the battery wisely and minimize energy consumption across the network. In WSN, sensor nodes cooperate with each other to gather data and then forward it hierarchically. Member nodes send data to the head node known as cluster head (CH) [2]. Deployment of nodes is often random that might lead to non-optimal clusters and uneven distribution of nodes across the field of interest resulting in hotspot problem where the network is partitioned into segments [3]. In addition, cluster head selection plays an important role in enhancing network lifetime and improve energy efficiency. Poor selection may lead to high network overheads resulting in quick battery depletion thus affecting overall network lifetime. A cluster head acts as a focal point due to which it consumes more energy as compared to the member nodes. Therefore, it is very important to rotate CH within the cluster. In literature, most of the approaches periodically rotates the role of a cluster head. Furthermore, the periodic reformation of clusters and re-election of CHs leads to extra energy consumption resulting in poor network performance.
In order to cope with the above mentioned problems, energy efficient grid-based hybrid deployment approach is proposed in this research work. The focus of this work is on energy efficient grid-based clustering algorithm that is capable of constructing balance grids (clusters) and even distribution of nodes by using novel merge and split technique. The zone head selection is based on weighted metrics to select the best node as a zone head (ZH) by lowering network overheads which contribute to improved overall network lifetime. In the proposed method the reselection process of ZH is optimized by eliminating the periodic re-election of ZH and grid reformation. In addition, ZH reselection process is initiated per zone when it is required by not disturbing overall network. In the reselection process, collection list is used which already have the cumulative values (CV) of all the nodes thus reducing overheads and maximizing the network lifetime.

The proposed technique is suitable for various applications that require energy efficiency such as health monitoring, environmental applications, military applications etc. The proposed grid-based clustering algorithm offers an energy efficient solution to prolong network lifetime and balance the load. The proposed method can easily be used as an underlying topology for other grid-based techniques.

1.2 Overview

1.2.1 Historical background

In the early 1980s, a program named Distributed Sensor Networks (DSNs) for US military was carried out by United States Defense Advanced Research Projects Agency (DARPA) [4]. This program aimed to use wireless sensor network for US military. It was assumed that DSNs will have large number of low cost tiny sensing devices, operated in an
unattended environment with self-organizing capabilities and can route information to the node that can best use it. At the early stage, researchers had the vision of implementing this but at that time technology was not ready. Moreover, the sensors were quite large and had the limitation of applications as well. Therefore, initial DSNs were not firmly linked with wireless connectivity. Around 1998, a new wave of research on WSN started attracting researchers and industrialists. The focus was on networking technology and on network processing capability for dynamic ad hoc environments with resource-constrained sensor nodes [5]. DARPA added new capabilities such as dynamic querying and tasking, ad hoc networking and multi-tasking in sensor networks by launching an initiative program SensIT [6].

Wireless sensor network has been identified as one of the most significant technology of 21st century. A tiny cheap device having sensors on board, connected wirelessly, self-organizing capability, can be connected to the Internet and deployed in large number offers exceptional opportunities for controlling and monitoring environments, homes, offices, cities and much more [4]. These sensor nodes can be deployed anywhere on the ground, underwater, on bodies, in the air, inside buildings and even in vehicles.

Since 2001 researchers and industrialists have shown great interest in developing WSN and have used sensors in a variety of other technologies such as IEEE 802.11, personal digital assistance (PDA), mobile phones, internet of things (IoT) and much more. In 1999, Kevin Ashton [7] introduced the term internet of things where a number of objects are uniquely identified in virtually an internet like structure. These objects can be anything such as buildings, vehicles, machines, goods, animals, plants, anything at home and office
and even parts of human body. The IoT does not support any specific communication technology, therefore WSN plays a major role in many applications of IoT due to its small size, low cost, low powered and capability to work in the harsh environment [5]. This extends IoT service to very small objects in any environment. This integration of IoT in WSN is a major evolution and can easily term as the future technology of smart society and by 2020 with estimation of around 50 billion devices intended to be linked to the network [8].

1.2.2 Working and Requirements of Wireless Sensor Network

Wireless sensor network is the network of unattended tiny sensor nodes which are spatially distributed over a targeted area to record and monitor the condition of an environment. Usually, these networks have hundreds and even thousands of resource constrained sensor nodes. WSN function in ad hoc manner, having no fixed infrastructure. Once the sensor nodes are deployed, they are left unattended, but these sensor nodes have capability to construct a network. Physical environmental factors such as pressure, humidity and heat are sensed, processed and then forwarded by sensor node to BS/CH/sink. The sink node or BS can also query sensor nodes [9]. The sensor nodes are built with constrained resources, due to which nodes consume energy quickly, and the battery cannot be recharged or replaced. Therefore, energy efficient schemes are required that offer high scalability and can ensure maximum network lifetime, which makes it one of the main design challenge in WSN.

Deployment in wireless sensor network plays very important role in the management of sensor nodes, it defines the way nodes are deployed in a network. Deployment of sensor
nodes is categorized into structured and unstructured. In structured deployment, the sensor nodes are positioned in a pre-defined way, thus reducing network maintenance and overheads. Usually, sensor nodes in structured deployment are limited in number, as their position has to be known and defined. While in the unstructured deployment, hundreds of sensor nodes are randomly deployed. These sensor nodes are left unattended to configure themselves for sensing and monitoring. Due to large number of sensor nodes, network maintenance and overhead in the form of link failures and managing connectivity are high [10]. WSN is different from the traditional wireless and Adhoc network due to its limited resources such as memory, processing capability and battery life. These limitations make the design of wireless sensor network a real challenge. Therefore, the design mechanisms for data communication between nodes and base station should be energy efficient to maximize network lifetime and overall performance of the network [11, 12].

1.2.3 Routing in WSN

In literature, protocols for routing of data from sensor nodes to base station are classified in to flat, location-based and hierarchical [13] as shown in Figure 1.1. In flat networks, all sensor nodes cooperate with each other through multihop routing in which each node has the same role. It is not practical to allocate a global identifier (ID) to each node, due to which data-centric routing is considered for flat routing in which BS requests from sensors in a specific region. Different protocols have been proposed for data-centric based routing to save energy such as Sensor Protocols for Information via Negotiation (SPIN) [14, 15] and directed diffusion [16]. The flat based approach has some advantages such as no need to maintain topology and provides quality links from source to destination. At the same
time, few disadvantages are, flat networks use flooding which is an expensive operation, redundant messages causes high bandwidth consumption, energy consumption is non-uniform and has high delay [17].

![Routing Protocols](image)

In location-based (geographic-based) routing, sensor nodes are addressed through their locations. On the basis of signal power, the distance between two nodes can be determined. The coordinates of the neighboring nodes can be obtained by sharing information, and it may be available by communicating with a satellite by means of GPS. In most of the location-based protocols, sleep period schedule is used to save energy [18, 19]. In hierarchical routing, usually two layer approach is used, where one layer is used for sensing the physical environment and the other is used for routing. The low energy nodes are used for sensing while high energy nodes are often used for collecting, aggregating and forwarding data. Sensor nodes are grouped in to clusters and the node having higher energy is usually selected as a cluster head. The sensed data is sent to CHs for processing and then further forwarded to the BS either through multihop or direct transmission [20, 21]. Clustering approach is the most widely used technique for energy efficiency to achieve
scalability and effective communication. Cluster-based hierarchical approaches have some advantages such as it increases scalability, efficient data aggregation and channel bandwidth is efficiently utilized. The main problem of clustering is non-uniform clustering which leads to high energy dissipation of sensor node, total energy consumption increases and network connectivity is not guaranteed [17].

A cluster head is the central point in cluster, as it is responsible for different activities in the network due to which its energy depletion is much faster than the member nodes. Therefore, in hierarchical techniques selection of an optimal set of CHs is a challenging task [22, 23]. Different hierarchical schemes are proposed for energy efficiency which aims to achieve improved network lifetime and scalability with minimum overheads [24-26]. The main challenges in hierarchical approach that still need to be addressed are the formation of optimized grids (clusters) and even distribution of nodes across the grids. Furthermore, the non-efficient selection of zone head may result in degradation of overall network structure. In most of the techniques after a certain number of rounds, zones are reconstructed, and zone heads are reselected periodically which leads to extra computational and communicational overhead. Therefore research presented in this document addresses the above highlighted issues.

1.3 Problem Statement

In the section above it has already been established that the field of WSN is challenging in many ways due to limited resources of sensor nodes in the network especially memory, computation and most importantly battery. Therefore, lightweight, energy efficient, flexible and scalable techniques are often required to overcome the limitations of sensor
nodes. The work done so far has limitations as already mentioned in the previous section. This research addresses four important issues in wireless sensor networks which are uneven distributions of nodes, non-optimized zone head selection, inefficient grid reformation and periodic zone head reselection process. This work addresses the problem of limited energy resources while gathering sensed data from nodes, which reduces the network lifetime.

- In most of the WSN applications, sensor nodes are usually randomly deployed over a targeted area. Nodes are grouped into clusters (in grid-based techniques, often called as grids) and one head node called as cluster head is responsible for receiving data from member nodes and forwards it to BS. As sensor node has limited resources specially limited battery power therefore, clustering approach has gained further attention from the researchers. Grid-based clustering is one of the technique to achieve efficient grid formation and improved energy consumption. In existing literature, many researchers have discussed different grid-based clustering techniques but most of them construct unbalanced grids which results in uneven distribution of nodes. Moreover, uneven distribution often leads to hotspot problem where the network is partitioned into segments resulting in poor network performance and unbalanced distribution of load. Issues such as, uneven distribution of nodes and optimizing energy consumption during grid formation are still open research questions. In addition, topology management is also very important to uniformly distribute nodes in grids and make the network efficient. To improve energy consumption and distribute nodes evenly to overcome hotspot problem, it is important to construct efficient grids and balance the load among nodes.
Furthermore, zone head selection is very important factor in WSN which is responsible for aggregating and forwarding gathered data from member nodes to BS. In literature different probabilistic and non-probabilistic approaches have been proposed to select the cluster head effectively. Most of the approaches have used probabilistic grid-based clustering approaches that select CH on the basis of probability or by considering the random approach. However, it causes high network overheads that leads to early battery consumption thus reducing network lifetime. Therefore, an energy efficient non-probabilistic zone head approach that considers certain weighted metrics such as residual energy, distance from the centroid, node proximity and number of nodes in a cluster must also be considered to select the best possible node as ZH. In addition optimum ZH selection increases over all network lifetime and lowers network overhead.

Moreover, the exhausted ZH node may affect a particular zone thus such scenarios must be avoided which might contribute to poor network performance. In particular sensor nodes have limited resources especially the battery power, therefore, it is important to rotate the ZH in each zone. In literature, different cluster-based and grid-based approaches switch the role of ZHs by periodic grid reformation and ZH reselection. However, the iterative process of grid reformation and periodic zone head reselection may result in extensive energy consumption of the nodes which could lead towards poor performance of the network. Therefore, such technique is required that can ensure efficient grid reformation or the process of reformation should be eliminated to avoid extra computational and communicational overheads. Furthermore, the
periodic zone head reselection process should be optimized to improve energy efficiency eventually prolonging individual node and network lifetime.

1.4 Design Goals

In the previous section, research issues that still need improvement were highlighted. Therefore, below are the design goals of the proposed work that will address the aforementioned problems.

- The first design goal is load balancing and efficient grid formation. In WSN, all the nodes cooperate with each other to perform a task because each node individually has limited resources. Therefore, it is important to distribute the load among nodes evenly. Load balancing improves overall lifetime of the network and also prolongs network stability. Efficient grid formation improves the overall network topology thus overcomes network breakage. One of the design goal of this work is to devise a technique which could evenly distribute nodes across the network that leads to efficient grid formation and balance the load.

- Energy efficiency is extremely important for WSN working in outdoor applications because they are usually deployed in areas where human intervention is either impossible or difficult. The energy resource as already established above are limited therefore it is important to consider energy efficiency at each level to ensure improved energy consumption thus prolonging network lifetime. Therefore, an energy efficient zone head selection and reselection technique is required that can ensure low energy
consumption during the whole process. The energy efficiency is another design goal of this work.

- The proposed framework should be scalable enough to support different node density and must sustain performance that should not depend on number of nodes. One of the characteristic of WSN is that they are application dependent, so the number of nodes may vary accordingly. Nodes physical damage rate might be high in some outdoor applications because they are subjected to harsh conditions such as, extreme weather or being trampled by animals. Battery depletion is also common in WSN so the network might shrink. In order to keep the network working, new nodes might be deployed so the network might also grow. Therefore, it is very important that the proposed framework should be flexible enough that support scalability.

- One of the design goal of this work is to select an optimal zone head using multi-criteria decision tool. In non-probabilistic approach, certain parameters for zone head selection are used which makes this a multi-criteria decision problem. Moreover, a mathematical model has been developed that can be used for different parameters depending on application requirements. The significance of such approach will be that it can be applied to cluster-based and grid-based techniques to select an optimal cluster/zone head depending on certain parameters to increase network lifetime with improved energy efficiency.

To achieve the above design goals, an energy efficient grid-based hybrid network deployment framework has been proposed. The proposed framework achieves load balancing through the novel merge and split technique. Moreover, it is tested to be energy
efficient at different levels such as during the zone head selection and reselection process. The framework will accommodate new nodes to achieve scalability depending on application requirements.

1.5 Research Contributions

Keeping in view the above considerations, this thesis presents a lightweight grid-based hybrid network deployment framework. The main contributions of this research work have been discussed as follows:

1) Literature survey was conducted regarding relevant energy efficient cluster-based and grid-based state of the art techniques. The challenges faced in the design of an energy efficient clustering technique for WSN were studied and identified. A new set of requirements were identified that could directly affect performance of any clustering technique such as cluster and grid formation, the optimal number of grids, cluster/zone head selection, reselection of cluster head and cluster reformation. Furthermore, these protocols were analyzed with respect to topology construction, cluster head selection and reselection.

2) The major contribution of this thesis is an energy efficient, light weight grid-based hybrid network deployment framework (GHND) that will ensure even distribution of load to minimize the energy consumption and to increase network lifetime. It will be used at the pre deployment stage. This framework consists of five phases which are network deployment phase, grid formation, zone head selection, transmission and zone head reselection. The proposed method is named as a hybrid because it combines two approaches centralized and distributed. Initially, the topology construction and zone
head selection is processed by the base station to avoid broadcast messages and have a global view of the network. In addition, the decision of reselection of zone head is localized at sensor node which will certainly reduce communicational overheads thus making it energy efficient. The framework is generic enough that can be used as an underlying topology for other grid-based clustering techniques. Moreover, it is more suitable for homogenous networks where all nodes have same resources. The proposed approach supports scalability with sustained performance and can be used in both small scale and large scale networks where number of nodes vary. The system is adaptable enough to adjust according to the parameters given while constructing the network topology.

a. It has already been mentioned in the design goals that load balancing is important to ensure longer network lifetime and network stability. To achieve load balancing, the even distribution of nodes among the clusters is important. In WSN, the deployment is often random, and situations, where nodes are unevenly distributed, may arise. Some zones might have less number of nodes and other zones might be very dense which could lead to poor network performance. In addition, low dense zones (LDZ) might lead to hotspot problem where the network is partitioned in to segments. To cover these problems, a novel merge and split technique is introduced, in which low dense and high dense zones are identified first. If the number of nodes are less than the lower threshold (known as lower bound) then nodes in the low dense zones are merged with its neighboring zones to avoid hotspot problem. High dense zones (HDZ) are split in to sub-zones, if the number of nodes exceeds the upper
Introduction

threshold (known as upper bound). Four splitting strategies are proposed which are horizontal, vertical, diagonal 45° and diagonal 135°. The proposed technique formulates nearly even sized grids by evenly distributing nodes across the network. Thus improving load balancing, reducing grid formation overheads (as the process has to be on BS, nodes energy will not be consumed) and maximizing network performance.

b. The lower bound (LB) and upper bound (UB) are optimized after extensive experimentations, as they directly affect the network topology. The threshold value for LB and UB is very important because it can directly affect the distribution of nodes that results in unbalanced load sharing. Therefore, LB and UB threshold values are identified to optimally merge and split the candidate zones so that nodes can be evenly distributed across zones, which will improve network performance. The threshold values of LB and UB are optimized through experimentation using different scenarios, which may vary for different applications. The proposed method will set LB and UB thresholds according to the parameters given at input. Therefore this makes the proposed technique adaptable and flexible as well which can be used according to applications requirement depending on network parameters.

c. In the proposed method, an energy efficient optimized non-probabilistic approach for zone head selection is used. The zone head plays a significant role in improving the network performance. Optimal selection of zone head (ZH) results in maximizing the individual sensor node lifetime and of the entire network as well. Moreover, poor selection could lead to early battery depletion
and might result in computational overhead, network partitioning and shortening network lifetime. In the proposed method, the selection is based on multiple weighted metrics with minimum computational overheads that leads to improved energy consumption and network lifespan. In addition, the network stability period also improves with optimum selection of ZH.

d. To improve energy consumption, the role of ZH is rotated periodically to gain energy efficiency. One of the objectives of this work is to reduce energy consumption during ZH reselection process. In literature, most of the techniques performed periodic CH re-election and reselection that results in extra energy consumption, communicational and computational overheads. Instead of performing periodic ZH re-election and reselection, the proposed method initiates the reselection process when it is required by the respective zone. In addition, the reselection process is independent of other zones thus not disturbing the overall network. Moreover, the process is initiated by sensor node itself and is localized at the node. The next ZH is selected from a list known as collection list having cumulative value of all nodes in their respective zones thus no need to re-elect the ZH. In addition, reselection of ZH is independent of the number of iterations. Thus the whole process of reselection is energy efficient resulting in improved energy consumption, reduced communicational and computational overheads.

3) The problem of CH selection, based on certain parameters, falls under multi-criteria decision system. The multi-criteria decision tool, analytic network process (ANP) is used to select the optimum node as CH. The ANP is used because it can deal with the
interdependencies and feedback relationship between elements and clusters. By using ANP, the alternatives and criteria parameters can be optimized by eliminating the elements having very low weights. Thus minimizing computational complexity of the process. The CH selection in WSN involves tuning of several inter-related parameters and have a great deal of dependencies on each other which could not be addressed through other multi-criteria decision tools. In literature, most of the techniques ignore interdependencies of elements within in cluster and between clusters. To come up with the optimum selection of CH node to cover minor dependencies as well, ANP method is used. A mathematical model is developed for ANP as an alternative method for optimum CH selection. One of the contribution of this work is to check the applicability of ANP model for cluster head selection in WSN. To the best of author’s knowledge, ANP has been used for the first time for cluster head selection in grid-based wireless sensor network.

1.6 Thesis Structure

The rest of this thesis is organized as follows.

Chapter 2 highlights the extensive review of the background and related work. The shortcomings of existing cluster-based and grid-based energy efficient hierarchical clustering protocols are identified. The existing schemes in terms of grid formation, zone head selection and reselection are evaluated.

Chapter 3 is about the research methodology of the proposed energy efficient grid-based hybrid network deployment approach that is used to develop the research objectives of this work. It explains the complete design process of the proposed work.
In Chapter 4, the proposed energy efficient grid-based hybrid network deployment framework in wireless sensor network is evaluated. The proposed method is compared with state of the art existing energy efficient cluster-based and grid-based techniques.

Chapter 5 is about the design and development of mathematical model for cluster head selection using multi-criteria decision tool. Moreover, analytic network process is used as a multi-criteria decision tool to select the optimum node as a cluster head. Furthermore, the applicability of the mathematical model is checked for ANP in wireless sensor networks.

Finally, the thesis is concluded in chapter 6 with contributions made in this research work and provides possible future directions.
CHAPTER 02

LITERATURE REVIEW

In this chapter, relevant literature is comprehensively reviewed to provide required background knowledge and make foundation for the research presented in this thesis. An overview of WSN is presented along with its characteristics, architecture and applications in today’s modern world. Afterwards, hierarchical clustering and its design challenges are discussed. The classifications of hierarchical clustering is presented with highlighting some important clustering parameters that effects energy efficiency. In literature, considerable efforts have been made for the development of energy efficient and load balancing protocols in wireless sensor networks. As WSN is application dependent, so the protocol development is based on architecture of network and needs of applications. As discussed in the previous chapter that resources are very limited in WSN, therefore when designing and developing energy efficient and load balancing protocols several factors need to be taken in to account. The most important among these factors is energy efficiency because network lifetime and performance directly depends on it. In literature, several efforts have been made to prolong overall network lifetime and network stability in terms of energy efficiency, few of them are discussed in the forthcoming sub sections.

2.1 Wireless Sensor Network

Wireless sensor network with its sole purpose of data collection, processing, and communication is widely used in various set of applications. Sensor networks are intended to operate in unattended unfriendly environments for longer period of time. Sensor nodes
are typically battery operated having an inherent energy limitation [27]. The scarce energy resource and the unpleasant environmental constraints make replacement or recharging of the battery very hard or even impossible in certain situations like battle field, volcano detection, deep sea sensing, and so forth. Therefore battery usage must be properly managed in order to minimize energy consumption across the network. The characteristics of WSN such as, low cost, energy efficient, small range and intelligence make sensor nodes one of the main building block of new looming technologies such as internet of things and software defined wireless sensor networks [28].

2.1.1 Characteristics of WSN

Wireless sensor network is widely used in unattended environment for different applications. Therefore, the following important characteristics must be considered for efficient deployment of sensor nodes [29].

\textit{i. Energy efficient}

One of the main resource of sensor node is its battery and is used in different activities such as communication, computation and storage. As the sensor node operates on battery and is not rechargeable neither replaceable, therefore the battery should be very efficiently utilized. Therefore, the protocols and algorithms developed for WSN should consider power consumption and energy efficiency while designing it.

\textit{ii. Cost}

In WSN, usually hundreds and even thousands of nodes are randomly deployed to sense the external environment. Therefore, the cost of individual sensor node must be as low as possible, thus reducing overall network cost.
iii. **Communication**

The sensor nodes communicate over a wireless channel using radio waves. Depending on the application requirement, the channel can either be unidirectional or bidirectional. Due to the unattended and harsh environment, it is hard to operate the network efficiently. Therefore, the hardware designed for communication must be efficient enough to consume less energy during communication and must have the provision for robustness and security as well.

iv. **Computational power**

As discussed earlier, the sensor node is limited in resources including processing. It is due to the size and cost of the sensor node. Due to small size and low cost the computational capabilities are also restricted.

v. **Security**

The sensor nodes usually deployed in bulk and in unattended manner, which can lead to security loop holes. Therefore, each node must have security mechanism which can avoid attacks from intruders, access from unauthorized nodes and accidental loss of data.

vi. **Sensing and processing**

Large number of sensor nodes are distributed randomly or uniformly depending on application requirement. Each sensor node must be capable of sensing, processing, sorting, aggregating and sending data to the next node or base station to add robustness.
vii. **Self-organizing**

In WSN, sensor nodes are often deployed in unattended manner, therefore each node must be capable to organize themselves. Nodes in the network usually collaborate with each other in a distributed manner to construct the network. Due to this characteristic, these network are feasible for harsh environments where human interaction is difficult.

viii. **Network topology**

WSN usually have dynamic topology, because sensor node might fail due to expired battery or can be damaged or some new nodes might be added as well that can lead to frequent changes in topology. Therefore, sensor nodes must have the capability to reconfigure or readjust themselves according to the topological changes in the network.

ix. **Multi-hop communication**

Sensor nodes can communicate directly or through some intermediate nodes with the sink or BS. In direct method the energy consumption is very high and is not feasible for large field network. Some nodes in the network might be near to the BS but most of the nodes are far away which might not be able to communicate directly. The feasible way for these nodes is to communicate through intermediate nodes.

x. **Application dependent**

Due to the nature of WSN, it is different from the traditional network. WSN is highly application dependent and nodes are deployed according to the type of use.

2.1.2 **Applications of WSN**

Wireless sensor networks have wide range of applications ranging from military operations to a new concept of Internet of Things (IoT). Few of them are discussed here.
i. **Military Use**

Initially, WSN were designed only for military use but with the passage of time and effectiveness of the sensor nodes, applications were extended to civil use as well. WSN have been used in a variety of military applications such as border monitoring, battlefield surveillance, rooftop monitoring, object tracking to track enemy tank movement, monitoring of friendly and unfriendly forces etc. Sensor nodes deployed in battlefield can monitor and track enemy tank as it moves through the area covered by the nodes. Robotic sensors have also been used to petrol along the border to monitor any unseen activity of enemy. Sensor are attached to the soldiers, equipment and vehicles to observe their movement [10, 30-33].

ii. **Environmental applications**

The advancement in technologies, especially wireless sensor network has made huge improvement in monitoring and controlling environmental factors. Number of applications has been developed for different environmental monitoring such as early flood detection, forest fire detection, earth quake, intensity of pollution, volcano monitoring, precision agriculture and many more [34-36]. Sensor nodes deployed in environmental monitoring usually require a lifespan of months or even can have years [37]. WSN is used to monitor the water flow, temperature and pressure in water pipelines to effectively monitor and distribute water [38, 39]. For outdoor monitoring, sensor nodes monitor ecological changes and habitat monitoring while indoor sensors are used to monitor room temperature and even light intensity according to the external light [40, 41].
iii. **Transportation system**

Sensor nodes have been deployed in number of different applications such as urban area monitoring, traffic light monitoring and parking area management to help drivers on the road to make their driving easy [42-44]. The number of vehicles on roads is increasing day by day with the growth in population. Moreover due to this growth, the traffic congestion has also increased and even traffic jam occur at times especially in urban areas. The nation economy can be directly affected by regular traffic jams as the citizens are affected directly as they might be getting late for some important tasks and can lead to stress and frustration. In addition, it can reduce productivity of individuals as they might not complete the assigned task in the given time frame. Therefore, by keeping all the above factors monitoring of traffic is very important especially urban areas. A variety of traffic monitoring applications are reviewed in [45-49]. Generally sensor nodes are mounted and fix at the road side lamp poles and even can be on vehicles as well. Sensors collects data about speed and position of vehicles, images captured at different intervals and traffic flow during different times. In [43], WSN based framework has been proposed that helps drivers to keep track of road conditions, traffic flow, position of and speed of vehicles.

iv. **Health Care Monitoring**

Wireless sensor network has been widely used in health care monitoring such as for blood pressure, heart beat, blood oxygen level, temperature monitoring etc [50]. Emergency rooms are usually overcrowded on daily basis due to frequent accidents or any other casualty considering patients health. However, the number of staff is limited and can lead to time waste from patient and staff perspective. Tele-health care has been
researched for rural areas and even implemented in China and India. However, researchers are exploiting the capabilities of health care in urban area to reduce the overburdened emergency rooms in hospitals. Furthermore, without needing the doctor physically patients should be provided with expert opinion at their home. Therefore, number of applications are proposed to monitor the patient’s vital signs and convey the information continuously to doctor for analyzing it. Sensor nodes are also used in wearable devices to monitor patient’s status and even are used to locate doctors in the hospital [51]. Sensor nodes are used in tele-rehabilitation such as recovering from bone injury while patient is at home or other remote location [52]. In literature different application based frameworks are introduced to assist doctors and patients at hospitals and even from remote locations [53-55].

v. **Industrial Use**

The use of sensors in industrial sector has improved business processes to great extent. In many of the industries, employees are replaced with robots (having sensors) for manufacturing and monitoring activities especially having large heavy equipment. Wireless sensor network has been used in number of industrial applications such as machines monitoring, object tracking, process automation, surveillance and random variations in temperature and pressure [56-59].

vi. **Smart Space**

Wireless sensor network, due to its characteristics has been widely used in the new concept of connectivity that is Internet of things (IoT) which developed a concept of smart spaces. The concept of IoT based network is to have everything on internet which
can be controlled and monitored remotely. Smart spaces covers smart homes, smart offices, smart parking, smart city and even smart grids [60-63]. In smart homes through sensor based IoT homes appliances such as microwave, refrigerators, lights etc can be controlled which gives lot of ease to users [63]. The concept of smart cities is to monitor public spaces by using sensor nodes to detect any anomalous event and passengers can easily be informed in case of emergency [61].

### 2.1.3 Architecture of WSN

In most of the literature, WSN is described as source, sink architecture which may include the following elements.

#### i. Sensor node

The main element of WSN is the sensor node, which senses the external environment such as temperature, humidity, pressure, etc. Different sensor nodes are used according to the applications. Main components of a sensor node are:

##### a. Sensing Unit

The component that senses the external environment is the sensing unit. It is comprised of sensors (used to observe the physical phenomenon) and analog-to-digital convertor (ADC). The analog signals generated by the sensors (on the basis of observed phenomenon) are then converted to in to digital signals by ADC component and forwarded to the processing unit for further processing.
2. **Processing Unit**
This unit is responsible to manage overall processes of the sensor node that make it collaborative with other sensor nodes in the network to perform their sensing task. It is also known as controller.

c. **Memory Unit**
To handle the processes of the sensor nodes, it has limited memory.

d. **Communication Device:**
It is also known as transceiver unit, which is responsible for the transmission and reception of data. It connects the sensor node to the entire network.

e. **Power Supply**
Sensor node is equipped with battery, usually are not rechargeable nor replaceable. The batteries are used in order to power up sensors, due to which they should be efficiently used to prolong the sensor node lifetime.

ii. **Gateway node**
In hierarchical network topology, nodes are grouped in to clusters and member nodes forward their sensed data to the node known as gateway (often called as cluster head). It is responsible to aggregate and forward the sensed data of the member nodes to the base station or sink.

iii. **Base station**
Super node of the entire network is base station (or sink), which manages all the activities carried out in the pre-deployment and post-deployment phase.
iv. **Task Manager**

The task manager is basically the remote user, which accesses the sensor network through internet. It is connected to sensor nodes through base station or sink as shown in figure 2.1. The task manager queries the sensor network remotely and is usually far away from the deployed network.

![Figure 2.1. Architecture of WSN](image)

2.2 **Clustering in WSN**

Due to scarce resources in WSN, direct communication of sensor node with BS or multi-hop communication of sensor nodes toward BS is not practical as energy consumption is high which results in early expiry of sensor nodes as shown in figure 2.2. Single-tier communication is not feasible for large scale network as WSN cannot support long-haul communication. Direct communication has its own disadvantages such as high energy consumption, duplication of data (sensor nodes that were close to each other, sending data with very small variation), and farthest nodes were quickly die. To overcome these
problems, two-tier communication through hierarchical approach is used where nodes are gathered into clusters. Leader node also called as cluster head is responsible to aggregate and then forward it to the BS.

Hierarchical network structure often makes two-level hierarchy, in which the cluster heads are placed at upper level and lower level is for member nodes. The member nodes periodically send data to their respective CH. The cluster head then aggregates that data and forward it to a base station. The CH node spends more energy than the member nodes, as all the time CH node sends data at higher distances [64]. Moreover, after certain rounds, the selected CH will be unable to perform due to high energy consumption and will perish soon. Therefore, it is very significant to ensure load balancing among all the sensor nodes in a network. To do so, the role of CH is rotated time to time to balance energy consumption. Communication within a cluster is single-hop intra-cluster and between
clusters is inter-cluster multi-hop communication as shown in Figure 2.3. Cluster-based and grid-based techniques are the most commonly used hierarchical techniques.

![Figure 2.3. Cluster based communication](image)

### 2.2.1 Cluster-based approach

Clustering is used to simplify the management of sensor nodes, minimize energy consumption, to increase scalability, to balance load, robustness and data aggregation. Nodes are grouped to form clusters. A node known as cluster head (CH) is made responsible to gather data from its member nodes (MN), aggregate it and then forwards to the BS directly or through some intermediate CH as shown in figure 2.3. Instead of sending data of all sensor nodes in a cluster, CH only sends the aggregated data, which in turns minimize the number of packets transmitted in the network and minimize energy consumption. The data received from the CH nodes are further processed at the base station, where it is accessed by the end users. The position of the BS can be with in a field...
or can be placed outside the network area. Usually BS is placed outside and at a distance from the sensor nodes. The data sensed by the base station is forwarded through gateway (CH) to the BS. The multi-level clustering hierarchy can have more than one BS in the network (if needed). In literature, various attempts have been made to improve the energy efficiency through different clustering techniques by addressing the problems of efficient cluster formation, even distribution of load, CH selection and reselection and cluster reformation [2, 21, 65-67].

2.2.2 Grid-based approach

Grid-based clustering techniques are also adopted for efficient clustering, in which the whole area is divided into virtual grids. Grid-based techniques are popular due to its simplicity. The decision of selecting CH is done by nodes themselves which makes it suitable for large scale networks. The focus of this work is on grid-based clustering. The main objective of grid-based techniques is to more effectively utilize the limited resources specially the battery which is usually not replaceable nor rechargeable. Gridding significantly contribute to overall network lifespan, energy efficiency and system scalability. Grid-based techniques are very useful for scalable networks where number of nodes in a network are hundreds and even thousands in number. In addition to the above mentioned objectives, grid-based clustering offers some other secondary advantages which adds up to the overall network performance. Through gridding, the routing table of a single node can be reduced by localizing the route setup. Due to grids the network topology maintenance overhead can be cut down at the sensor node level thus resulting in more stable network. CH can switch the member nodes to low-power or sleep mode to reduce the energy consumption. Due to all of the above discussed objectives, grid-based clustering
techniques are widely used by researchers to achieve energy efficiency and prolong network lifetime [68-73].

2.3 Design Challenges of Hierarchical Clustering

Wireless sensor network presents some challenges regarding design and implementation of clustering algorithms. As WSN is composed of tiny low-cost sensors with constrained resources having limited battery, computation and memory, etc. In most of the WSN applications, it’s not easy to recharge the battery or replace the entire sensor. Due to limited hardware, the processing capabilities also needs to be considered. A lightweight clustering algorithm is required because of the limited memory. Moreover, with these restrictions it is very difficult to manage scalability and prolong network lifetime. Along with the limitations mentioned above, following are some other challenges which needs to be addressed properly while designing clustering algorithms. Cluster formation and number of clusters are very important factors in clustering. Clusters should be well balanced and number of messages generated during cluster formation should be kept low. Complexity of the algorithm (if possible) should be independent and remain constant as the network grows.

The CH selection is another important challenge that directly affect the network performance. The best possible node should be selected so that the network stability period and overall network lifetime should be maximized. In most of the techniques, CH selection is based on several parameters such as: energy level, location of the node etc. Data aggregation is performed on the sensed data received by CH from member nodes, that’s why it is still considered as the fundamental design challenge. It should also be considered
that the designed clustering algorithm should be able to handle different application requirements, as WSN is application dependent. Another very important factor is to make sure that the designed algorithm is secure enough and can be used in applications where data is very much sensitive such as military application or health monitoring. Their

2.4 Cluster formation parameters

Parameters that can directly or indirectly affect the cluster formation process are briefly explained below.

i. Cluster count

In most of the existing approaches, cluster head election and cluster formation leads to variable cluster count, where the number of clusters is predefined. It is a key parameter with respect to clustering algorithm efficiency, which varies depending on network size.

ii. Cluster formation

The approach of cluster formation can be centralized where the decision of cluster formation is handled by BS, while in distributed approach clusters are formed without any coordination. In literature, hybrid approaches are also being used where the advantages of both approaches are used.

iii. Intra-cluster communication

The communication of sensor nodes with its elected CH within a cluster. In most of the approaches sensor nodes directly (one-hop) communicates with CH as it depends on distance between node and CH. In large scale network, multi-hop communication may also be adopted for intra-cluster communication.
iv.  **Mobility**

In static network, where sensor nodes and CHs are static leads to stable clusters. Moreover, static position of nodes results in facilitated network (intra-cluster and inter-cluster) management. The cluster and CH will evolve with respect to time if the nodes change its position, thus requiring continuous maintenance.

v.  **Node types**

In the existing proposed approaches, some of them have used heterogeneous nodes and some have used homogenous nodes in the network. In heterogeneous environment, usually CHs are equipped with high communication and computation resources than normal nodes. While in homogenous, all the nodes have same capabilities and few of them are nominated as CH through efficient techniques.

vi.  **Cluster head selection**

The overall network performance also depends on cluster head selection. In some proposed techniques, the cluster head is predefined (usually in heterogeneous environments). In most cases, the CH selection is based on some parameters (distance from nodes and center, energy level etc.) or probabilistic approach is used or through any random technique.

vii.  **Multi-level cluster hierarchy**

In literature several techniques used the concept of multi-level cluster hierarchy to attain even improved energy consumption and distribution. Sensor nodes communicates with CH in their respective level 1 clusters and level 1 clusters
communicates with level 2 clusters. In this approach, inter-cluster communication is of high significance especially for large scale networks.

**viii. Algorithm complexity**

Another important parameter in clustering is the algorithm complexity, aim of recent algorithms is the quick formation of clusters and selection of CH. In most techniques the time complexity or convergence is kept constant while in some it depends on number of sensor nodes in the network.

**2.5 Taxonomy of clustering protocols**

In WSNs, the existing clustering protocols generally fall into different groups that are (i) Homogenous and heterogeneous networks (ii) Centralized or distributed algorithms (iii) Static and dynamic clustering (iv) Probabilistic and non-probabilistic algorithms (v) Uniform and non-uniform clustering approach.

**i. Homogenous and Heterogeneous networks**

Clustering algorithms for homogenous and heterogeneous networks are built on the characteristics and functionality of the sensor nodes in a cluster. In homogenous networks, all of the sensor nodes have same hardware and processing capabilities. Moreover, every node can be a CH based on some parameters such as residual energy level, distance from the center of the cluster etc. To achieve energy efficiency and load balancing, the role of CH is rotated periodically. While in heterogeneous networks, where there are usually two types of sensor nodes. Nodes with higher hardware and processing capabilities usually used as CH with in a cluster, function as data collectors.
or even cab be used as backbone within the network. Nodes having lower capabilities are the common sensor nodes that sense the desired field attributes.

**ii. Centralized or Distributed algorithms**

In centralized algorithms, usually CH or BS is responsible for network partitioning and cluster formation. These types of algorithms are usually not suitable for large scale networks and more suitable for limited-scale applications. Whereas, in the distributed techniques CH election, selection and cluster formation is done by the sensor nodes themselves to gain flexibility and quick execution and convergence time. Usually distributed algorithms are more commonly used in homogeneous environment. Hybrid techniques are also used where advantages of centralized and distributed algorithms are utilized.

**iii. Static and Dynamic clustering**

Clustering in WSN can be static or dynamic depending on the application requirements. In static clustering, the cluster formation and CH election are fixed. Once clusters are formed and CH are elected then it will remain for long time. In most of the techniques clusters are formed once but CHs are periodically changed to gain energy efficiency. Dynamic clustering offers high energy efficiency by periodic re-election of CH and reformation of clusters. It is used, where topology frequently changes and clusters needs to reorganize to effectively react to topological changes and leads to improved energy efficiency.
iv. **Probabilistic and Non-probabilistic approaches**

In probabilistic clustering approaches, each sensor node is assigned prior probability to decide the CHs or any random election technique is used. Moreover, the probabilities assigned to nodes act as the primary criteria but some other secondary criteria can also be used during the process of CH reselection or cluster reformation for improved energy consumption and maximize network lifetime. In addition, these techniques have fast execution and convergence time and minimizes the number of exchange messages. Non-probabilistic clustering techniques, deterministic criteria are considered for CH election and cluster formation/reformation. In addition, it mainly depends on the information received from the one-hop or multi-hop neighbors and require excessive messages to be exchanged resulting in worse time complexity than the probabilistic approaches. Moreover, non-deterministic approaches give more reliable, robust and balanced clusters, as the selection is based on multiple criteria such as residual energy, node proximity, mobility, transmission power etc.

v. **Uniform and Non-uniform clustering approach**

In uniform clustering approach, the number of nodes are evenly distributed among clusters to achieve energy efficiency. However, it is often applicable in environments where nodes are static and their location is predefined. In literature, several efforts are made to achieve even distribution of nodes through uniform clustering approaches. Moreover, in non-uniform clustering the number of nodes are not uniform per cluster. In clustering the data forwarding pattern is many-to-one in which the nodes closer to the sink are used more resulting in high energy consumption. Most of the deployment in WSN is random, where sensor nodes are distributed unevenly. Some efforts are
made to come up with some solutions regarding the uniform distribution of load and to achieve energy efficiency though non-uniform deployment of nodes.

On the basis of above classifications, clustering has been widely used for various applications in different environments to attain energy efficiency and network scalability in WSN. Instead of sending messages by all nodes, a head node is responsible for forwarding data to the BS to preserve energy. In addition, clustering technique is used to simplify the management of sensor nodes, minimize energy consumption, increase scalability, improve load balancing, increase robustness and improve data aggregation. In literature, different cluster-based and grid-based schemes are proposed for energy efficiency and maximizing network lifetime. Few of them are discussed in the forthcoming sections.

2.6 Cluster-based Hierarchical Energy Efficient Protocols

The whole network is divided into clustered layers in hierarchical approach. Nodes are grouped into clusters and one node (Cluster Head) is made responsible to collect, aggregate and forward data to the base station. Multi-hop transmission is used between CH and BS is used to avoid long transmissions. Many techniques are introduced in literature to make it more energy efficient, few are them are discussed here.

i. Low-Energy Adaptive Clustering Hierarchy

Low energy adaptive clustering hierarchy (LEACH) was proposed by Heinzelman [21], which was one of the first energy efficient routing protocol and is still used as state of the art protocol in WSN. Basic idea of LEACH was to select CH among number of nodes by rotation so that energy dissipation from communication can be spread
among all sensor nodes in the network. The operation of LEACH is divided into two phases, the setup phase and steady-state phase. In setup phase, each node takes a decision whether to become a CH or not for current round. Which all depends on the percentage of CHs suggested and number of times a node has been CH. A random number is choose from 0 to 1, nodes becomes a cluster head if the number is less than the threshold which is shown in Equation 2.1.

\[
T(n) = \begin{cases} 
\frac{P}{1 - P \left( r \mod \frac{1}{P} \right)}, & \text{if } n \in G \\
0, & \text{otherwise}
\end{cases}
\]  

(2.1)

Where, P is the desired percentage of CHs, r is the current round and G is the set of sensor nodes that has not been selected as CHs in the last 1/P rounds. The selected CH will broadcast an advertisement message to other nodes and on the basis of receive signal strength, nodes decide which cluster to join and will send a membership message. CHs rotation is performed to evenly distribute energy load among nodes. In steady-state phase, nodes sense and transmit data to its CH which is then aggregated and send to BS directly. In order to avoid inter and intra cluster collisions, LEACH uses TDMA/CDMA MAC. Due to distributed approach LEACH does not require any global information. Various modifications have been made to LEACH in literature such as MR-LEACH [74], LEACH-B [75], ER-LEACH [76], ID-LEACH [77] etc.

LEACH has some disadvantages such as probabilistic approach using random number for cluster head selection, which might result in sub-optimal CH node thus resulting in high energy consumption. Furthermore, the dynamic clustering overhead and non-
uniform distribution of CH will consume more energy and lead to poor network performance.

**ii. Low-Energy Adaptive Clustering Hierarchy Centralized**

Low energy adaptive clustering hierarchy centralized (LEACH-C) [65] is the modified version of LEACH. It uses the base station for cluster formation whereas in LEACH each node self-configures them into a cluster. Base station receives all the information regarding the location and energy of all the nodes deployed in the network. By doing so, BS determines the number of cluster head (CH) and arranges the network into clusters. Number of cluster heads varies from round to round due to the lack of coordination between nodes. In LEACH-C the number of CHs in each round equals a determined optimum value. A centralized routing approach, in which base station first computes average energy of the network and then chooses a set of sensor nodes having energy level above average. Cluster head will be selected from the set of nodes to ensure that nodes selected should have sufficient energy to be a cluster head. The algorithm splits the network into two sub clusters and then they are further divided until the desired number of CHs is approached. By this way the nodes are evenly distributed to ensure that load is eventually distributed. Base station chooses the lowest energy routing paths and forwards the information of clustering and CH to all nodes in the network using minimum spanning tree approach. However, due to centralized approach communication overhead will increase in the reselection of CH, because reselection decision has to be made by BS. In addition, every cluster will send request thus energy consumption will be high.
iii. **Power Efficient Gathering in Sensor Information System**

Power efficient gathering in sensor information system (PEGASIS) [66] is based on chain-based topology in which a chain of sensor nodes is constructed in a greedy fashion. Every node in a chain senses the data, forwards it to next hop node (predecessor), data is fused with the predecessor’s node data and transmit to succeeding sensor node in a chain. Nodes will only communicate with their one hop closest neighbors and in order to save node’s energy they take turns to communicate with the BS. By using collaborative approach, the lifetime of each nodes is increased thus increasing overall network lifetime and less bandwidth is consumed through local coordination. Furthermore, it eliminates the dynamic clustering overhead and reduces the distance between sensor node and cluster head. PEGASIS may increase topology adjustment overhead in highly utilized networks because nodes needs to be aware of energy status of their neighboring nodes. Moreover, bottleneck can be there due to single leader in the chain. In addition, PEGASIS works well with static nodes but protocol functionality can be affected if nodes are allowed to move thus not suitable for applications with mobile nodes.

iv. **K-means Algorithm**

The cluster head is selected using K-means algorithm to prolong overall network lifespan [25]. Authors divided the whole process in to three phases. LEACH protocol is used to determine initial CH selection. Then network is partitioned in to k clusters, based on the Euclidean distance nodes joins their nearest CH. Once the nodes joins the CH, center of each cluster is determined and each node is assigned an ID based on the distance from centroid. Node closer to the center will have smaller number. CH is
rotated and the next comparative nearer node to the center is selected as new CH. As compared to other schemes, it improves overall network lifetime but periodic reformation of clusters results in additional network overhead and high energy consumption. Moreover, as cluster are formed in random manner initially thus it can result in sub-optimal clusters and uneven distribution of load.

v. **Cluster Head Election using Fuzzy logic**
Authors in [78] proposed cluster head election approach using fuzzy logic (CHEF). Based on random number, tentative CHs are elected in each round. The elected CH then uses two fuzzy parameters which are local distance and energy level. Local distance is basically the sum of all distances from neighboring nodes. By using fuzzy if-then rules, each CH determines its chance value and then advertises it. CH having greater chance value will be selected as CH and will advertise itself so that member nodes can join it. CHEF improves network lifetime as compared to earlier solutions but due to periodic messages it adds network overhead and unnecessary traffic load. Furthermore, cluster head election process is expensive in terms of energy consumption as it is performed in the entire network that results in high energy consumption.

vi. **Unequal Clustering Size Model (UCS)**
The variable size clustering approach unequal clustering size model (UCS) for wireless sensor network is proposed [79]. It is assumed that sensing field is circular and is divided into two layers. Clusters in layer one has same shape and size while layer two will have different shape and size. The problem of unbalance energy consumption is
addressed in UCS model. To keep the energy consumption minimum, the CH must be positioned somewhere or near to the center of a cluster. Area covered by the clusters can be changed in each layer by changing radius of the layer near to BS, hence will change density of a particular cluster. The authors claimed that this model works well in homogenous networks and provides balanced energy consumption through unequal clustering approach especially for network that deals with large amount of data. One of the limitation of this approach is the number of nodes per cluster, as in WSN deployment is often random and the number of nodes per cluster may vary to great extent. Furthermore, the optimal number of CH per layer is another concern as the approach deal with multiple layers.

vii. Non-Uniform Deterministic Node Distribution

The weaknesses of uniform clustering is pointed out in non-uniform deterministic node distribution (NUDND) [80], where it can leads towards energy hole in the network. A new model non-uniform deterministic node distribution is proposed, where number of nodes increases towards the sink node. As nodes nearer to BS will be used more than other nodes in the network. A simple distributed algorithm is introduced to load balanced data gathering. The proposed technique might work well in predefined node positions but in random deployment nodes are often scattered which can lead to energy hole problem.

viii. Energy Aware Distributed Clustering (EADC)

Energy Aware Distributed Clustering (EADC) [81] is proposed for non-uniform distribution of nodes to balance the load across the network. EADC construct unequal
clusters to solve the problem of energy holes. Through routing algorithm the CHs choose nodes with high energy along with least hop count to member nodes to achieve load balancing in CHs. The cluster head is then selected on the basis of ratio of average remaining energy of nearby nodes and the energy of node itself. Some of the nodes were redundant and were consuming extra energy which was ignored. This problem was addressed in [82], the redundant nodes were identified and turned OFF according to the schedule based on their residual energy. Furthermore, the overall energy consumption was reduced by avoiding unnecessary sensing and transmission.

In literature, many cluster-based techniques are proposed but few are them are discussed above and their summary is presented in Table 2.1. Different techniques are used to achieve energy efficiency and increase network lifetime but also have some limitations which needs to be addressed. In addition, issues such as random selection of CH, dynamic reformation and reselection of clusters and CHs, uneven distribution of nodes often leads to hotspot problem and periodic exchange of messages are identified and addressed in the proposed method. A non-probabilistic approach is used to determine optimal zone head (cluster head) to extend network lifetime. Zones (clusters) are constructed one time and zone heads are reselected from collection list thus minimizing network overhead. To avoid hotspot problem where nodes are partitioned in to segments, merge and split technique is used that will ensure even distribution of nodes to improve energy consumption.
### Table 2.1. Summary of cluster-based protocols

<table>
<thead>
<tr>
<th>Protocol</th>
<th>CH selection Approach</th>
<th>Type</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEACH [21]</td>
<td>Probabilistic</td>
<td>Distributed</td>
<td>• Nodes equally shares load up to some extent.</td>
<td>• Single hop inter-cluster communication.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• TDMA avoids unnecessary collisions.</td>
<td>• Energy holes and coverage problems.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Allocated time slots avoid excessive energy consumption.</td>
<td>• CH selection is probabilistic without considering energy.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Extra overheads due to dynamic clustering.</td>
</tr>
<tr>
<td>LEACHC [65]</td>
<td>Probabilistic</td>
<td>Centralized</td>
<td>• Global view of the entire network</td>
<td>• Network overhead</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Even distribution of load</td>
<td>• CH selection is probabilistic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Energy efficient routes</td>
<td>• Reselection process is resource expensive</td>
</tr>
<tr>
<td>PEGASIS [66]</td>
<td>Non-probabilistic</td>
<td>Distributed</td>
<td>• One-hop communication.</td>
<td>• High topology adjustment overhead</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Eliminating dynamic clustering overhead.</td>
<td>• Long delay in data transmission</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Collaborative approach.</td>
<td>• Not suitable for large scale networks.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Suitable for static and small scale networks.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Improved network lifetime.</td>
<td>• Inefficient distribution of load.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Reselection is based on centroid distance.</td>
</tr>
<tr>
<td>CHEF [78]</td>
<td>Probabilistic/Non-probabilistic</td>
<td>Distributed</td>
<td>• Keeping in view the entire network for CH election.</td>
<td>• Excessive message and communicational overhead.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Optimal CH selection</td>
<td>• CH election process is expensive in terms of energy consumption.</td>
</tr>
<tr>
<td>UCS [79]</td>
<td>Non-probabilistic/Probabilistic</td>
<td>Distributed</td>
<td>• Balance energy consumption.</td>
<td>• Due to random deployment the number of nodes may vary great deal.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Suitable for homogenous networks.</td>
<td>• Optimal number of CH due to multi-layer approach.</td>
</tr>
</tbody>
</table>
2.7 Grid-based Hierarchical Energy Efficient Protocols

Grid-based is one of the popular method of clustering for energy efficiency and load balancing in which the whole network area is divided into virtual grids. Some of the existing grid-based approaches proposed in literature are discussed with advantages and disadvantages, which are below.

i. Grid Based Data Dissemination

In grid based data dissemination (GBDD) [68], BS divided the network in to equal sized square grid cells. The node that first shows interest in sending/receiving data is set as a crossing point (CP) of the grid and its coordinates become starting point for the grid cells creation. The cell size depends on the twofold range of sensor node. Every node works in two modes, high power radio (high range transmission) and low power radio (low range transmission). In intelligent grid based data dissemination (IGBDD) [69] network is partitioned in to virtual grids. It is basically the enhanced version of GBDD in which CH selection is based on location of the virtual CP and no need to send the any data to the neighboring nodes for CP selection. In IGBDD linear programming is used to select CP to increase overall network lifespan. GBDD
guarantees continuous data transfer from source to destination but consumes extra energy when the speed is high.

**ii. Cycle Based Data Aggregation Scheme**

A grid-based approach, cycle based data aggregation scheme (CBDAS) [70] is proposed in which the whole network is divided into 2-D square-sized grid cells. Each cell head is linked with other cell head to make a cyclic chain. In every round one cell head acts as a cycle head (selected by BS) having high residual energy. Each cell head will only transmit data to the cycle head. Through cycle head the amount of traffic is reduced and energy consumption is less because only cycle head is responsible to communicate directly with BS. The disadvantage of CBDAS is cycle head can be far away from BS thus consuming more energy due to long distance and may die early. Furthermore, far away nodes will suffer from such problem and can partition the network by breaking chain.

**iii. Distributed Uniform Clustering Algorithm**

A distributed uniform clustering algorithm (DUCA) [72] is introduced to evenly distribute the cluster heads and to decrease the differences in the cluster sizes. Grid approach is used for clustering but each grid does not represent a cluster. Overlapped regions are identified which helped in reducing the cluster sizes, as it often occurs in random deployment. The cluster head selection is based on LEACH which selects the CH based on random number thus ignoring other important parameters and may lead to sub-optimal selection of CH.
iv. **Combination of Grid and Genetic Algorithm for Clustering**

Genetic algorithm is combined with grid technique for clustering in wireless sensor network [73]. On the basis of nodes location, the whole grid is partitioned and then using membership degree of Genetic algorithm the grid midpoints are computed. The dimensionality of high-dimension samples is reduced and then mapped into two-dimensional space. Due to dynamic data of sensors, the clustering midpoints of grids are continuously calculated and dynamically changes clustering midpoints. At the end cluster midpoint in grids of different types are transmitted to the sink. Due to periodic calculations and dynamic changes of clustering midpoints increase network overhead and may deplete sensor nodes quickly.

v. **Path Based approach for Data Aggregation**

Path based approach for data aggregation for wireless sensor networks (PBDAS) [71] is a grid based technique that uses single chain which is constructed by connecting the cell heads from furthermost row left to right and then the following furthermost row right to left till the nearby row to the BS reaches. The authors claimed that cell head selection based on energy increases network lifetime.

vi. **Grid Sectoring**

Grid sectoring (GS) [83] is adopted for even distribution of load and energy consumption over uniform and random deployment of nodes in the field. The whole network is divided in to equal sized square grids and is further divided in to sectors, each representing cluster. The node which is nearer to the center of a cluster is selected as cluster head. Area of interest is further divided into small sectors, this process continues until an optimum number of clusters are achieved. They proposed that
optimum number of clusters will be 5 percent of the number of nodes. In this approach, number of nodes per cluster can vary greatly and can result in isolated nodes thus leading to network partitioning where nodes will be unable to communicate but still having enough energy.

vii. **Grid Based Reliable Routing**

The authors in [84] presented a grid based reliable routing (GBRR) mechanism, in which virtual clusters are formed on the basis of grids. Features of cluster and grid based are combined to achieve adaptability for dense and large scale randomly deployed sensors. Active node is selected as head node and to avoid exhaustion of CH, GBRR calculated the effective paths within and between clusters. Moreover, source node does not need to transmit via head node and can bypass if the route is effective towards BS. As several grids may represent one cluster, so the area covered by that cluster will be large as compared to other cluster having one grid. Furthermore, node at the edge of a cluster might lead to sub optimal CH and member nodes energy consumption will be more due to large distance resulting in early depletion of sensor battery.

Different grid-based clustering algorithms are discussed above and their summary is presented in Table 2.2. Different efforts are made to achieve load balancing, uniform distribution of nodes and optimal CH selection. However, some of the techniques still have some issues such network overhead due to dynamic changes of clustering, sub-optimal CH selection and far away nodes early depletion of battery. In addition to these one of the main limitations of grid-based clustering is the restriction on the number of grids and suitable

48
grid size. Often it becomes difficult to achieve the desired number of grids for a particular deployment scenario. Secondly, the network performance is affected in case of non-uniform deployment. Moreover, grid-based techniques in some cases do not give fair selection of CH with respect to all nodes in the network. The proposed technique addresses these problems such as optimum CH is selected based on non-probabilistic weighted metrics, zones are constructed one time thus eliminating dynamic clustering and depending on certain weights the CH is selected thus minimizing the chances of faraway nodes to be CH. The restriction on number of grids and optimal grid size is achieved through extensive experimentation that depends on certain parameters.

Table 2.2. Summary of grid-based hierarchical protocols

<table>
<thead>
<tr>
<th>Protocol</th>
<th>CH selection Approach</th>
<th>Type</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
</table>
| GBDD [68]| Probabilistic         | Distributed| • Guarantees continuous data transfer from source to destination.     | • Communication overhead  
|          |                       |            |                                                                      | • Time stamp used for grid validity and have to reconstruct it, which is an overhead |
| CBDAS [70]| Non-probabilistic     | Distributed| • Energy efficiency is achieved through cycle head, as only one is responsible to send data of the entire network. | • In long chain far away nodes might be selected as CH resulting in high energy consumption.  
|          |                       |            |                                                                      | • Chain breakage due to sub-optimal CH.  
|          |                       |            |                                                                      | • Cycle head selection is based on only residual energy |
### Literature Review

<table>
<thead>
<tr>
<th>Method</th>
<th>Type</th>
<th>Scheme</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>DUCA [72]</td>
<td>Random</td>
<td>Distributed</td>
<td>• Even distribution of cluster heads. • Decrease the differences in the cluster sizes though identifying overlapped regions.</td>
<td>• CH selection is based on random number might lead to sub-optimal CH. • Not suitable for mobile node and large scale networks.</td>
</tr>
<tr>
<td>Grid and Genetic Algorithm [73]</td>
<td>Non-probabilistic</td>
<td>Distributed</td>
<td>• Optimal CH selection • Energy efficient</td>
<td>• Periodic calculations and dynamic changes of clustering midpoints increase network overhead.</td>
</tr>
<tr>
<td>PBDAS [71]</td>
<td>Random/Non-probabilistic</td>
<td>Distributed</td>
<td>• Improves network performance. • Only chain head is responsible for sending data to BS, rest of cell heads will be in sleep mode.</td>
<td>• Sub-optimal CH can cause chain breakage. • Initial selection is random thus can lead to sub-optimal CH. • Not suitable for large scale networks due to large chains</td>
</tr>
<tr>
<td>Grid Sectoring [83]</td>
<td>Non-probabilistic</td>
<td>Hybrid</td>
<td>• Energy efficient. • Even distribution of load</td>
<td>• CH selection is based on only one parameter that is distance from centroid. • Might have isolated node which can lead to network partitioning.</td>
</tr>
<tr>
<td>GBRR [84]</td>
<td>Non-probabilistic</td>
<td>Distributed</td>
<td>• Adaptive approach • Suitable for large scale randomly deployed sensor nodes.</td>
<td>• Far away nodes might be lead to sub-optimal CH. • Can have grids having no node.</td>
</tr>
</tbody>
</table>

#### 2.8 Summary

A brief introduction of wireless sensor networks, characteristics and applications have been discussed in this chapter. The basic architecture of WSN is discussed with limitations of a sensor node. In most of the existing techniques, various attempts have been made to achieve energy efficiency through hierarchical clustering. This work focuses on hierarchical clustering scheme, for that purpose the design challenges of hierarchical
clustering have been discussed along with classification and cluster formation parameters. In this chapter, existing state of the art energy efficient cluster-based and grid-based techniques in WSN are critically evaluated. The performance of each protocol is significantly evaluated in terms of clustering, energy consumption and network lifetime. Moreover, the design issues and research challenges of hierarchical approaches are discussed. On the basis of some evaluation metrics, existing protocols were compared. In order to provide energy efficient, load balanced, scalable and adaptive protocol, some important issues were identified in the existing energy efficient schemes. To overcome the limitations of existing discussed protocols, an energy efficient grid-based scheme is proposed. In addition, the aim of this work is to evenly distribute load to achieve balanced grids, achieve energy efficiency in the zone head selection and reselection process to prolong network lifetime and to achieve scalability and flexibility that can be used in small and large scale networks.
CHAPTER 03
ENERGY EFFICIENT GRID BASED HYBRID NETWORK DEPLOYMENT FRAMEWORK

Previous chapter presents background of the area and few problems were identified in the previous discussion on existing techniques. This chapter presents an energy efficient Grid-based Hybrid Network Deployment (GHND) framework to ensure load balancing and energy efficiency in wireless sensor networks. The main objective of this work is to minimize energy consumption during grid formation and zone head (in cluster based schemes known as cluster head) selection process while prolonging the overall network lifetime which is an important factor in WSN applications. The rest of this chapter is organized as in section 3.1 requirement analysis is briefly explained. The detailed design and algorithms of the proposed technique are explained in section 3.2 and at the end, chapter summary is presented in section 3.3.

3.1 Requirement Analysis

In literature, various probabilistic clustering techniques have been proposed based on random number for efficient cluster formation and CH selection. However, only considering random approach and not considering some important parameters such as residual energy, distance from center of a cluster, node proximity and number of nodes in a cluster, results in insignificant clusters and leads to more energy depletion. The energy efficiency has always been a critical factor in almost all WSN applications due to limited resources of sensor nodes. The proposed framework should be energy efficient that efficiently use the available resources especially battery. The distribution of nodes is often
random and might lead to uneven distribution of nodes, the proposed technique should distribute nodes nearly even. Moreover, network congestion should be minimum and extra communication within the network should be minimized. To address the above mentioned limitations in existing techniques, an energy efficient grid-based hybrid network deployment (GHND) framework is proposed.

3.2 Design of the proposed approach

This section introduces the proposed framework which is developed to meet the requirements mentioned in previous section. The proposed grid-based hybrid network framework is composed of five different phases, which are dependent on each other because one phase works as an input to the next phase. The clustering technique used is grid-based because it have minimum network overheads and simplified management due to the process held at base station, which adds to reduce overall network overhead. The framework is named as hybrid, initially topology construction and zone head selection will be done by BS which makes it centralize. The advantage of centralized approach is that BS will have global view of the entire network and will minimize the exchange of messages to construct network topology and ZH selection process. As BS is not resource constrained, so there is no issue of computational overhead. However, the ZH reselection is distributed and the decision will be made by the node itself. Moreover, the battery of a node is limited therefore most of the processing operations are done by BS to maximize node life.

The deployment of nodes is random, for example, nodes can be thrown from helicopter or through any other source, and here the way through which nodes are deployed is of no
concern of this work. The sensor nodes considered are homogenous having same resources. Few assumptions are made such as nodes deployed are static, nodes know their position and ID. Once nodes are deployed, nearer nodes communicate directly with BS while far away nodes will communicate through multi-hop. Base station will be initiating the process of topology construction and ZH selection. Base station will directly communicate with the selected zone heads. The proposed GHND approach is developed to evenly distribute load across network, improve network management and prolong overall network lifetime. The proposed framework is shown in Figure 3.1. The working of GHND is divided into five phases which are deployment, grid formation, zone head selection, transmission and zone head reselection.

![Figure 3.1. Proposed framework](image-url)
In deployment phase, the number of nodes and network area is determined along with field height and width. Sensor nodes determine their coordinates, which is used in zone formation. In grid formation phase, the information collected from nodes in deployment phase is used for zone formation and network topology construction. The main objective of this phase is to ensure efficient load balancing by forming uniform sized zones. In the proposed method, ZH selection is initiated through cumulative weighted metrics to ensure optimum selection. In transmission phase, member nodes will send their sensed data to their elected ZH within the predefined timeslot to preserve energy resource. In reselection phase, main focus is to reduce the energy consumption in reselecting ZH. Instead of periodic selection, the proposed method reselects ZH when required in order to reduce energy consumption and network overhead. Each phase is explained in detail in the following sub sections.

### 3.2.1 Deployment Phase

In deployment phase, sensor nodes are randomly deployed over an area of interest, where number of nodes are represented by $N$ (where $N = 1, 2, 3, ..., n$) in a squared targeted area $A = F_H \times F_W$. Field height is represented by $F_H$ and $F_W$ represents field width as shown in Figure 3.2. Energy level, position ($x, y$ coordinates) and node identity (ID) are assumed to be known to the sensor nodes. Every node $i$ will share this information with the base station, which will be used later on to carry grid formation process more efficiently. In this way, base station will have a global view of entire network to minimize computational and communicational overhead. Furthermore, there is no need to exchange messages for grid formation and zone head selection.
3.2.2 Grid Formation Phase

Once the sensor nodes are deployed, BS will divide whole network in to virtual equal sized grids. The main objective of this phase is to efficiently construct the network topology to ensure load balancing. In addition, nodes are nearly even distributed over the network by using novel merge and split technique, which is one of the contribution of this work. The proposed technique will merge the nodes of low dense zones with the neighboring zones in order to avoid network segmentations. Four splitting strategies are introduced to split the high dense zones in to sub-zones. The grid formation phase is further divided into two main steps.

i. Zone Formation

The zone formation is initiated by BS and network is divided in to grids where each grid represents a single zone identified by a unique zone identifier (Zone_ID). Figure 3.2 illustrates zone formation, where nodes are randomly positioned through $M \times M$ grids. The network area is divided in to grids in the form of columns and rows. The columns are represented by $C_0$ to $C_{m-1}$ and $R_0$ to $R_{m-1}$ represents rows. The BS calculates height and width of each zone through Equations 3.1 and 3.2, where $Z_H$ and $Z_W$ represents zone height and width respectively. Starting and ending coordinates are determined for each zone, represented by $(Z_x \to Z_y)$ and $(Z_{xe} \to Z_{ye})$ respectively. Once the zones are identified, BS determines number of nodes per zone by calculating starting and ending point of each zone as shown in Algorithm 1. BS will have the complete information of node density per zone to identify zones with low and high density, which is used in merge and split technique. Terminologies used in zone formation are represented in Table 3.1.
$Z_H = \frac{F_H}{M} \quad (3.1)$

$Z_W = \frac{F_W}{M} \quad (3.2)$

Figure 3.2. Zone Formation

Algorithm 1. Zone Formation

1. procedure Zone Formation
2. Input: number of zones, $Z$; height and width of deployment area, $M$; zone width, $ZW$; zone height, $ZH$;
3. for $Zn = 1$ to $Z$ do
4.     $R = \lceil (Zn)/M \rceil$
5.     $C = \lceil (Zn - 1) \mod M \rceil + 1$
6.     $Z_{xs} = C \times ZH - ZW$
7.     $Z_{ys} = R \times ZW - ZH$
8.     $Z_{xe} = Z_{xs} + ZW$
9.     $Z_{ye} = Z_{ys} + ZH$
10. for $n = 1$ to $N$ do
11.     if $(n_x \geq Z_{xs} \& n_x < Z_{xe} \& n_y \geq Z_{ys} \& n_y < Z_{ye})$ then
12.        IncrementZD$(Zn)$
13.        NodeInZone$(n) = Zn$
14.     end if
15.     end for
16. end for
17. end procedure
18. Output: Zone formed, $Zn$.  

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Table 3.1. Terminologies used in zone formation

<table>
<thead>
<tr>
<th>S.No</th>
<th>Terminology</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Z</td>
<td>Number of zones/grids</td>
</tr>
<tr>
<td>02</td>
<td>Zn</td>
<td>Zone number</td>
</tr>
<tr>
<td>03</td>
<td>Nz</td>
<td>Number of nodes per zone</td>
</tr>
<tr>
<td>04</td>
<td>FH</td>
<td>Field height</td>
</tr>
<tr>
<td>05</td>
<td>FW</td>
<td>Field Width</td>
</tr>
<tr>
<td>06</td>
<td>ZH</td>
<td>Height of each zone/grid</td>
</tr>
<tr>
<td>07</td>
<td>ZW</td>
<td>Width of each zone/grid</td>
</tr>
<tr>
<td>08</td>
<td>R</td>
<td>Rows</td>
</tr>
<tr>
<td>09</td>
<td>C</td>
<td>Columns</td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>Dimensions of the field</td>
</tr>
<tr>
<td>11</td>
<td>SC</td>
<td>Candidate for splitting</td>
</tr>
<tr>
<td>12</td>
<td>(Zxs, Zys)</td>
<td>Starting coordinates of zone</td>
</tr>
<tr>
<td>13</td>
<td>(Zxe, Zye)</td>
<td>Ending coordinates of zone</td>
</tr>
<tr>
<td>14</td>
<td>ZHT</td>
<td>Total number of zone heads</td>
</tr>
<tr>
<td>15</td>
<td>Nz</td>
<td>Neighboring zone</td>
</tr>
<tr>
<td>16</td>
<td>(nx, ny)</td>
<td>Coordinates of a node</td>
</tr>
<tr>
<td>17</td>
<td>(ZCx, ZCy)</td>
<td>Centroid coordinates of a zone</td>
</tr>
</tbody>
</table>

**ii. Merging and Splitting**

The deployment is random, which may result in uneven distribution of nodes as earlier discussed in the deployment phase. Moreover, this can lead to hotspot problem where the network might have isolated zones. In random deployment, there can be a situation where nodes in some zones might have very less number of nodes and still they are making a zone. The lifetime of these nodes will be less as compared to nodes in other zones as they have sufficient number of nodes. Furthermore, due to early depletion of battery the network breakage can occur and results in isolated zones. Nodes in isolated
zones will not be a part of network resulting in poor network performance. A novel merge and split technique is used to solve the problem of uneven distribution of nodes to increase network performance. Low density (LD) and high density (HD) zones are identified first and are termed as interest zone (IZ). If the number of nodes in a particular zone is less than minimum threshold (lower bound, LB) then nodes will be merged with its neighboring zone. Furthermore, if the number exceeds maximum threshold (upper bound, UB) then that particular zone will be split into sub-zones. The threshold for merging and splitting is achieved after extensive experimentations. The difference between UB and LB is called as inter bound gap (IBG) as shown in Equation 3.3.

\[
IBG = UB - LB \quad (3.3)
\]

The parameters such as deployment area, node density and grid dimension are considered for merging and splitting. The average number of nodes per zone is inversely proportional to grid dimension. If the number of grids \(M \times M\) in a network are increased by keeping constant the node density, the average number of nodes per zone will be reduced. It is very important to have optimum number of nodes per zone. To attain optimal grid dimension, the number of zones need to be adjusted according to number of nodes in a particular zone. For example, far less nodes in a zone might result in void zones, where node density is less and more computational and transmission power is required resulting in early depletion of battery causing network partitioning problem. The proposed merge and split technique achieves optimum number of nodes per zone to achieve even distribution of nodes, and is explained below.
a. **Merging of low density zones**

In randomly deployed static nodes, there can be a situation where very few number of nodes are grouped to form zones which might lead towards hotspot problem as mentioned earlier. To address this problem, nodes in such zones are merged with its neighboring zone(s). LB is set as a minimum threshold, if the number is less than LB, it will be merged by the BS. An aggregated metric known as weighted merge score (WMS) is introduced to merge nodes with its nearby zones. Parameters such as distance (dist) and density (den) are aggregated, where distance and density are weighted according to the importance as shown in Equation 3.4. The weight given to distance is represented by $D$ and $\sigma$ represents density weight.

\[
WMS = [(D \times \text{dist}) + (\sigma \times \text{den})] \quad (3.4)
\]

The BS calculates WMS for each individual node in a specific zone to decide the optimum nearby zone for merging as shown in Algorithm 2. The WMS of a node is calculated against every possible direct neighbor zone. The zone having minimum WMS will be selected for merging of that specific node into it. To calculate the WMS by using equation, distance from the center and density of neighboring zone is considered to have the best zone for merging. The interest zones are identified first and then the whole process of merging is applied. Figure 3.3 shows that nodes in few zones are merged with its neighboring zones depending on WMS. For simplicity, nodes from different zones having same color mean they have been merged and belongs to one zone.
Nodes are merged depending on WMS: Nodes in zone1 are merged with zone2 and zone5 depending on WMS. Node 79 is merged with zone2 as it is closer to it and Node 59 is merged with zone5. Accordingly nodes in zone3 and zone10 are merged with their neighboring zones.

Algorithm 2. Merging of Low Density Zones

1. procedure MERGING OF ZONES
2. Input: height and width of deployment area, $M$; lower bound for merging, $LB$; number of zones, $Z$; weighted score for distance, $D$; weighted score for density, $\sigma$;
3. for $Zn = 1$ to $Z$ do
4.   if $(\text{zone}_{Zn}.\text{density}(Zn) < LB)$ then
5.     $R = \lfloor Zn/M \rfloor + 1$
6.     $C = \lfloor (Zn - 1) \mod M \rfloor + 2$
7.     $\text{neigh}_n = \text{zone}_{Zn}\_\text{density}(nz)$
8.     Determine the nodes in current zone ($Zn$)
9.     for $j = 1$ to length(\text{NodesInZn}) do
10.    for $i = 1$ to length(nz) do
11.       $\text{dist} = \sqrt{(n_x - ZC_x)^2 + (n_y - ZC_y)^2}$
12.       $\text{den} = \text{zone}_{Zn}\_\text{density}(nz_{ij})$
13.       $WMS = (D \ast \text{dist}) + (\sigma \ast \text{den})$
14.       end for
15.     Min WMS = nz(min wms)
16.     Assign node to new zone
17.     end for
18.     Eliminate merged zone
19.     end if
20. end for
21. end procedure
If nodes in the LD zone are not close to each other and by merging all the nodes with one neighboring zone might lead to extra communicational overhead, as the distance of certain nodes might be large. In the proposed method, this problem is overcome by not merging all nodes with one neighboring zone as they are merged on the basis of WMS. For example: In scenario shown in Figure 3.4, nodes in zone1 (interest zone) is supposed to be merged with neighboring zones, as the number of nodes are less than LB (consider \( LB = 4 \), if number of nodes are less than 4 then merge it). All nodes in zone1 needs to be merged with nearby zones. The total number of nodes in zone1 are 3 (N1, N2 and N3) as shown in Figure 3.4 (a). All nodes in zone1 are not merged with nearby zone because Node1 and Node11 are near to zone2 but Node2 is near to zone3 as shown in Figure 3.4 (b). If Node2 is merged with zone2 as well, due to long distance it will deplete battery quickly and may die soon. To cover this problem, the proposed merging technique will add Node2 with zone3 and will merge Node1 and Node11 with zone2 on the basis of WMS as shown in Algorithm 2. Furthermore, it will enhance the connectivity and lifetime of Node2 thus contributing to improved network performance.
Figure 3.4. Merging of nodes in low density zone: (a) Zone1 is selected as interest zone for merging as number of nodes are 3 which is less than LB (LB = 4), so the nodes will be merged with its neighboring zone depending on WMS. (b) Node1 and Node11 are merged.

b. Splitting of high density zones
As discussed earlier, due to random deployment, some zones might have high number of nodes that leads to uneven distribution of load. To handle this problem and evenly distribute the load across the high density zones, novel splitting techniques are used. Through splitting techniques, the high density zones are split into sub-zones to evenly distribute load and stabilize the network, thus enhancing overall network lifetime. Once nodes are deployed and zones are created, BS will determine the density of all zones and will observe high density and low density (already discussed in the previous section) zones. If number of nodes exceeds upper bound (UB), the BS will split that zone into sub-zones by adopting the proposed splitting strategies. To do so, four splitting strategies are proposed as shown in Figure 3.5, (i) Vertical Splitting (ii) Horizontal Splitting (iii) Diagonal 45° Splitting (iv) Diagonal 135° Splitting.
The BS will split a zone by adopting any of the four splitting strategies. The optimum order of splitting is achieved by extensive experimentations (1000 times) and the order in which BS will perform splitting is shown in Figure 3.7. The figure shows that in most cases horizontal splitting was adopted than vertical, diagonal 45° and diagonal 135°. The most important question to answer is when to split, how to split and what should be the threshold value for adopting any of the above strategies. Upper bound is used to answer the question of when to split and optimal range ratio (ORR) is to answer how to split and what should be the threshold value. If node density exceeds UB, the BS will split it accordingly. Moreover, ORR is basically the range in which the splitting ratio falls, BS will adopt that strategy. After extensive experiments, ORR is set from 0.75 to 1. The proposed four splitting strategies are evaluated in a defined order and a splitting strategy is selected if it falls in ORR as shown in Algorithm 3. If a splitting ratio (horizontal splitting ratio (HSR), vertical splitting ratio (VSR), diagonal 45°
splitting ratio (D45SR) and diagonal 135° splitting ratio (D135SR)) falls in ORR, then BS adopts that particular strategy and do not further compute other strategies to avoid extra computation as shown in Figure 3.6. The sub-zones are assigned zone identifiers (ID) by the base station for further corresponding. For simplicity, nodes having same color means they belong to the same zone as shown in Figure 3.8. It can be seen in Figure 3.8 that zone1 and zone2 are split in to sub-zones because the number of nodes exceeded UB. For zone1 the splitting strategy adopted is horizontal and zone2 is vertically split. This is because for zone1, HSR is in the range of ORR and thus giving optimal splitting. For zone2 the vertical splitting strategy is adopted because HSR wasn’t in the range of ORR thus adopted vertical splitting for efficient splitting.
Figure 3.6. Flow chart for Zone splitting
Figure 3.8. Zone splitting: Zone1 and Zone2 are split into sub-zones, Zone1 is horizontally split resulting in Zone1 and new sub-zone17 while Zone2 is vertically split resulting in Zone2 and new sub-zone18.
3.2.3 Zone Head Selection Phase

Once the topology is constructed and zone merging and splitting is applied to the interest zones, ZHs are selected for each zone. The main function of ZH is to gather data from its member nodes, aggregate it and then forward it to the BS for further processing. ZH selection is very important for any energy efficient technique because poor selection may lead to early depletion of battery and may result in shortening network lifetime. Furthermore, it can result in network partitioning where network is divided into different
segments. Due to the problems mentioned above, it is very crucial to outline ZH selection criteria. This phase is further divided into two main steps, zone head selection criteria and zone head selection.

i. Zone head selection criteria

As discussed earlier, the proposed method is non-probabilistic where certain parameters are set for ZH selection to ensure optimum node to be ZH. The overall performance of a zone and of the entire network as well depends on the zone head, therefore, it makes ZH selection a very significant step. Therefore, in the proposed method two parameters (1) energy level (EL) and (2) average distance value (ADV) are taken into account for ZH selection. In the deployment phase, all the nodes share their information such as energy level, node coordinates and node ID. So, BS have information of all nodes in the network. Both parameters are aggregated to have cumulative value (CV) of an individual node i, upon which decision of ZH has to be made as shown in Equation 3.5. The BS calculates CV of all nodes and node having maximum CV will be selected as ZH. Moreover, a list known as collection list of each zone is shared with respective ZHs containing CVs of their respective nodes. The collection list is then used in the reselection process of ZH.

\[
CV_i = (EL_i + \frac{1}{ADV_i}) \quad (3.5)
\]

Where \(EL_i\) represents the energy level of a node \(i\). Initially all nodes have same EL but in reselection process EL will vary and the node having higher value of EL will have higher chance to become next ZH. The ADV is average distance value of each node in a specific zone as shown in Equation 3.8. It is basically the distance of node from its
neighboring nodes (with in a zone) and distance of node from the center of a zone as shown in equations respectively. Node having minimum value of ADV, will increase its chance to be ZH. The BS will calculate ADV of all nodes in the network. As the nodes are stationary, so it will be calculated once.

\[
d(i,j) = \sqrt{(ix - jx)^2 + (iy - jy)^2}\quad (3.6)
\]

Where \(d(i,j)\) is the distance of a node from nearby nodes in that zone in order to identify distance of a node from its one-hop neighbors. This is an important parameter, because if a node is at one corner of a zone and rest of the nodes are grouped at other corner then that node will have less chance to be a ZH as compared to other nodes in the zone.

\[
\text{cent}(i,c) = \sqrt{(ix - cx)^2 + (iy - cy)^2}\quad (3.7)
\]

In addition, \(\text{cent}(i,c)\) will calculate the distance from center of a zone in order to identify the location of the node in its zone.

\[
\text{ADV}_i = \alpha \times \text{cent}(i,c) + \frac{\beta}{n-1} \sum_{j=1}^{n} d(i, j), \quad j \neq i\quad (3.8)
\]

Putting the values of \(d(i,j)\) and \(\text{cent}(i,c)\) from Equations 3.6 and 3.7, we can calculate the value of ADV for each individual node as shown Equation 3.8. Where \(\alpha\) and \(\beta\) are the weights assigned to the indices of centroid and distance. By putting the values of EL and ADV, will get CV of each single node.


ii. **Zone head selection**

In this step, ZH for each individual zone will be selected on the basis of CV calculated through equation. The selection will be from a collection list, which contains the CVs of all nodes in a zone. Each zone will have its own collection list. The node having maximum CV will be selected as ZH for that specific zone as shown in Algorithm 4. The advantage of having the collection list is to avoid the broadcast messages of BS to each node to avoid communication overhead. Once ZH is selected, it advertises itself and member nodes join their respective ZHs. Initially the process of ZH selection is done through BS but later on for reselection, the process is decentralized where decision of reselection will be made by ZH itself.

Algorithm 4: Zone Head Selection

![Algorithm 4: Zone Head Selection](image)

3.2.4 **Data Transmission Phase**

In data transmission phase, member nodes start sending their sensed data to their respective ZH. Each ZH shares time division multiple access (TDMA) schedule with their member nodes. A technique used to share communication channel on the basis of time. Each node
will send its sensed data according to their assigned time slot, which enables the nodes to keep their radios OFF (sleep) until their turn. Furthermore, this sleep period preserves node energy and battery is used when it is required. A zone head aggregates and compresses received data from all the member nodes and forwards it to BS.

### 3.2.5 Reselection Phase

One of the main objectives of this work is to minimize the energy consumption during reselection process. Instead of performing regular ZH reselection that results in network overhead and extra energy consumption, the proposed method (GHND) based on EL of ZH initiates the process of reselection when required. A threshold value (TV) is set to decide when to reselect the ZH. If the value of EL is less than or equal to $\text{TV} (EL \leq TV)$, then the corresponding ZH will start the process of reselection as shown in Algorithm 5. The current ZH will ask the 1st candidate ZH (CZH) to send updated CV. If reply exceeds the timer then 2nd CZH is asked to send its updated CV else compare initial CV and updated CV of the CZH. If difference is less than X then select the first CZH as new ZH and update status of Current ZH to member node and CZH will act as new ZH. The X factor is introduced in order to check the abnormality of energy decrease as shown in Equation 3.9.

$$X = (\text{InitialCV}_i - \text{UpdatedCV}_i) - \text{EFP} \quad (3.9)$$

Where EFP is the error factor percentage representing marginal error. Initially, ZH selection was done by the BS, in order to avoid extra energy consumption the ZH reselects next ZH according to collection list they have. In the proposed method, reselection of ZH is independent of the number of iterations and is initiated when required. Furthermore, it reduces the network traffic and overall network is not disturbed. The value of TV varies
according to the traffic generated by ZH. If the value of TV is fixed, a situation may arise where certain nodes still having sufficient energy fail to be elected as ZH and thus might lead to a flat network. Thus, in order to avoid such situations, the value of TV changes with decrease in energy level of a ZH. Furthermore, it will be monitored by the ZH periodically.

Every ZH maintains two lists, trusted and untrusted. The trusted list will have nodes which can compete in ZH selection process, while untrusted list will have nodes which are black listed and cannot compete in the ZH reselection process. Any sudden change in energy level will put a node in the untrusted list which will be calculated through Equation 3.9.

Algorithm 5: Zone Head Re-selection

```
(1) procedure ZONE HEAD RESELECTION
(2) Input: Energy Level of Current Zone Head, oldELZH; Threshold Value, TV;
Cumulative Value of each node, CV; Candidate Zone Head, CZH;
difference of Initial and updated CV, X;
(3) if (newELZH = oldELZH - oldELZH × 0.1) then
(4) if ELZH ≤ TV then
(5) Ask first CZH to send updated CV
(6) if first CZH reply exceeds timer then
(7) Fetch CV from second CZH
(8) else
(9) Compare updated.CV and initial.CV
(10) if difference < X then
(11) Select first CZH as new ZH
(12) ZHcurrent ← member_node
(13) ZHnew ← first_CZH
(14) else
(15) Fetch CV from second CZH
(16) end if
(17) end if
(18) else
(19) Remain as ZH
(20) end if
(21) else
(22) Continue Transmission
(23) end if
(24) end procedure
(25) Output: New Zone Head, ZHnew.
```
3.3 Summary

This chapter presents an energy efficient Grid-based Hybrid Network Deployment (GHND) approach that solve the problems of uneven distribution of nodes, uneven formation of grids and high energy consumption during zone head selection. In literature, most of the existing approaches construct sub-optimum grids, distribution of nodes in the network is often uneven and ZH selection consumes high energy. Thus, leads to high energy consumption and reduce overall network lifetime. Furthermore, most of the approaches performs periodic cluster reformation and CH reselection resulting extra energy consumption and communicational overheads. The proposed GHND approach addresses these limitations by evenly distributing the nodes across grids that leads to nearly optimum load balancing within a grid using merge and split technique. Furthermore, the proposed GHND approach uses optimized non-probabilistic approach for ZH selection based on multiple weighted metrics with minimum computational overheads that leads to enhanced energy consumption and network lifespan. The selected ZHs will advertised their status among member nodes to join them and start sending their sensed data through the assigned time slots. The role of ZH is rotated as required that does not depends on number of iterations. Each ZH will reselect the next ZH independently to overcome extra communicational overheads and not to disturb the overall network. The collection list is introduced that will have the CVs of all nodes in a grid and the new ZH will be selected from collection list. In the proposed method no need to re-elect new ZH thus minimizes computational overheads resulting in improved energy consumption.
CHAPTER 04

PERFORMANCE ANALYSIS OF GHND PROTOCOL

In this chapter, performance of the proposed method is assessed by carrying out extensive experiments to achieve even distribution of nodes, energy efficiency and maximizing network lifetime. The proposed approach is compared with some existing state of the art energy efficient grid-based and cluster-based techniques such as LEACH [21] and PEGASIS [66]. To better evaluate the proposed approach, it is compared with CBDAS [70] which is a grid based approach to enhance energy consumption and increase network lifetime. It is concluded through results that in zone formation, zone head selection/reselection and total energy consumed has been improved in the proposed method. Moreover, the impact of certain parameters on overall network lifetime is discussed in the later sections of this chapter.

4.1 Overview of the Proposed System

A grid-based hybrid network deployment approach (GHND) is proposed, in which the whole network is divided into virtual squared grids, where each grid represents a zone. Initially, the network topology is constructed using centralized approach, in which BS initiates the grid formation and cluster head selection process. To evenly distribute the nodes, authors have used merge and split technique. Zones with low density and high density are identified and called as interest zones on the basis of lower bound (LB) and upper bound (UB). If a number of nodes is less than LB, then nodes in that particular zone are merged with neighboring zones depending on weighted score called as weighted merge score (WMS). On the other hand, if the number exceeds UB, the BS will split the zone into
sub-zones using any splitting strategy. Four strategies are introduced namely horizontal, vertical, diagonal $45^0$ and diagonal $135^0$. In order to achieve energy efficiency, the non-probabilistic approach is used for cluster head selection based on various parameters.

### 4.2 Simulation Setup

This section is about the simulation setup and working environment. The proposed method is implemented and evaluated in MATrix LABoratory (MATLAB) of version 2012a with other relevant existing approaches. It is the most widely used tool for research data and numerical processing. Most of the existing hierarchical protocols developed for WSN are available in MATLAB.

The total number of sensor nodes ($S_i$) deployed are $N, i \in \{1, 2, 3, ..., N\}$ in a squared targeted region $Area = F_H \times F_W$, where $F_H$ and $F_W$ represents field height and width respectively. The whole area is divided into virtual grids of $M \times M$ dimension, for example $M = 4$ means that total number of grids are 16. In the proposed work, few assumptions are made regarding sensor nodes and deployment area which are:

- The position of BS is outside the deployment area and is known to all nodes.
- The BS and all sensor nodes are static (don’t change their position) once deployed.
- Sensor nodes are deployed in homogenous environment having same initial energy $E^0$.
- All the sensor nodes already have the information of node IDs, energy and location (coordinates).
The energy consumption of all nodes is evaluated using first order radio model [21] as shown in Equations 4.1, 4.2 and 4.3 respectively. A radio consumes energy of 50nJ/bit (represented as $E_{elec}$), where $E_{elec}$ is the energy consumed to run the transmitter and receiver circuitry. Transmission amplifier is used at the transmitter end which further consumes an amount of $E_{amp}$ $d^2$ energy, where $E_{amp}$ represents energy consumption ($E_{amp} = 100$ pJ/bit/m$^2$) and $d$ is the distance between sensor nodes. By using first order radio model, in order to transmit $k$ bits of message over a distance $d$, the transmission energy consumed (ETx) is given through Equation 4.1.

$$ETx(k,d) = (E_{elec} \times k) + (E_{amp} \times k \times d^2) \quad (4.1)$$

While energy consumed at the receiving end (ERx) is shown as:

$$ERx(k) = E_{elec} \times k \quad (4.2)$$

The total energy consumed in transmission is generalized as:

$$E_{total}(k) = (E_{elec} \times k + E_{amp} \times k \times d^2) + (E_{elec} \times k) \quad (4.3)$$

The impact of different parameters such as node density (number of nodes), initial energy (residual energy), grid dimension (number of grids), network lifetime (overall number of rounds till the last node die) and over all energy consumed were analyzed in accordance with the existing related cluster-based and grid-based techniques. The value of almost all parameters were not fixed as the performance is analyzed in different scenarios. For instance, the impact of varying initial energy on the overall network lifetime was analyzed. The value of parameters will change with respect to scenario by considering certain
parameter. For this purpose, value of some of the parameters are mentioned by taking range as shown in Table 4.1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>Network Area (meters)</td>
<td>200 x 200</td>
</tr>
<tr>
<td>N</td>
<td>Number of nodes</td>
<td>100 – 500</td>
</tr>
<tr>
<td>E₀</td>
<td>Initial Energy (Joules)</td>
<td>0.25 – 1.0</td>
</tr>
<tr>
<td>Packet</td>
<td>Packet size (bits)</td>
<td>2000</td>
</tr>
<tr>
<td>M</td>
<td>Grid Sizes</td>
<td>4, 6, 8, 10</td>
</tr>
<tr>
<td>LB</td>
<td>Lower Bound</td>
<td>4</td>
</tr>
<tr>
<td>UB</td>
<td>Upper Bound</td>
<td>8</td>
</tr>
<tr>
<td>Eamp (pJ / bit / m²)</td>
<td>Amplifier energy at transmitter</td>
<td>100</td>
</tr>
<tr>
<td>Eelec (nJ / bit)</td>
<td>Circuitry energy</td>
<td>50</td>
</tr>
</tbody>
</table>

4.3 Performance Evaluation of the Proposed Solution

The proposed method is compared with the related existing cluster-based and grid-based protocols in terms of certain parameters such as initial energy, grid size, number of nodes, network lifespan and total energy consumed. In literature, most of the protocols are compared with respect to initial energy, node density, number of grids and total energy consumed. Moreover, impact of these parameters on overall network lifetime is analyzed to come up with the most efficient protocol. Therefore, in this work same parameters are considered to better evaluate the proposed protocol with the existing ones.
i. **Effect of Initial Energy**

The initial energy of a sensor node plays an important role in maximizing network stability and overall network lifetime. Therefore, the impact of varying initial energy of all nodes on the whole network lifetime (by keeping other parameters constant such as grid size, number of nodes and network area) is analyzed in this subsection. As previously discussed that the network is homogeneous, means all nodes will have same resources. In the first experiment, initial energy of all nodes is 0.25J to evaluate LEACH, PEGASIS, Direct, CBDAS and GHND (proposed method). Moreover, number of rounds are determined when 1%, 25%, 50%, 75%, and 100% nodes die to analyze network stability and overall network lifespan. The proposed method has better results than other techniques in terms of number of rounds as shown in figures 4.1-4.3. The initial energy of the nodes was then set to 0.5J and 1.0J respectively and the impact of this increase was analyzed on all the algorithms mentioned above. In comparison the proposed network is more stable than other protocols because it takes more rounds for the first node to die (1%). Furthermore, the number of rounds when all nodes die (100%) are analyzed against other protocols. It is concluded that in all three cases, the proposed method outperforms other techniques as shown in figures 4.1 - 4.3. This increase is due to reduction in control messages in the process of ZH selection. Moreover, initially, BS selects the most suitable node as ZH per zone having maximum cumulative value based on weighted metrics. Furthermore, the ZH reselection process is distributed and initiated when required that leads to improved network life time and energy consumption as shown in the results.
Figure 4.1. Nodes with $E_0 = 0.25\text{J}$, when 1%, 25%, 50%, 75% and 100% nodes die

Figure 4.2. Nodes with $E_0 = 0.5\text{J}$, when 1%, 25%, 50%, 75% and 100% nodes die
**ii. Effect of Grid Sizes**

In the proposed method, network is divided into virtual grids to construct topology. Therefore, the grid dimension becomes important to achieve efficient network topology. To analyze the effect of grid sizes on the network lifetime, different grid dimensions such as 6 x 6, 8 x 8 and 10 x 10 are considered. In this case, LEACH is not considered because it is not a grid-based technique. The increase in number of grids with respect to network lifetime is evaluated by keeping other parameters such as node density (300), initial energy ($E_0 = 0.5J$) and packet size (2000 bits) are kept constant. As shown in figures 4.4 – 4.6, GHND (proposed technique) has better results in terms of number of rounds that leads to improved network lifetime. For grid sizes 6 x 6, 8 x 8 and 10 x 10, GHND is approximately 1.3, 1.2 and 1.4 times better than CBDAS. This is because the proposed method evenly distributes the nodes across the grids by using...
merge and split technique. Moreover, the nodes in low dense zones are merged with nearby zones based on weighted merge score that avoids unreachable segments thus increasing number of rounds. Furthermore, the high dense zones are split into sub-zones depending on four splitting strategies. The proposed merge and split technique leads to improved energy balancing and nearly even node distribution.

Figure 4.4. Impact of grid size on number of rounds w.r.t node density, grid size is 6x6.
4 - Performance Analysis of GHND Protocol

Figure 4.5. Impact of grid size on number of rounds w.r.t node density, grid size is 8x8.

Figure 4.6. Impact of grid size on number of rounds w.r.t node density, grid size is 10x10.
iii. **Effect of Number of Nodes**

Wireless sensor network come across with hundreds of sensor nodes depending on applications. The proposed method should work well with different node densities to allow a network to grow with sustaining its performance. Therefore, the proposed method is analyzed with the existing protocols by considering different number of nodes. The impact of node density on the number of rounds (network lifetime) is carried out by varying initial energy and keeping constant the grid dimension, network area and packet size. Number of nodes are varied from 100 to 500 in each iteration. Figures 4.7 – 4.9 show the number of rounds from nodes 100 to 500 with initial energy values 0.25 J, 0.5 J, and 1.0 J, respectively. The result shows that for each approach, the number of rounds increases by increasing the number of nodes except for the direct method where very small change is detected. In all three cases, the proposed method outperforms all other approaches by having more number of rounds in turns maximizing the overall network lifetime. This is because, by increasing node density, the load across the zone heads is evenly distributed. Moreover, the number of nodes are more evenly distributed thus leads to load balancing across the entire network. As the proposed method works better when number of nodes are increased, therefore, it is suitable for large networks as well where the network is scalable.
4 - Performance Analysis of GHND Protocol

Figure 4.7. Impact of node density with respect to initial energy, $E_0 = 0.25J$

Figure 4.8. Impact of node density with respect to initial energy, $E_0 = 0.5J$
iv. **Network Lifespan**

To analyze the network lifespan against each method, different initial energy were considered by taking 0.25J, 0.5J and 1.0J respectively for 100 number of nodes and packet size of 2000 bits. The objective is to analyze the number of rounds when all nodes having 0.25J, then 0.5J and finally 1.0J in comparison with other protocols. In figures 4.10 – 4.12, the proposed method (GHND) has maximum number of rounds resulting in prolonged network lifetime. This is because, nodes are evenly distributed across the grids and optimum node is selected as zone head based on weighted metrics. The results show that the proposed method surpasses currently employed approaches in load balancing, in energy efficiency, and in prolonging network lifetime.
4 - Performance Analysis of GHND Protocol

Figure 4.10. Initial energy $E_0 = 0.25J$

Figure 4.11. Initial energy $E_0 = 0.5J$

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v. **Total Energy Consumed**

The total energy consumed is used in literature to evaluate the protocols, as it is very important to analyze the energy consumed during the whole process. Therefore, the proposed method is also compared with other protocols in terms of overall energy consumed. The total energy consumed in sensing, computation and communication is analyzed against the number of rounds for total number of nodes as shown in Figure 4.13. This comparison shows the overall energy consumed (in Joules) by all nodes by completing how much rounds. As Figure 4.13 shows, the energy consumption of direct method is much more than other approaches because each node directly communicates with BS. Moreover, energy consumed by the proposed method is less than all other approaches hence resulting in enhanced network lifetime. This is due to the even distribution of nodes across network resulting in steady energy consumption and zone
head is intelligently selected by considering weighted metrics. Furthermore, the re-
formation of grids and reselection of ZH is optimized which reduced the
communicational and computational overhead thus resulting in improved energy
efficiency. In comparison with LEACH, CBDAS, and PEGASIS, the proposed method
maximized the network lifetime approximately by 25.14%, 12.12%, and 46.2%,
respectively. Thus, it is concluded that the proposed method is energy efficient in terms
of network deployment and load balancing.

![Graph showing energy consumption over rounds](image)

**Figure 4.13. Total energy consumed (in Joules)**

### 4.4 Summary

In this chapter, the proposed energy efficient grid-based hybrid network deployment
framework in wireless sensor network is evaluated. The proposed method is compared with
state of the art existing energy efficient cluster-based and grid-based techniques.
Parameters such as initial energy, grid dimensions, node density, network lifetime and
overall energy consumed are taken into account for evaluation. It is concluded from
results, that the proposed scheme outperforms other techniques in terms of network lifetime and load balancing. Therefore, the proposed method is more energy efficient than the other existing techniques which leads to optimal grid formation by evenly distributing the nodes and efficient zone head selection.
CHAPTER 05

OPTIMUM CLUSTER HEAD SELECTION USING MULTI-CRITERIA DECISION TOOL IN WSN

In the previous chapter, a grid-based hybrid network deployment framework was proposed to achieve energy efficiency and load balancing. A non-probabilistic weighted metrics were used for ZH selection to achieve energy efficiency. In this chapter, an optimum cluster head selection approach using multi-criteria decision tool is used. Selection through various parameters makes it a multi-criteria decision making (MCDM) problem. The selection of CH is through non-probabilistic approach based on certain parameters. In non-probabilistic approach, on the basis of certain parameters cluster head has to be selected and in this work, the selection of cluster head selection is also based on certain parameters which makes it a multi-criteria decision problem. Therefore, Analytical network process (ANP) is used as a multi-criteria decision tool due to its characteristics such as it deals with interdependencies between elements within a cluster or between clusters and feedback. In this chapter, ANP is used for cluster head selection and a mathematical model has also been developed. The results are then analyzed using different scenarios to check stability of nodes ranking. Cluster and cluster head are interchangeably used with zone and zone head respectively. In this chapter, section 5.1 explains multi-criteria decision system. The analytical network process is explained in detail in section 5.2. The proposed method cluster head selection using analytical network process and mathematical model are explained in section 5.3. The obtained results are discussed in section 5.4 and at the end, summary of chapter is presented in section 5.5.
5.1 Multi Criteria Decision Making

The process of selecting two or more options of act is known as decision making. Though it may be possible that the decision made might not always be a correct decision. However, at the time of decision there may have been a better option or unavailability of right information. Multi-criteria decision problems have number of known alternatives; therefore, it is very difficult to evaluate alternatives and the associated evidence to make optimal and efficient decisions. Multiple factors effect these decisions such as set of alternatives, set of criteria and available information of each alternative may be imperfect. The decision makers find it difficult to process and evaluate the relevant information because the evaluation process comprises of challenging tradeoffs among different alternatives considered. The individual decision maker may have different decision priorities and if the priorities are more than one then it may conflict, thus increasing complexity and difficulty of the whole process. If proper procedure are not followed to assess and evaluate alternatives and assigned priorities, there could be inconsistency on an individual criterion significance in the decision. Therefore, proper procedures and methods need to be followed while making decisions, here in this work analytical network process has been used as a multi-criteria decision tool.

Multi criteria decision making (MCDM) systems are used, where one component among multiple components is to be selected on the basis of certain criteria [85]. The complex decision making problems can be modeled by MCDM using organized and logical approach. The MCDM is used in several fields of science such as natural resource management [86], software engineering [87], environment, energy, health care, wireless
sensor networks and so forth [19-21][88]. In literature different multi-criteria decision tools are used such as analytical hierarchy process (AHP) [89], analytical network process (ANP) [90], Fuzzy ANP [91], Decision Tree [92] and many others. In [93], a centralized cluster head selection approach using AHP is proposed. Three factors, mobility, energy and distance to the center of a cluster were considered. Authors claim that AHP performs better than LEACH. The ANP has also been used as a tool for MCDM such as in [94], suitable waste water treatment (WWT) technology was selected using ANP approach. In [95], ANP was used along with risk priority index to model risks in megaprojects. In [96], on the basis of quality criteria, used ANP as a MCDM tool for software component selection. In this work, ANP is used for selection of CH and explained in detail in the forthcoming section.

5.2 Analytical Network Process

Analytical network process has been widely used as a multi-criteria decision making tool. It is basically the generalized form of analytical hierarchy process (AHP). In literature, AHP has also been widely used as a multi-criteria decision tool and still very effective and successful in solving some practical problems. The problem is broken down in to a hierarchy of different levels defining goal, criteria and alternatives. Furthermore, each layer elements are functionally not dependent of each other and levels are also independent. Moreover, AHP uses a top-to-bottom approach to decompose the problem. Though in real life there are problems which cannot be structured hierarchically as they have strong dependency and interaction between inter level elements and intra level elements. The importance of criteria determines importance of alternative as well as the importance of
alternatives also determines importance of criteria. Thus, these dependencies are addressed through ANP along with the feedback. ANP is represented through network approach rather than hierarchy of layers.

The ANP provides complex relationships between decision levels and attributes while AHP represents a uni-directional hierarchical relationship framework [97]. Moreover, in ANP problem is represented as a network of elements which are gathered into clusters [98]. Elements in a cluster may affect all or some of the elements in other cluster, means that a network may include interdependencies between clusters and feedback within them. The ANP works with interdependent criteria and gives more accurate modelling for decision problems in complex environment [99, 100]. The elements in a network can be associated in any possible fashion by taking in to account inter-relationships and feedbacks between inter and intra clusters. The generalized steps of ANP are discussed below.

1) The main problem is divided in to sub problems by clearly identifying the goal, criteria/sub-criteria and alternatives as shown in Figure 5.1. Goal is what we want to achieve, criteria is a set of parameters on which decision depends and alternatives are the elements upon which decision has to be made.

2) Criteria and alternatives are scaled according to the qualitative scale of importance introduced by Saaty [101] and then it is converted to quantitative scale range that is from 1 to 9 as shown in Table 5.1.

3) Pairwise comparison is done after scaling. Matrix of criteria is created by comparing the ith row with jth column. If the ith row criteria is superior then it is denoted by (i, j)
otherwise (j, i). A score of 1 represents equal importance, whereas 9 represents extreme importance of one element over other.

4) Relative importance is calculated through Eigen vectors of the comparison matrix. Weights of the criteria or sub-criteria are obtained as the elements are normalized.

5) In order to assure judgments reliability, it is very important to ensure consistency between the comparisons made. The consistency index (CI) and consistency ratio (CR) are defined by Saaty [102] and briefly explained in section 5.3.2. CR is the consistency ratio and RI is consistency index of random reciprocal matrix generated from the quantitative 9-point scale [101]. The value of $CR \leq 0.1$ is acceptable otherwise pairwise comparison needs to be revised.

6) The local priority values (Eigen vectors) obtained from comparison matrix results in unweighted supermatrix. It is transformed into weighted supermatrix if summation of each column is 1 otherwise, there is interdependence between the clusters in a network. Weighted supermatrix is the outcome of unweighted supermatrix and cluster matrix.

7) The Limit matrix is obtained by raising weighted supermatrix to the power of $2k$ until it is converged to get more stable set of weights, where $k$ is an arbitrary large number. The final priorities of all elements in a network can be obtained by normalizing each block of limit matrix. The best alternative should be selected having largest priority.

8) At the end, a sensitivity analysis is performed to check the results stability and ranking of alternatives provided by whole ANP process. Sensitivity analysis is not mandatory but it’s recommended to check the impact of criteria on alternatives by changing weights of certain criteria.
5.3 Cluster Head selection using Analytical Network Process

The performance of cluster-based WSN directly depends on CH, therefore it is very important to select the optimum node that will ensure efficient resource utilization, thereby
improving network lifetime. In this work, ANP is used for CH selection using the topology constructed through grid-based hybrid network deployment (GHND), which is explained in chapter 3. The constructed topology is shown in Figure 5.2, where a network is partitioned in multiple zones. Each zone has a CH responsible for data aggregation and forwarding. Cluster head plays a very important role in network stability and prolonging network life time, therefore it should be intelligently selected. The problem of selecting a best node as CH based on certain parameters and can be easily tackled by using multi-criteria decision system. The ANP has been widely used as a multi criteria decision tool, in which dependencies among elements and feedback are dealt with \cite{90, 103}. After network deployment, the base station runs ANP based CH selection for all clusters. In literature, different techniques are proposed for cluster head selection using MCDM, but to the best of author’s knowledge, cluster head selection using ANP has been used for the first time in grid-based wireless sensor networks. In this work, the cluster head selection criteria is extended to five distinct parameters so that the most effective node can be selected as a cluster head using ANP approach. Parameters are shown in Table 5.2 which are REL, DistNodes, DistCent, TCH and MN. The steps involved in ANP model for cluster head selection are explained in detail as follows.
5 - Optimum Cluster Head Selection Using Multi-criteria Decision Tool in WSN

Table 5.2. Criteria parameters

<table>
<thead>
<tr>
<th>S.No</th>
<th>Terminology</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>REL</td>
<td>Residual Energy Level of the node</td>
</tr>
<tr>
<td>02</td>
<td>DistNodes</td>
<td>Distance of the node from its neighboring nodes in the current zone</td>
</tr>
<tr>
<td>03</td>
<td>DistCent</td>
<td>Distance of a node from the center of zone</td>
</tr>
<tr>
<td>04</td>
<td>TCH</td>
<td>Number of times a node has been selected as Cluster Head</td>
</tr>
<tr>
<td>05</td>
<td>MN</td>
<td>Node that has been in-grouped from the neighboring low density zone.</td>
</tr>
</tbody>
</table>

5.3.1 Problem Formulation

The first step of ANP process is to structure the problem into sub-problems. The ANP model structures given problem into goal, criteria and alternatives as shown in Figure 5.1.

In this work, goal is to select a best node as a cluster head among the alternatives in a
specific cluster. For example, in Figure 5.2, goal is to select a cluster head in the highlighted cluster (zone 6). Parameters are REL, DistNode, DistCent, TCH and MN, whereas alternatives are sensor nodes available in particular cluster. Criteria and alternatives are represented by two sets, C and A respectively. Relationship between criteria and alternatives is identified for constructing a network along with their dependencies. The whole process of ANP is initially applied for cluster head selection in a certain zone as shown in Figure 5.3. This process can easily be repeated for all other zones in the network.

Set 1: \[ C = \{REL, DistNode, DistCent, TCH, MN\} \]
Set 2: \[ A = \{N1, N2, N3, N4, N5\} \]
5 - Optimum Cluster Head Selection Using Multi-criteria Decision Tool in WSN

Figure 5.3. Steps involved in ANP model of CH selection
5.3.2 Pairwise comparison of elements

Once the problem formulation is done, elements are pairwise compared. The pairwise comparison is a method of establishing comparative significance of different elements (criteria and alternatives) with respect to a specific component in the network. The same is also used to judge quantitative impact of elements on the goal and is scaled according to Saaty 9-point scaling [101] shown in Table 5.1. A score of 1 represents equal importance, whereas 9 represents extreme importance of one element over another. These quantitative numerical values, representing personal judgments, must be carefully assigned to both criteria and alternatives set elements for drawing the pairwise comparisons. For example, checking the impact of criterion DistNodes on alternatives such as N1 and N2. As N2 is relatively closer to other nodes in the cluster than N1 as shown in Figure 5.7, therefore its quantitative importance is set to scale 3. Matrix of criteria is created by comparing ith row with jth column. If the ith row criteria is superior then it is denoted by (i, j) otherwise (j, i). The relative weights of elements are represented in square matrix of order n which is shown as $a_{ij}$. (a represents elements as shown in Matrix 5.1) where i and j represents row and column respectively. The diagonal elements having same importance are represented by 1 as shown in Matrix 5.1. The pairwise comparison is done in two folds, (1) Elements of alternatives are pairwise compared with respect to all elements in criteria. (2) All elements of criteria are pairwise compared with respect to all elements in alternatives.
Alternatives comparison using criteria

For each criteria, all the elements of alternatives are pairwise compared with each other. Once all the alternatives are compared, the resultant matrix will be comparison matrix, its general form is shown in Matrix 5.2, where C1 to Cn represents columns and R1 to Rn represents rows. Starting from DistCent as the first criteria element, all alternatives are compared with each other (represented by N1 to N5) according to 9-point scale (as shown in Table 5.1). Entries above the diagonal values in Matrix 5.3 are obtained from pairwise comparison according to quantitative 9-point scale (Table 5.1), the entries below diagonal values are generated automatically with the corresponding reciprocal values. Initially N1 is compared with N2, N3, N4 and N5 taking into account the DistCent parameter resulting in row 1 of Matrix 5.3. In this row, N1 is of same importance to itself (represented by value 1), N1 is moderately more important than N2, N3 is strongly to very strongly more important than N1 (scaling value 8, here represented by reciprocal value) and nodes (N4 and N5) are equally to moderately more important than N1 (represented by scaling value of 2, here represented by reciprocal values). All the elements are compared by assigning weights to 9-point scale (shown in table 5.1).

\[
\begin{bmatrix}
 a_1 & a_2 & a_3 & a_4 & a_5 \\
 a_1 & 1 & & & \\
 a_2 & & 1 & & \\
 a_3 & & & 1 & \\
 a_4 & & & & 1 \\
 a_5 & & & & 
\end{bmatrix} 
\] (5.1)
After pairwise comparison, all the elements of each column in Matrix 5.3 are summed using Equations 5.4 and 5.5. The result of this summation is shown in Matrix 5.6. Equation 5.4 shows the process for C1 to Cn-1 and Equation 5.5 is for last column (Cn), where Si represents the respective column sum.

For C1 to C_n-1

\[ S_i = \sum_{j=1}^{k-1} a_{ij} + \sum_{j=k}^{n} \frac{1}{ajj} \text{ where } k = 2, 3, 4, ..., n \text{ and } i = 1, 2, 3, ..., n - 1 \]  

(5.4)
For $C_n$

$$S_n = \sum_{j=1}^{k-1} a_{ji} \quad \text{where } k = n + 1, i = n \quad (5.5)$$

$$\begin{bmatrix}
N_1 & N_2 & N_3 & N_4 & N_5 \\
1.0 & 2.0 & 0.125 & 0.5 & 0.5 \\
0.5 & 1.0 & 0.125 & 2.0 & 0.5 \\
8.0 & 8.0 & 1.0 & 8.0 & 8.0 \\
2.0 & 0.5 & 0.125 & 1.0 & 0.5 \\
2.0 & 2.0 & 0.125 & 2.0 & 1.0 \\
\text{Total} & 13.5 & 13.5 & 1.5 & 13.5 & 10.5 \\
\end{bmatrix} \quad (5.6)$$

Matrix 5.7 is the normalized form of Matrix 5.6, in which each column individual value is divided by the sum of their respective columns represented as $S_i$.

$$\begin{bmatrix}
N_1 & N_2 & N_3 & N_4 & N_5 \\
\frac{1.0}{13.5} & \frac{2.0}{13.5} & \frac{0.125}{1.5} & \frac{0.5}{13.5} & \frac{0.5}{10.5} = 0.074 & \frac{0.083}{0.047} \\
\frac{0.5}{13.5} & \frac{1.0}{13.5} & \frac{0.125}{1.5} & \frac{2.0}{13.5} & \frac{0.5}{10.5} = 0.037 \\
\frac{8.0}{13.5} & \frac{8.0}{13.5} & \frac{1.0}{1.5} & \frac{8.0}{13.5} & \frac{8.0}{10.5} = 0.592 \\
\frac{2.0}{13.5} & \frac{0.5}{13.5} & \frac{0.125}{1.5} & \frac{1.0}{13.5} & \frac{0.5}{10.5} = 0.148 \\
\frac{2.0}{13.5} & \frac{2.0}{13.5} & \frac{0.125}{1.5} & \frac{2.0}{13.5} & \frac{1.0}{10.5} = 0.095 \\
\end{bmatrix} \quad (5.7)$$

Each individual row is summed and their average is taken to get Eigen vector (EV). To check the reliability of pairwise comparisons (consistency check), the consistency metrics used are Consistency Measure (CM), Consistency Index (CI) and Consistency Ratio (CR).
a. **Consistency Measure**
Consistency Measure (CM) is the first step in making consistency analysis. The CM vector is input for consistency index and ratio (CI and CR) calculation. In order to find CM, matrix 5.6 is first row-wise multiplied with the Eigen vector as in Matrix 5.12 and then divided by the corresponding element of the EV as shown in Figure 5.4. The general form for obtaining CM is given in Equation 5.8, where Rj is the corresponding row of comparison matrix, EV is the Eigen vector (priority vector) and EVj represents the corresponding element in EV. The average of CM vector is $\lambda_{max}$.

$$CM_j = \frac{R_j \times EV}{EV_i} \quad \text{where } j = 1, 2, \ldots, n \quad (5.8)$$

![Figure 5.4. Consistency measure calculation](image)

b. **Consistency Index**
According to Saaty, CI is the degree or deviation of consistency. To calculate CI for DistCent iteration, we need to put the values of $\lambda_{max} = 5.37$ and $n=5$ in Equation 5.9, results in CI=0.092.

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (5.9)$$
c. **Consistency Ratio**

To check the reliability of pairwise comparisons, it is very important to ensure the consistency between the pairwise comparisons made. To get consistency ratio (CR), we need to calculate consistency index (CI) as shown in Equation 5.9 and RI (value of RI is drawn from Table 5.3 according to the order of matrix represented by n, in our case n=5). RI is the consistency index of random reciprocal matrix generated from quantitative 9-point scale. The value of n in Table 5.3 have been experimentally obtained as in [104]. For order of matrix greater than 9, the values for RI are nearly leveled with negligible change as shown in Figure 5.5. However, in literature researchers have proposed the order of matrix greater than 9 to calculate RI [105]. Putting the values of CI (from Equation 5.9) and RI (from Table 5.3) in Equation 5.10 results in CR= 0.08 which means that inconsistency is 8% satisfying the maximum criteria which is less than 10% (0.1).

\[
CR = \frac{CI}{RI} \quad (5.10)
\]

![Figure 5.5. Random Inconsistency](image)
The value of \( CR \leq 0.1 \) is acceptable otherwise the pairwise comparison needs to be revised. It means that if the value of \( CR \) is less than 0.1, then less than 10% inconsistency is acceptable. Inconsistency is basically the modification required to improve the consistency of the pairwise comparison. But modification should not be as large as the judgment itself nor so small that it should have no significance, hence it has to be of one order smaller scale. The overall inconsistency for a specific comparison should be less than 10% \([104]\). Eigen Vector (EV1) in Matrix 5.12 is obtained through Equation 5.11, which represents the average value of each row.

\[
EV_i = \frac{1}{n} \sum_{j=1}^{n} a_{ij} \quad \text{where } i = 1, 2, 3, \ldots, n \quad (5.11)
\]

\[
\begin{bmatrix}
N_1 & N_2 & N_3 & N_4 & N_5 & EV_1 \\
N_1 & 0.074 & 0.148 & 0.083 & 0.037 & 0.047 & 0.078 \\
N_2 & 0.037 & 0.074 & 0.083 & 0.148 & 0.047 & 0.078 \\
N_3 & 0.592 & 0.592 & 0.666 & 0.592 & 0.762 & 0.641 \\
N_4 & 0.148 & 0.037 & 0.083 & 0.074 & 0.047 & 0.078 \\
N_5 & 0.148 & 0.148 & 0.083 & 0.148 & 0.095 & 0.124 \\
\end{bmatrix}
\]

\( CR = 0.08 \)

The remaining matrices of all pairwise comparisons are solved through the same process. \( CR \) against all matrices must be less than 0.1, otherwise recalculate the pairwise comparison. In Matrix 5.13 nodes are compared with respect to DistNode (distance from other nodes). The column values of N1, N2, N3, N4 and N5 are basically

<table>
<thead>
<tr>
<th>N</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI</td>
<td>0</td>
<td>0</td>
<td>0.52</td>
<td>0.89</td>
<td>1.11</td>
<td>1.25</td>
<td>1.35</td>
<td>1.40</td>
<td>1.45</td>
</tr>
</tbody>
</table>
the weights obtained after pairwise comparison and E.V is directly calculated by following the same process for DistCent.

\[
\begin{bmatrix}
    N_1 & N_2 & N_3 & N_4 & N_5 & EV_2 \\
    N_1 & 0.10 & 0.18 & 0.09 & 0.06 & 0.17 & 0.119 \\
    N_2 & 0.03 & 0.06 & 0.09 & 0.03 & 0.02 & 0.051 \\
    N_3 & 0.61 & 0.37 & 0.60 & 0.72 & 0.52 & 0.583 \\
    N_4 & 0.20 & 0.18 & 0.09 & 0.12 & 0.17 & 0.156 \\
    N_5 & 0.05 & 0.18 & 0.09 & 0.06 & 0.08 & 0.091 \\
\end{bmatrix} \quad (5.13)
\]

\[CR = 0.06\]

MN (Merged Node) criteria is taken in to account for every alternative in Matrix 5.14.

\[
\begin{bmatrix}
    N_1 & N_2 & N_3 & N_4 & N_5 & EV_3 \\
    N_1 & 1.0 & 0.5 & 0.5 & 0.5 & 2.0 & 0.140 \\
    N_2 & 2.0 & 1.0 & 0.5 & 0.5 & 2.0 & 0.185 \\
    N_3 & 2.0 & 2.0 & 1.0 & 1.0 & 2.0 & 0.322 \quad (5.14) \\
    N_4 & 2.0 & 2.0 & 0.5 & 0.5 & 2.0 & 0.244 \\
    N_5 & 0.5 & 0.5 & 0.5 & 0.5 & 1.0 & 0.106 \\
\end{bmatrix}
\]

\[CR = 0.04\]

Nodes are compared with respect to residual energy level (REL) in Matrix 5.15.

\[
\begin{bmatrix}
    N_1 & N_2 & N_3 & N_4 & N_5 & EV_4 \\
    N_1 & 1.0 & 0.5 & 0.5 & 0.5 & 0.5 & 0.102 \\
    N_2 & 2.0 & 1.0 & 2.0 & 0.5 & 0.5 & 0.194 \\
    N_3 & 2.0 & 0.5 & 1.0 & 2.0 & 0.5 & 0.194 \quad (5.15) \\
    N_4 & 2.0 & 2.0 & 0.5 & 1.0 & 0.5 & 0.194 \\
    N_5 & 2.0 & 2.0 & 2.0 & 2.0 & 1.0 & 0.314 \\
\end{bmatrix}
\]

\[CR = 0.08\]

Pairwise comparison of nodes (alternatives) with respect to TCH (Number of times a node has been CH) is shown in Matrix 5.16. All weights of the nodes are same, this is
due to the fact that TCH in the first round is same for every node. In the first round every node has TCH = 0 resulting same weights and same E.V.

\[
\begin{bmatrix}
N_1 & N_2 & N_3 & N_4 & N_5 & EV_5 \\
N_1 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 0.2 \\
N_2 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 0.2 \\
N_3 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 0.2 \\
N_4 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 0.2 \\
N_5 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 0.2 \\
\end{bmatrix} \quad (5.16)
\]

\[CR = 0.0\]

ii. Criteria comparison using alternatives (nodes)

The parameters in criteria (DistCent, DistNode, MN, REL and TCH) are compared with respect to all the elements of alternatives (N1, N2, N3, N4 and N5) one by one and are shown in Matrices 5.17 to 5.21 respectively. Matrix 5.17 shows the pairwise comparison of parameters in accordance to the weights described in Table 5.1 by keeping in view N1. The column values of DistCent, DistNode, MN, REL and TCH in Matrix 5.17 are the weights obtained after pairwise comparison and E.V is obtained by following the same process for DistCent.

\[
\begin{bmatrix}
DistCent & DistNode & MN & REL & TCH & EV_6 \\
DistCent & 1.0 & 0.25 & 4.0 & 0.16 & 3.0 & 0.113 \\
DistNode & 4.0 & 1.0 & 4.0 & 0.2 & 4.0 & 0.217 \\
MN & 0.25 & 0.25 & 1.0 & 0.14 & 2.0 & 0.056 \\
REL & 6.0 & 5.0 & 7.0 & 1.0 & 9.0 & 0.573 \\
TCH & 0.33 & 0.25 & 0.5 & 0.11 & 1.0 & 0.041 \\
\end{bmatrix} \quad (5.17)
\]

\[CR = 0.09\]
### Optimum Cluster Head Selection Using Multi-criteria Decision Tool in WSN

#### (5.18)

<table>
<thead>
<tr>
<th>DistCent</th>
<th>DistNode</th>
<th>MN</th>
<th>REL</th>
<th>TCH</th>
<th>EV_7</th>
</tr>
</thead>
<tbody>
<tr>
<td>DistCent</td>
<td>1.0</td>
<td>0.25</td>
<td>2.0</td>
<td>0.2</td>
<td>3.0</td>
</tr>
<tr>
<td>DistNode</td>
<td>4.0</td>
<td>1.0</td>
<td>4.0</td>
<td>0.2</td>
<td>6.0</td>
</tr>
<tr>
<td>MN</td>
<td>0.5</td>
<td>0.25</td>
<td>1.0</td>
<td>0.14</td>
<td>3.0</td>
</tr>
<tr>
<td>REL</td>
<td>5.0</td>
<td>5.0</td>
<td>7.0</td>
<td>1.0</td>
<td>6.0</td>
</tr>
<tr>
<td>TCH</td>
<td>0.33</td>
<td>0.16</td>
<td>0.33</td>
<td>0.16</td>
<td>1.0</td>
</tr>
<tr>
<td>CR = 0.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

#### (5.19)

<table>
<thead>
<tr>
<th>DistCent</th>
<th>DistNode</th>
<th>MN</th>
<th>REL</th>
<th>TCH</th>
<th>EV_8</th>
</tr>
</thead>
<tbody>
<tr>
<td>DistCent</td>
<td>1.0</td>
<td>0.33</td>
<td>4.0</td>
<td>0.16</td>
<td>2.0</td>
</tr>
<tr>
<td>DistNode</td>
<td>3.0</td>
<td>1.0</td>
<td>5.0</td>
<td>0.16</td>
<td>3.0</td>
</tr>
<tr>
<td>MN</td>
<td>0.25</td>
<td>0.2</td>
<td>1.0</td>
<td>0.14</td>
<td>0.33</td>
</tr>
<tr>
<td>REL</td>
<td>6.0</td>
<td>6.0</td>
<td>7.0</td>
<td>1.0</td>
<td>5.0</td>
</tr>
<tr>
<td>TCH</td>
<td>0.5</td>
<td>0.33</td>
<td>3.0</td>
<td>0.2</td>
<td>1.0</td>
</tr>
<tr>
<td>CR = 0.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### (5.20)

<table>
<thead>
<tr>
<th>DistCent</th>
<th>DistNode</th>
<th>MN</th>
<th>REL</th>
<th>TCH</th>
<th>EV_9</th>
</tr>
</thead>
<tbody>
<tr>
<td>DistCent</td>
<td>1.0</td>
<td>0.25</td>
<td>2.0</td>
<td>0.16</td>
<td>0.5</td>
</tr>
<tr>
<td>DistNode</td>
<td>4.0</td>
<td>1.0</td>
<td>4.0</td>
<td>0.16</td>
<td>4.0</td>
</tr>
<tr>
<td>MN</td>
<td>0.5</td>
<td>0.25</td>
<td>1.0</td>
<td>0.16</td>
<td>0.5</td>
</tr>
<tr>
<td>REL</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
<td>1.0</td>
<td>6.0</td>
</tr>
<tr>
<td>TCH</td>
<td>2.0</td>
<td>0.25</td>
<td>2.0</td>
<td>0.16</td>
<td>1.0</td>
</tr>
<tr>
<td>CR = 0.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### (5.21)

<table>
<thead>
<tr>
<th>DistCent</th>
<th>DistNode</th>
<th>MN</th>
<th>REL</th>
<th>TCH</th>
<th>EV_10</th>
</tr>
</thead>
<tbody>
<tr>
<td>DistCent</td>
<td>1.0</td>
<td>0.25</td>
<td>3.0</td>
<td>0.2</td>
<td>3.0</td>
</tr>
<tr>
<td>DistNode</td>
<td>4.0</td>
<td>1.0</td>
<td>5.0</td>
<td>0.2</td>
<td>4.0</td>
</tr>
<tr>
<td>MN</td>
<td>0.33</td>
<td>0.2</td>
<td>1.0</td>
<td>0.12</td>
<td>2.0</td>
</tr>
<tr>
<td>REL</td>
<td>5.0</td>
<td>5.0</td>
<td>8.0</td>
<td>1.0</td>
<td>8.0</td>
</tr>
<tr>
<td>TCH</td>
<td>0.33</td>
<td>0.25</td>
<td>0.5</td>
<td>0.12</td>
<td>1.0</td>
</tr>
<tr>
<td>CR = 0.07</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
5.3.3 Unweighted and Weighted Supermatrix

Table 5.4 shows the unweighted supermatrix of the ANP model. It contains the local priorities of nodes obtained from pairwise comparison Matrices 5.12 to 5.21. Eigenvectors of each individual matrix are combined, which form the unweighted supermatrix shown in Table 5.4 (shaded region represents the corresponding Eigen vectors). This unweighted matrix is then transformed into weighted supermatrix to make it column stochastic (the sum of each column will be 1) as shown in Table 5.5. Weighted supermatrix is the outcome of unweighted supermatrix and cluster matrix.

Table 5.4. Unweighted Supermatrix

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DistCent</td>
</tr>
<tr>
<td></td>
<td>(EV1)</td>
</tr>
<tr>
<td>Node1</td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td>0.1189</td>
</tr>
<tr>
<td>Node2</td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td>0.0511</td>
</tr>
<tr>
<td>Node3</td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td>0.5833</td>
</tr>
<tr>
<td>Node4</td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td>0.1562</td>
</tr>
<tr>
<td>Node5</td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td>0.0905</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>DistCent</td>
<td>0.1129</td>
</tr>
<tr>
<td></td>
<td>0.0993</td>
</tr>
<tr>
<td></td>
<td>0.1096</td>
</tr>
<tr>
<td></td>
<td>0.0681</td>
</tr>
<tr>
<td></td>
<td>0.1072</td>
</tr>
<tr>
<td>DistNode</td>
<td>0.2168</td>
</tr>
<tr>
<td></td>
<td>0.2367</td>
</tr>
<tr>
<td></td>
<td>0.1968</td>
</tr>
<tr>
<td></td>
<td>0.2129</td>
</tr>
<tr>
<td></td>
<td>0.2278</td>
</tr>
<tr>
<td>MN</td>
<td>0.0560</td>
</tr>
<tr>
<td></td>
<td>0.0712</td>
</tr>
<tr>
<td></td>
<td>0.0399</td>
</tr>
<tr>
<td></td>
<td>0.0521</td>
</tr>
<tr>
<td></td>
<td>0.0550</td>
</tr>
<tr>
<td>REL</td>
<td>0.5727</td>
</tr>
<tr>
<td></td>
<td>0.5502</td>
</tr>
<tr>
<td></td>
<td>0.5731</td>
</tr>
<tr>
<td></td>
<td>0.5780</td>
</tr>
<tr>
<td></td>
<td>0.5661</td>
</tr>
<tr>
<td>TCH</td>
<td>0.0416</td>
</tr>
<tr>
<td></td>
<td>0.0425</td>
</tr>
<tr>
<td></td>
<td>0.0806</td>
</tr>
<tr>
<td></td>
<td>0.0890</td>
</tr>
<tr>
<td></td>
<td>0.0438</td>
</tr>
<tr>
<td></td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td>0.0000</td>
</tr>
</tbody>
</table>
Table 5.5. Weighted Supermatrix

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Criteria</th>
<th>DistCent</th>
<th>DistNode</th>
<th>MN</th>
<th>REL</th>
<th>TCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Node1 0.0000</td>
<td>0.0389</td>
<td>0.0595</td>
<td>0.0703</td>
<td>0.0514</td>
<td>0.1000</td>
<td></td>
</tr>
<tr>
<td>Node2 0.0000</td>
<td>0.0389</td>
<td>0.0256</td>
<td>0.0927</td>
<td>0.0972</td>
<td>0.1000</td>
<td></td>
</tr>
<tr>
<td>Node3 0.0000</td>
<td>0.3204</td>
<td>0.2916</td>
<td>0.1614</td>
<td>0.0972</td>
<td>0.1000</td>
<td></td>
</tr>
<tr>
<td>Node4 0.0000</td>
<td>0.0389</td>
<td>0.0781</td>
<td>0.1223</td>
<td>0.0972</td>
<td>0.1000</td>
<td></td>
</tr>
<tr>
<td>Node5 0.0000</td>
<td>0.0622</td>
<td>0.0453</td>
<td>0.0533</td>
<td>0.1571</td>
<td>0.1000</td>
<td></td>
</tr>
<tr>
<td>DistCent</td>
<td>0.1129</td>
<td>0.0993</td>
<td>0.1096</td>
<td>0.0681</td>
<td>0.1072</td>
<td></td>
</tr>
<tr>
<td>DistNode</td>
<td>0.2168</td>
<td>0.2367</td>
<td>0.1968</td>
<td>0.2129</td>
<td>0.2278</td>
<td></td>
</tr>
<tr>
<td>MN</td>
<td>0.0560</td>
<td>0.0712</td>
<td>0.0399</td>
<td>0.0521</td>
<td>0.0550</td>
<td></td>
</tr>
<tr>
<td>REL</td>
<td>0.5727</td>
<td>0.5502</td>
<td>0.5731</td>
<td>0.5780</td>
<td>0.5661</td>
<td></td>
</tr>
<tr>
<td>TCH</td>
<td>0.0416</td>
<td>0.0425</td>
<td>0.0806</td>
<td>0.0890</td>
<td>0.0438</td>
<td></td>
</tr>
</tbody>
</table>

5.4 Results and Discussions

In literature, different research articles were studied regarding cluster head selection in WSN, in which different parameters were used for selection of CH using different approaches. In this work, five parameters were considered for CH selection using ANP approach, already discussed in detail in section 5.3.1. Once unweighted supermatrix is transformed into weighted supermatrix by converting it to column stochastic, the final priorities are obtained through limit matrix. Ranking of alternatives elements are obtained through limit matrix, which shows the final optimum selection and is discussed below.

5.4.1 Limit Supermatrix

Limit supermatrix is used to obtain stable weights from weighted supermatrix. All the values in weighted supermatrix are raised to the power of \(2k\), where \(k\) is the random
number. Process is repeated until same and stable values are achieved. Limit supermatrix contains the summary of all the pairwise comparison made. It comprises of all indirect impacts between elements. Table 5.6 shows the limit supermatrix, where the standing alternative and criteria can easily be figured out. In table 5.6, Node3 has the high value which means that it is the most desirable node to be cluster head among these nodes, and REL is the most important criteria element among others. Priorities of alternatives are shown in Figure 5.6 and nodes are ranked accordingly as well. It is clear from Figure 5.6 that Node3 is the best choice to be the CH having maximum priority score and Node1 has low score.

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alternatives</strong></td>
<td><strong>Node1</strong></td>
</tr>
<tr>
<td>Node1</td>
<td>0.0299</td>
</tr>
<tr>
<td>Node2</td>
<td>0.0367</td>
</tr>
<tr>
<td>Node3</td>
<td>0.0900</td>
</tr>
<tr>
<td>Node4</td>
<td>0.0440</td>
</tr>
<tr>
<td>Node5</td>
<td>0.0495</td>
</tr>
<tr>
<td><strong>Criteria</strong></td>
<td><strong>DistCent</strong></td>
</tr>
<tr>
<td>DistCent</td>
<td>0.0752</td>
</tr>
<tr>
<td>DistNode</td>
<td>0.1035</td>
</tr>
<tr>
<td>MN</td>
<td>0.0629</td>
</tr>
<tr>
<td>REL</td>
<td>0.1923</td>
</tr>
<tr>
<td>TCH</td>
<td>0.0661</td>
</tr>
</tbody>
</table>
The Node3 (N3) has the highest score among all the alternatives because of its position in the zone and distance from other nodes in the zone. As it is clear from figure that N3 position is quite close to the center of zone. Therefore in pairwise comparisons, the weight of N3 with respect to all other nodes will be high which makes it the optimum choice while considering the CentDist parameter. Moreover, other nodes in the zone are almost at equal distance to N3, thus N3 will weight high in the comparisons made. REL and TCH are initially same for all the five nodes. Because initially all nodes will have same residual energy level and no node has been cluster head in the first round of CH selection thus TCH will be same for all nodes. As it is shown in figure that N3 is not merged thus its weight with all other nodes will be same except N1. The node with the minimum priority score is N1, which means that it aggregate weight is low among all the nodes. It can be seen in Figure 5.6 that N1 and N2 are close with respect to
priority score with N2 having slight high score. Because of the fact that N1 is basically merged from other zone that’s why it’s priority in terms of MN parameter is low as compared to all other nodes. Merged node parameter has quite an impact on the selection of CH and nodes which are merged from the neighboring zones will have low weight with respect to all other nodes in a zone. To further analyze and discuss the stability of the alternatives ranking, sensitivity analysis is carried out by considering different scenarios.

5.4.2 Sensitivity Analysis

Sensitivity analysis is highly recommended to check the stability of alternatives ranking. This is used to check the results and ranking of alternatives obtained through ANP model. According to weighted supermatrix, it should be considered that the elements in alternatives are influenced by the elements in criteria and vice versa. To start with the sensitivity analysis, elements having highest weights are identified first. The impact of these weights must be observed on all other elements (alternatives).

Referring to Table 5.6, the highest ranked elements are REL and DistNode with values of 0.19229 and 0.10351 respectively. We have chosen DistNode, the second highest ranked element, as initially all nodes of the cluster have the same REL value. In this case sensitivity analysis is carried out to check the impact of DistNode on the ranking of alternative elements for three different scenarios as shown in Figures 5.7, 5.9 and 5.11. Sensitivity analysis of the mentioned scenarios is carried out and represented in Figures 5.8, 5.10 and 5.12. In these figures the x-axis represents cluster head selection weight (goal) and y-axis represents alternatives priority (nodes).
Initially we applied this process to only one cluster containing 5 nodes (N1, N2, N3, N4 and N5 as shown in Figure 5.2 where Zone 6 is considered) against REL, DistNode, DistCent, TCH and MN one by one respectively. The same process can easily be extended to all other clusters in the network containing different number of nodes, where the criteria parameters will remain same while alternatives will vary according to the number of nodes in a specific cluster.

i. **Scenario 1**

The basic configuration of 5 sensor nodes (represented by N1, N2, …, N5) each one at a specified location, generally denoted by \((x_i, y_i)\) where \(i=1, 2, 3, 4, 5\) as shown in Figure 5.7. In sensitivity analysis, DistNode parameter is considered in existing topology in order to check the corresponding ranking of the nodes. The result shown in Figure 5.8, reveal that Node3 is of highest rank and therefore the most suitable candidate for CH selection.
ii. **Scenario 2**

Sensitivity analysis aims at checking the stability of the rankings of alternatives. In scenario 2 as shown in Figure 5.9, the position of N3 is slightly changed in direction of N4 i.e. from location (2, 2) to new location (2, 3). Changing the location of the N3 requires re-computation of the pairwise comparisons of alternatives (nodes). The sensitivity analysis obtained from the recomputed pairwise comparison show that N3 is still the most suitable node to be selected for CH as shown in Figure 5.10. It is concluded that the alternatives are stable and robust as ranking of the alternatives didn’t change by slightly changing the criteria parameter, in this case DistNode.
iii. Scenario 3

To check the stability and robustness of the alternatives ranking even more, we targeted N1 to vary its position as shown in Figure 5.11. N1 was moved closer to the center of grid. While considering distance from other nodes (DistNode), N1 seems to be the good choice. Sensitivity analysis is shown in Figure 5.12. It is clear that N3 is still the high
ranked node but there is a notable change in the ranks of alternatives i.e. N1 and N4. It is due to the fact that N1 has more neighbor nodes than it had in scenario 1 and 2, thus making it second highest priority node to be selected for CH.

![Figure 5.11. Scenario 3](image)

![Figure 5.12. Sensitivity analysis of alternatives w.r.t DistNode, when N1 gets closer to center](image)
In all cases, results illustrated that alternatives ranking was stable and in all three scenarios Node 3 was selected to be the best alternative node for cluster head. Here we can conclude that ANP can be used as one of the alternative method for cluster head selection in wireless sensor network. The limit matrix represents selection priority for all candidate nodes where a node with the highest priority weight is selected as CH. In addition to this, the limit matrix also reports priority weights for all criteria parameters. Moreover, it can be used to optimize criteria list for efficient cluster head selection by eliminating selection parameters with the low weights thus minimizing computational complexity of the ANP process. Additionally, this information can be used for optimization of parameters and could serve as input to other cluster head selection techniques.

5.5 Summary

This chapter presents a technique for optimal cluster head selection using multi-criteria decision tool. In multi-criteria decision making, a decision has to be taken on the basis of certain parameters. In non-probabilistic approach, CH depends on certain parameters which makes it a multi-criteria decision problem. The analytical network process is used as a multi-criteria decision tool, which is used for selecting CH in grid-based wireless sensor network and a mathematical model has also been developed. In ANP, elements are grouped in to a network of clusters as it doesn’t follow hierarchical top-bottom approach as was adopted by AHP. Furthermore, ANP is suitable in those situations where elements have interdependency within clusters or between clusters. In this work, goal is to select the CH by considering five distinct parameters such as REL, DistCent, DistNodes, TCH and
MN as criteria to select the best alternative (nodes). Each individual element is pairwise compared with each other according to Saaty 9-point quantitative scale and the resultant of each comparison is presented in unweighted supermatrix. Eigen vector is the resultant of each comparison. To normalize the Eigen values in unweighted supermatrix, each Eigen vector is made column stochastic and the resultant matrix is called as weighted supermatrix. The values in weighted supermatrix are raised to the power of $2^k$ and process is repeated until the whole matrix have stable values to get limit matrix. The limit matrix represents selection priority for all the candidate nodes where a node with the highest priority weight is selected as CH. At the end, to check stability of the alternatives ranking, sensitivity analysis is carried out to analyze how much the alternatives are stable by changing one or more criteria weight.
CHAPTER 06

CONCLUSION AND FUTURE DIRECTIONS

6.1 Evaluation

The proposed method is evaluated concerning design goals as previously discussed in chapter 1. To achieve the design goals, an energy efficient grid-based hybrid network deployment framework has been proposed. The results show that the proposed framework achieves load balancing through the novel merge and split technique. Moreover, the results show that it is energy efficient at different levels such as during the zone head selection and reselection process. The framework accommodates new nodes to achieve scalability depending on applications requirement. Moreover, a mathematical model is proposed using ANP approach, which is a multi-criteria decision tool to select the optimum cluster head to maximize network stability and lifetime. Following sub-sections describes the goals achieved by the proposed method.

6.1.1 Load balancing and even distribution of nodes

The proposed solution provides load balancing and distributes nodes evenly across a network through the merge and split technique. The nodes in low dense zones are merged with its neighboring zones to avoid hotspot problem where the network is divided in to unreachable segments. Nodes are merged on the basis of weighted merge score that depends on the neighboring zone density and distance from the centroid. In the proposed method there will not be even a single zone that will contain number of nodes less than the lower threshold. The high density zones are split in to sub-zones if it exceeds the upper threshold. Four splitting strategies are proposed in order to split a particular zone. The
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proposed merge and split technique achieve even distribution of nodes and load balancing resulting in an efficient grid formation that leads to stable network and eliminates network breakage.

6.1.2 Energy efficiency
Energy efficiency is being achieved through grid-based approach, because it directly affects the overall network performance as sensor nodes are equipped with a limited battery. In the proposed method, a non-probabilistic weighted approach is used to select optimum zone head. The proposed approach is based on certain parameters that ensure the best node selection. The zone head energy decreases after certain number of rounds, so to keep the network alive role of ZH is rotated that depends on the defined threshold value. Moreover, reselection process is independent of the overall network, it is initiated when required thus minimizing network load also results in improved energy consumption.

6.1.3 Scalability
The proposed framework is scalable enough that supports network with different densities. It is analyzed against different node densities to check performance of the proposed method with existing approaches. Moreover, it is shown in results that the proposed approach performs well in terms of varying node densities which makes it suitable for small and large scale networks.

6.1.4 Reduce network overhead
The communicational overhead is minimized right from the node deployment till the last node die. The zone formation and zone head selection are done by the BS to avoid broadcast messages. After a certain number of rounds the ZH is rotated, the process is
initiated by the corresponding ZH to select the new zone head. Moreover, to avoid extra messages and to minimize energy consumption, the reselection process is done when it is required.

Performance of the proposed method is evaluated with respect to design goals discussed in chapter 1. Moreover, all of the design goals have been achieved as discussed above.

6.2 Future Directions

In this thesis, an energy efficient grid-based hybrid network deployment framework is proposed to achieve load balancing, energy efficiency, scalability and improved network lifetime. The proposed scheme was evaluated while considering static homogenous nodes while introducing mobility and heterogeneous nodes still needs to be analyzed. Based on the research work presented in this thesis, the proposed scheme can be further investigated based on following suggested future directions:

- The proposed network deployment scheme ensures load balancing and energy efficiency in comparison with existing energy efficient protocols. However, the proposed framework can be also used as an underlying framework for different cluster head selection schemes to minimize energy consumption during grid/cluster formation.

- Moreover, efficient grid formation is achieved through merge and split technique based on lower and upper threshold. However, further research is needed to make the framework adaptive by optimizing IBG, lower bound, upper bound, and number of grids for given node density and network area.
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- The proposed scheme is evaluated considering different node density to achieve scalability, and performed better in terms of network lifetime. However, this work can further be used with other existing clustering approaches in context of different sizes of a network.

- Furthermore, an optimum cluster head selection approach is used based on multi-criteria decision tool to achieve network stability and maximize network lifetime. The analytical network process is used for optimum cluster head selection. However, as ANP work on multi-criteria, therefore, it can be used for optimization of parameters through limit matrix, where the least important criteria can be identified to overcome computational cost.

6.3 Final Remarks

In this thesis, an energy efficient grid-based hybrid network deployment framework has been proposed for load balancing to ensure energy efficiency in wireless sensor network. For a random node deployment scenario, the proposed method construct grids by dividing the deployment area into different zones. All the nodes are associated with their respective zones where a BS determines the number of nodes per zone. In order to evenly distribute the nodes across a zone, low and high density zones are identified based on the experimentally obtained threshold value. The nodes in low density zones are merged with their neighboring zones depending on the distance from center of zone and node density. Moreover, the high density zones are split into subzones according to the proposed four splitting strategies (horizontal, vertical, diagonal 45° and diagonal 135°). This novel merge and split technique is used to solve the hotspot problem. Once the network topology is
constructed, BS will select the node with maximum CV (cumulative value) as ZH across every zone. The overhead messages and reselection process are simplified in the proposed approach which helps to maximize network lifetime. The proposed method is compared with other approaches such as LEACH, PEGASIS, CBDAS and Direct approach. Simulation results show that the proposed method is better than the above mentioned state-of-the-art techniques by evenly placing ZH across the field and balanced grid formation. The proposed algorithm outperforms these approaches in terms of varying initial energy, grid dimensions, node density, network lifetime, and total energy consumption.

A mathematical model is developed based on multi-criteria decision system to solve CH selection problem in WSN using analytical network process. The CH selection in WSN involves tuning of several interrelated parameters such as residual energy level, distance from the center of a zone, distance from neighboring nodes, number of times a nodes has been selected as ZH and if a node is merged or not were taken as criteria for ANP process. The mathematical framework was then tested for three different scenarios. In the first scenario, a cluster of 5 nodes was considered for ANP based cluster head selection. The criteria parameters; REL, DistCent, DistNodes, TCH and MN were taken into account. Each parameter is pairwise compared with all alternatives respectively. The limit matrix shows that REL parameter has the highest value 0.1923. As initially REL is same for all nodes, therefore the second highest parameter (DistNodes with value 0.1035) is selected for sensitivity analysis. Node 3 was evaluated to be the best node for CH selection with a priority value of approximately 40%. For the second scenario, Node 3 was moved a bit closer to Node 4 and 5 and sensitivity analysis was checked. The result showed that Node 3 is still the best node to be the CH. In scenario 3 in order to check the stability of
alternatives ranking, Node 1 was moved to the center of the zone. Sensitivity analysis showed that node 3 was still the best choice for CH selection. In all cases, results illustrated that alternatives ranking was stable and in all three scenarios Node 3 was selected to be the best alternative node for cluster head. Here we can conclude that ANP can be used as one of the alternative method for cluster head selection in wireless sensor network. Limit matrix represents selection priority for all candidate nodes where a node with the highest priority weight is selected as CH. In addition to this, the limit matrix also reports priority weights for all criteria parameters, which can further be used to optimize the criteria list for efficient cluster head selection by eliminating selection parameters with the low weights thus minimizing computational complexity of the ANP process. Additionally, this information can be used for optimization of parameters and could serve as input to other cluster head selection techniques.

The proposed framework can be used in any network that require sensors for sensing and gathering data. As sensors are almost everywhere from mobile devices to industrial use and from Internet of things to smart cities. Large number of sensors will be required for these concepts to gather huge amount of data. Therefore, energy efficient techniques are required to minimize energy consumption and prolong network lifetime. The proposed architecture can easily be fitted in these upcoming booming concepts to achieve energy efficiency and sense more data for decision making.
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