Smart Clustering Approach for Lifetime Maximization in Underwater Acoustic Sensor Networks

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Approval

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Dedication

Dedicating this thesis to my parents, siblings and wife for constant emotional and financial support.

Certificate of Originality

I hereby declare that this submission titled "Smart Clustering Approach for Lifetime Maximization in Underwater Acoustic Sensor Networks" is my own work. To the best of my knowledge it contains no materials previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any degree or diploma at NUST SEECS or at any other educational institute, except where due acknowledgement has been made in the thesis. Any contribution made to the research by others, with whom I have worked at NUST SEECS or elsewhere, is explicitly acknowledged in the thesis. I also declare that the intellectual content of this thesis is the product of my own work, except for the assistance from others in the project’s design and conception or in style, presentation and linguistics, which has been acknowledged. I also verified the originality of contents through plagiarism software.

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List of Abbreviation

UWSNs	Underwater sensor networks
ANC-UWSNs	Adaptive node clustering technique for underwater sensor networks
UOC	Underwater optical communication
CH	Cluster head
WSNs	Wireless sensor networks
UAC	Underwater acoustic communication
DAR	Data Aggregation Ratio
BS	Base Station
LEACH	Low-Energy Adaptive Clustering Hierarchy
TWSNs	Terrestrial Wireless Sensor Networks
UW-ASN	Underwater Wireless Acoustic Sensor Networks

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Abstract

Routing protocols are critical after sensor node placement for safe and efficient communication. Network lifetime and power consumption are taken into account as important difficulties in the way of establishing underwater communication in UWSNs. Many procedures have been proposed in the last decade to deal with these issues in dynamic circumstances. We have proposed a smart clustering approach for predicting rapidly moving and adjacent nodes to skip them from clusters. As a result, the skipped nodes became idle and conserved energy so that they can perform better in upcoming iterations. Because the residual energy level of idle nodes is larger than that of used nodes in the next cycle, they will form a cluster. Neighbor nodes encompass overlapping areas and are utilized to collect a degree of matching information, which is then eliminated at the aggregate level. Our proposed algorithm estimates the pace of moving nodes to distinguish between acceptable and unsuitable nodes for the cluster. Furthermore, we have distinguished between long-range and short-range communication, extending the life of the network. We took advantages of both communication media for intra-cluster and inter-cluster communication. Our proposed approach has increased network lifetime by using smart clustering approach and hybrid communication medium to save power consumption.

Chapter 1: Introduction

Underwater Sensor Networks are commonly used to monitor underwater activities such as catastrophe information, surveillance, and pollution monitoring. In 2018, the International Seabed Authority awarded more than 30 exploration contracts covering nearly a million square kilometers of the Deep Ocean. Underwater sensor networks are typically composed of wireless sensors, and many researchers have proposed various node deployment methodologies to cover the greatest number of locations with the fewest number of sensors. Although optical waves are susceptible to scattering and are therefore unsuitable for underwater sensor networks, to conserve energy, they can be utilized for close-range communication. Any technique that operates in the fluid environment of water has difficulty remaining effective; we must adapt depending on the deployment area. We assumed 3D node placement to cover the most area with the fewest nodes. Sensors in 3D models provide the added flexibility to move a deployment in any direction. Because sensors' residual energy and position may change after a successful transmission, we employ a dynamic clustering technique to re-cluster.

While comparing UWSN communication with terrestrial, nature of Underwater Wireless SN is different from the terrestrial network in various aspects. Some of the differences are given below:

1. In underwater environment localization is considered very difficult as compare to terrestrial networks.
2. Many issues arises with dynamically changing environment in UW in comparison to terrestrial sensor networks,
3. Radio signals are normally considered best communication medium for terrestrial networks but not for UW environment. UWSN make use of acoustic signals for communication purpose.
4. In Underwater environment energy of sensor nodes is very limited and we cannot charge their batteries by using nay conventional methods. Moreover, it is not considered a feasible option to replace or recharge the batter of sensors often specifically as compare to terrestrial sensors.

We are employing Round Based Clustering (RBC) and a similarity-based clustering technique with minor enhancements. During cluster formation, we skip neighboring and quickly moving nodes. Neighbor nodes are nodes that are close to one other and may collect the same information. They must thus be avoided in order to reduce similarity and preserve the n/2 nodes' energy in each cluster. Fast moving nodes are those that flow with the current; because of their rapid movement, they can't remain put for a long time to form a cluster to collect and send data to CH. using a variety of techniques, we may determine a node's neighbors by calculating the distance between them, and we can determine a node's speed of movement by calculating its location. Our second improvement is to employ a new kind of communication for data travelling between and within clusters. To minimize the quantity of the data and eliminate comparable data, we employ methods for aggregating data at the CH level. Along with the benefits of aggregation, it also reduce number of messages and redundancy which affects the accuracy of final results.

1.1 Background and Motivation

The thesis mainly focused on efficiently and balanced usage of energy in underwater environment to enhance network life span. Major goal is to make underwater routing protocols adaptive and self-configured in order to avoid early destruction of networks.

In UWSN, researchers of this domain focused on quick data transmission while maintaining efficient energy consumption. In [1] Clustered Based Energy Efficient Routing (CBE2R) is proposed which ensures reliable data delivery but duplicate data packets are also being generated. Moreover, continues parallel transmissions overload the channel and the chance of collision also increases as a result requirement of retransmission increases and the end-to-end delay occurs. Keeping above decencies of the CBE2R protocol in view, there is room for improvement and further optimization can be achieved by considering the movement of nodes. Hence, the aforementioned situation was the motivation to devise smart clustering approach to prolong the network.com lifespan.

As in UWSN, we can deploy sensor nodes in two mechanisms i.e sparse and dense deployment. In the case of sparse network deployment we normally face problem of void holes, in which one node cannot find any further in-range node who can forward its packet to sink node. In case of dense network we may face big number of collisions and failures, ultimately it cause end-to-end delay along with more energy consumption. Network stability is one of the key metrics when working on network performance, so researchers focus on those factors which directly effects network stability. Second most important metric is selection of optimal route to counter void hole problem. In [2] Weighting Depth and Forwarding Area Division Depth Based Routing (WDFAD-DBR) have been proposed in which forwarding node is being choosed on basis of depth and two hop neighbors information which reduce the probability of void hole problem.

Low energy adaptive clustering hierarchy (LEACH) protocol for the first time used probability method to select cluster heads [3]

1.1.1 Data Aggregation Based Energy Efficient Clustering

Khoa Thi-Minh et al. [4] proposed a 2-Dimensional homogeneous clustering scheme, which is considered energy economical even after performing data aggregation. The researchers actually split the entire procedure into phases i.e Initial Phase, cluster head selection, clustering phase, data aggregation phase.

1. In first phase, to begin the process sink node on the surface broadcasts a message which contains time instance, round interval and distance from node to sink. In first phase only sink node will be active for efficient consumption of energy.
2. In second phase, in reply to initial message every node will broadcasts a HELLO message which contains current time, level of energy, and distance from node to sink. By using broadcast delaying tactics collisions are being avoided. After exchanging HELLO message, every node maintain a table and selects CH on the basis of residual energy and less distance from sink node.
3. In the third phase of cluster formation, clusters are actually formed in surrounding of their respective CH. The selected cluster head will send INVITE message to its adjacent node and all in-range nodes. Upon receipt of INVITE message each node calculate its distance from the inviting cluster head(Distance = Speed × Time) in order to make the best cluster choice.
4. In the last phase, aggregation is being performed at CH level after receiving messages from source nodes and redundant data is discarded. Similarity functions are being used for this purpose to find the similarity between messages. It has been already proved that clustering without data aggregation saves more energy as compare to clustering without data aggregation.

A new and more efficient aggregation protocol is proposed in [5] named as DUCS. It is the energy efficient protocol and considered easily scalable. It actually divides the entire network into small clusters based on distributed algorithms.

According to authors the DUCS algorithm is distributed and self-organizing routing protocol. All nodes are labeled as CH nodes and NCH nodes. The transmission between CH and its member will be direct transmission without involvement of any third node. As soon as the packets received, aggregation will be performed to remove redundancy and then transmit data to sink node using multi hop fashion. DUCS protocol is designed in a way to work in two phases, initial setup phase and second one is operation phase. In first phase all the things will be setup i.e selecting cluster heads and creating clusters and in operation phase it will make the transmissions from source node to CH and then after aggregation from CH to sink node. Intra Cluster and Inter Cluster communications modes are based on long-range and short range mode of communications. In operation phase multiple datasets are collected by source nodes, passed on to CH which later transmitted to sink node.

Some shortcomings of DUCS protocols are:

1. In UWSN environment movement of nodes is continuous due to water current and it affects the structure of formed clusters, and clusters needs to be formed again and again.

2. In case if CH node left its place due to water current, it will directly affect data delivery ratio and it will reduced.

	Acoustic	**Optical**
Mode	Omni-directional	Directional
Propagation Speed	1500 m/s	2.55 x 108 m/s
Data Rate	Low data rate for long distance	Large data for small distance only
Energy Consumption	Not Efficient	Energy Efficient

Table 1Properties of Acoustic & Optical Communication in UWSN

1.2 Problem Statement

In UWSN the sensors have very limited battery power and their replacement is as difficult as their recharging via conventional methods which directly affects the stability of a network. In this thesis, smart clustering approach is proposed to solve the aforementioned problem.

1.3 Objectives

The objective of this research is to:

1. Prolong UW Network life span without affecting any other performance metric.
2. Divide network logically and create clusters in order to make efficient communication with less energy consumption.
3. Diagnose energy wasting factors in existing approaches and eliminate them.

1.4 Thesis Contribution

Following is the thesis contribution:

1. In UWSNs, the data collected by sensors could be redundant sometimes and the same is passed to respective CH. The moment it is passed to CH, it will consume unnecessary power to pass redundant data. In contrast when we use the neighbor skipping technique, we may save the energy of source nodes and the CH
2. To the best of our knowledge, no existing UWSN routing protocol is using node skipping technique to reduce the network overhead, energy consumption and wastage of resources.
3. Comparison of LEACH with our proposed smart clustering protocol based on optimal number of clusters and network longevity.
4. We have diagnosed and eliminated a couple of energy wasting factors in cluster based protocols. In practice, a number of nodes deployed in closed vicinity are gathering almost identical data and passing it to respective CH, which later considered redundant and discarded. Second factor was to include fast moving nodes which become part of any cluster when passing by but goes out of range before passing any data to respective CH. We have eliminated both of these factors.
5. This research critically analyzes LEACH algorithm’s performance on a cluster formation and energy dissipation. The proposed evaluation methods are feasible in nature and can be utilized in the future to evaluate the severity of natural hazards on people and the infrastructure. This research focuses on an in-depth analysis of energy consuming factors and aggregation techniques which effects proposed protocol performance.

LEACH	**Proposed**
Cluster Heads periodically get rotated among nodes to consume power equally	Election of cluster heads on the basis of their residual energy and distance from sensor node to sink node.
CH election is updated in each iteration	CH election is updated when energy level of previously elected CHs goes below 50%
Each iteration has two phases: Setup phase(Election of CH and Cluster formation) Steady-state phase(Data sent to sink node)	First iteration has two phases same as LEACH but second iteration will not have setup phase until CHs energy goes below 50%
Not considering movement of nodes with water current	Considered movement of nodes with water current
Adding all nearest nodes to CH	Adding only suitable nodes to CH

Table 2: Overall Comparison of Proposed scheme with LEACH

Chapter 2: Literature Review

In this chapter, we evaluated and compared different existing routing protocols that aim to extend network lifespan by balancing energy consumption and avoiding variables that consume too much energy. Routing protocols addressing energy balance, routing protocols addressing energy depletion, routing protocols avoiding the void hole, and routing protocols containing mobile sink are among the relevant efforts. The following is a brief discussion:

2.1. Energy Balancing Routing Protocols

In this part, many authors have proposed routing protocols which mainly focus on energy balancing; and ultimately they all are designed in a way to achieve maximum network life. Relay node selection in EBET is based on optimum distance, whereas number of hops reduction in EEBET is based on a depth threshold. Both methods avoid using direct transmission to balance energy usage in rings, whereas EEBET does so across the whole network. Similarly, in [8,] the uneven energy consumption in deep undersea is found, and this issue is overcome by adding automotive underwater vehicles (AUVs). AUVs collect data from all of the overburdened deep-sea networks. Furthermore, when significant data is present, this protocol switches the layers. The latency is decreased by using AUVs to receive data fast from the closer nodes. As a result, both far away nodes and closer nodes in the network have balanced energy consumption, resulting in maximum network lifespan and maximum data received at the end of the network lifetime. The routing in [9] is designed to avoid UASN energy holes. As a result, the authors employ a distributed technique to balance a network's total load. As a result, all nodes are limited to continually transmitting created data inside their *Trange.* Furthermore, forwarding policy calculates the load weight of forwarder nodes and chooses the one that uses the least amount of energy. Routing protocol contributes to balanced energy usage by employing this balancing strategy. As a result, it deals with the energy gap and extends the network's life. In [10], the authors present a balanced energy transmission mechanism in which each node adjusts its transmission mode based on its energy level. In this approach, the network's energy consumption is balanced. The balanced adaptive routing protocol (BEAR) is a location-based protocol introduced by the authors in [11]. It is a routing mechanism that is based on location. The BEAR uses location information to identify the forwarder nodes in multi-hop communication. The cost function is then used to find the successor and facilitator nodes among forwarder nodes. To balance energy usage, one of the successor and facilitator nodes with the highest relative residual energy is chosen for transmission. This balanced approach aids in the effective transmission of data packets to the base station, as well as achieving a maximum network lifespan of up to 55 percent longer than base protocols while using the least amount of residual energy. The authors of [12] offer a method for extending the network lifetime in UASNs by dealing with the limits of energy hole and uneven energy consumption. As a result, the authors offer two protocols: an EBCHA (balanced energy consumption and hole alleviation) and an EBCHA (energy-aware) (EA-EBCHA). The first protocol balances the network's imbalanced load distribution, whereas the second protocol focuses on maximizing throughput with the least amount of energy depletion. Both protocols were effective in delivering greater packet delivery ratios, longer network lifetimes, and energy usage that was balanced. However, the additional delay is the price paid for this success.

Similarly, in [13], the attained parameter is balanced energy consumption per node, which is the major cause for the network's longer lifetime. Similarly, the authors of [14] seek to improve network longevity by adding various drains into the network. Furthermore, in [15], more energy is allotted to nearby base station nodes than to the furthest nodes for balanced energy use across the network. In [16], author presents an optimum multimodal routing protocol (OMR). Radio waves and acoustic waves are mixed in this protocol to enable equitable access to all nodes.

2.2 Energy Depletion Routing Protocols

In this part, we'll look at different routing techniques that make the most of the little energy available to underwater nodes. The authors of [17] propose to characterize geographic multipath routing for UASNs based on geographical division in duty cycle. This routing technique divides the whole network into three-dimensional tiny cubes. During the data transmission phase, greedy geographic forwarding based on geospatial division (GGFGD) method is used to efficiently choose relative tiny cubes of source nodes. Then, using geographic forwarding based on geographical division, a forwarder node in that particular cube (target cube) is chosen (GFGD).Finally, the target cube sends the data packet to the sink as a group. Both approaches aid in the discovery of the best packet forwarding paths. As a result, this routing protocol achieves the shortest end-to-end delay while using the least amount of energy. In addition, a duty cycled process is used, in which a group of nodes worked to save energy by switching to sleep mode among themselves.

The geographical routing technique known as relative distance based forwarding (RDBF) for UASNs is presented by the authors in [18]. The fitness function is used by RDBF to compute the degree of a node. This function selects the most dependable successor nodes in the network and limits the number of nodes engaged in the routing in this way. The network's energy usage has been lowered as a result of this limitation. In [19], the authors suggested an energy-efficient and interference-aware routing system for UASNs called EEIAR. The major goal of this project is to increase throughput while reducing packet loss by avoiding the interference path. The forwarder node in UASNs is in charge of successfully delivering data packets to the sink. As a result, this study presents a method for choosing a forwarder node. The minimal depth and least number of neighbor nodes are used to choose an acceptable forwarder node. As a result, this method uses a minimal number of nodes in the routing process, which helps to reduce interference when forwarding packets to the sink. As a result, this technique prevents packet collision and loss.

The AUV-based data distribution protocol (ADDP) for Ad hoc UASNs is proposed by the authors in [20]. The movement of the AUVs is controlled by a unique feature of ADDP. The results reveal that ADDP has a greater throughput, lower overhead, and lower network energy usage. The AUVs assisted effect data gathering (AEDG) in [21] is another routing strategy for trustworthy data transmission. AUVs and gateways collaborated in AEDG to extend the network's lifespan. Similarly, the authors of [22] show how to collect data efficiently in the field by exploiting sink mobility. The designers of this routing system include AUVs, courier nodes (CNs), and master nodes (MSs) in the network to maximize network longevity while minimizing energy use. Similarly, writers in [23] include AUVs into the network to reduce packet loss and propagation latency in the network. As a result, a hierarchical idea is used for large-scale networks, which improves performance to some extent. Similarly, the authors of [39] suggest an AUV-aided routing strategy (AURP). Multiple AUVs are deployed in the network under this protocol. These AUVs collected data from all of the sensor nodes before transmitting it to the sink. The network's throughput is maximized because to AURP's efficient energy usage. Similarly, the authors of [24] present an energy-efficient routing protocol in UASNs that takes into account the distance-dependent collision probability and residual energy of each node (DRP).This protocol detects transmission collisions caused by differing transmission distances, as these collisions have a detrimental influence on a network's lifetime. As a result, the authors recommend picking a route with a high transmission rate and the least amount of leftover energy. DRP delivers a longer network lifetime in this fashion, which is supported by theoretical study. Lower latency, maximum throughput, and network longevity are among DRP's accomplishments.

In [25], the authors offer an energy-efficient grid routing system based on 3D cubes (EGRCs). ERGCs are a data transmission mechanism for complicated environmental monitoring in UASNs that is both energy-efficient and dependable. The largest residual energy and sensor node localization (minimum distance to sink) are used to choose appropriate cluster heads in this procedure. The purpose of [26] is to reduce energy usage, improve dependability, and lower communication costs. To organize the transmission power and regulate the data rate over the whole network, a unique layered multi-path power control (LMPC) approach was utilized, which took into account noise attenuation in deep water. Present the selection of transmission range (OSTR) for UASNs in [27]. The nodes in this network are distributed at random. The network employs an adaptive transmission power approach across all nodes to meet the aim of efficient energy use or lowest energy consumption.

Optimizing the number of hops and retransmissions in multi-hop communication for efficient energy use is discussed in [28]. It saves energy in a variety of different situations, as well as in modest retransmission experiments. The writers of this work examined and investigated how much energy is necessary for multi-hop transmissions to transmit data properly. The number of hops to use, retransmissions, coding rate, and signal-to-noise ratio are all taken into account. This approach uses the least amount of energy while having a longer end-to-end latency. [29] presents a complex network method to the topology control problem in UASNs. Coverage, connection, optimum energy use, and as little propagation delay as feasible are the goals of this project. In a 3D environment, a scale-free model is used. To construct a double clustering structure, a topology control method based on complex network theory (TCSCN) is employed to pick cluster heads. The scheme is incompatible with self-adaptive solutions such as transmission rate. Yan et al. [30] propose a routing technique based on depth for efficient energy use in UASNs. If a node's depth is smaller than the depth of the previous relay node, it is designated as a forwarder node in this protocol. The multi path free error correction (M-FEC) technique, based on Hamming Code, was presented by the authors in [31], which improves network dependability while reducing energy usage. The Markovian model is used to reduce the frequency of packet errors and the amount of hop counts. However, with Hamming code, encoding at the source and decoding at the destination increased network latency. Wu et al. offer the time synchronize routing protocol in [32], which allows for easy network creation and node conflict minimization. As a result, the TSR algorithm (time slot based routing) was created. This technique reduces network repetition while avoiding bit error rates. Finally, it produces a consequence of reduced energy depletion and increased network longevity.

In the threshold optimized depth based routing (iAMCTD) protocol, Javaid et al. presented better adaptive mobility of courier nodes [33]. For time-sensitive applications, it is a reactive, localization-free, flooding-based routing system. The forwarding functions (FFs) are calculated by iAMCTD to maximize network lifespan and transmission loss. This protocol also employs the usage of ideal courier nodes to enhance the quantity of packets in networks received while reducing network latency. Furthermore, eligible forwarders nodes are chosen based on depth-based criteria.

In [34], Yang et al. offer a multi-path routing strategy for directional antenna underwater ad hoc networks (UMDR). The entire network region is separated into distinct segments in this protocol. Through direct antenna, each node from its own segment communicates with the others. This approach has the benefit of consuming less energy and overcoming interference. Without the use of broadcasting, the data sent to the destination is transmitted directly. Direct data distribution reduces network latency by reducing end-to-end delays. However, each forwarder node requires a direct antenna calculation each time. The network's overhead rose as a result of this estimate.

In [35], vector based forwarding (VBF) creates a vector for forwarder nodes to use while transmitting data packets. A vector was constructed by the source node's distance from the destination. The source node then chooses those nodes in the vector that are forwarders. Data packets are sent to their destination in this manner. Modify the VBF using topology control VBF (TC-VBF) for dense networks in [36]. Similarly, in [37], a routing scheme based on received signal strength (RRSS). The received signal intensity is used by RRSS to choose a forwarder node inside the vector. As a result, it consumes the least amount of energy; yet, the nodes within the vector quickly exhaust their energies due to the severe stress placed on them. In [38], Li et al. propose a data collecting depth-based routing aware MAC approach (DBR-MAC). A forwarder node is chosen in this protocol based on three metrics: low depth, angle, and overhead. This selection criterion typically chooses nodes that are closer to the sink, resulting in network hotspots. This hotspot node creates a void in the network and raises the packet loss rate. Similarly, in [39], a message distribution technique in storage-limited

(MDA-SL) routing protocol is suited for maximizing throughput. A forwarder node in MDA-SL is chosen based on its high mobility and maximum residual energy. As a result of the network's constant selection of that particular forwarder node, that node dies quickly, causing the void hole problem. Zhou et al. propose a greedy and localization-free routing system in [40]. In the internet of underwater things, an energy-efficient routing protocol for UASNs. The forwarder nodes in this protocol are chosen hop by hop and when the network is steady. The routing protocol concludes with a longer delay while it waits for a stable network. Authors in [41], [42], and [43] introduce two MSs in a network to achieve balanced energy usage. By travelling on a random and preset circular course, these MSs gather data from all nodes on a regular basis. Walayat et al. in [44] include two MSs for the distant nodes in addition to these protocols. To obtain data, these sinks follow a predetermined linear course. As a result, the achievement in the form of fewer packets lost over the network.

2.3 Mobile Sink Routing Protocols

Because nodes in an underwater environment change location owing to the water current, we addressed some of the existing routing methods that use the movable sink in this part, which are listed below: In [45], the Mobicast routing protocol (MR) addressed the void hole problem. A MS is used in MR to travel along predetermined routes. This MS gathers data from all sensor nodes, effectively covering the whole network field. Four techniques for efficient energy usage in TSNs were described in [46]. BEENISH is a balanced energy efficient network with a highly heterogeneous routing protocol. Different energy levels of nodes are examined in BEENISH, and the cluster head is chosen based on the average energy levels. To extend the network's lifetime, improved-BEENISH (iBEENISH) is created with a dynamically nominated cluster head. A mobile sink is implemented in both the aforementioned routing protocols, MBEENISH and iMBEENISH, to maximize the amount of packets received across the network and increase the network stability period. In addition, the authors present a cluster and a mobile sink approach for minimizing energy usage and increasing throughput in [47] and [48]. The balanced transmissions based trajectories of mobile sink in homogeneous TSNs is another routing protocol developed for this approach of mobile sink. The architects of the [49] routing protocol focus on maximizing network lifespan while minimizing route loss and end-to-end latency. As a result, the authors utilize an MS that gets data from both random and static locations. [50] Presents an energy scaled and extended vector-based forwarding method with sink mobility (ESEVBF) that is ideal for low-energy and delay-sensitive networks. The ability to pick minimal and eligible forwarder nodes for transmission is greatly aided by the growth of holding time. Forwarding nodes are usually helpful in balancing the network's energy consumption and depletion.As previously stated, the fundamental reason for maximizing of network lifespan is balanced energy utilization in routing protocols [21], [23], [24], [25], [26], [27], [28], [29], [30], and [31]. In order to avoid energy waste and balance energy consumption, we applied certain ways to bypass neighboring and neighbor nodes. Furthermore, as shown in [11], [12], [13], [15], [16], [17], and [18], this method is both energy efficient and lifetime-aware. As a result, we include it in protocols.

In [51], the author proposes a cluster-based routing mechanism. Routing protocol nodes act as initiator nodes, deciding which CHs to use. The CHs are very active and have a lot of energy. Other nodes, however, are still dozing off. To ensure dependable data delivery, the CH selection continues transmission to the sink node. The suggested methodology reduces EC while improving PDR and network longevity. When you choose the same CH over and over again, though, network performance suffers.

[52] Proposes a multilayer network-based irregular-clustering technique. The authors conducted a theoretical study first to determine the anticipated value of nodes and the distribution density of each layer inside the UWSN. The network is then split up into irregular clusters. The authors employed a recovery technique to balance the EC in the clusters in this study. As a result, PDR is improved, and EC is reduced, resulting in increased network lifespan. In UWSN, however, irregular clustering causes change.

For heterogeneous WSNs, [53] proposes an Enhanced Developed Distributed Energy Efficient Clustering (EDDEEC). The authors suggest two EC-minimization models in this paper. The first is the EC model, while the second is the heterogeneous network model. Following that, the authors suggested a cluster-based routing system. The authors attempted to adjust the likelihood of CH selection competently in the suggested method. The authors enhanced their performance in terms of stability period, network lifespan, and PDR in this paper. The clustering, however, is unbalanced, and reelection adds to the expense.

The protocol [54] proposes a cluster-based routing scheme. Dijkstra and breadth-first search routing techniques are used to elect CHs in this paper. All cluster members deliver their data to their respective CHs under both suggested routing methods. As a consequence, information is sent to the appropriate sink. With the use of high energy, the network's PDR is enhanced.

An energy-efficient routing system based on clusters is suggested in [55]. Using an event-driven energy-efficient routing, the proposed routing strategy extends the network lifespan. The proposed protocol determines the shortest way for transmitting the DPs while maintaining consistent EC. The network's PDR improves as a result of this. Layering and cluster-based routing protocols are suggested in [56] to balance the EC and extend network lifespan. However, no mention is made of the EC on collision overhead.

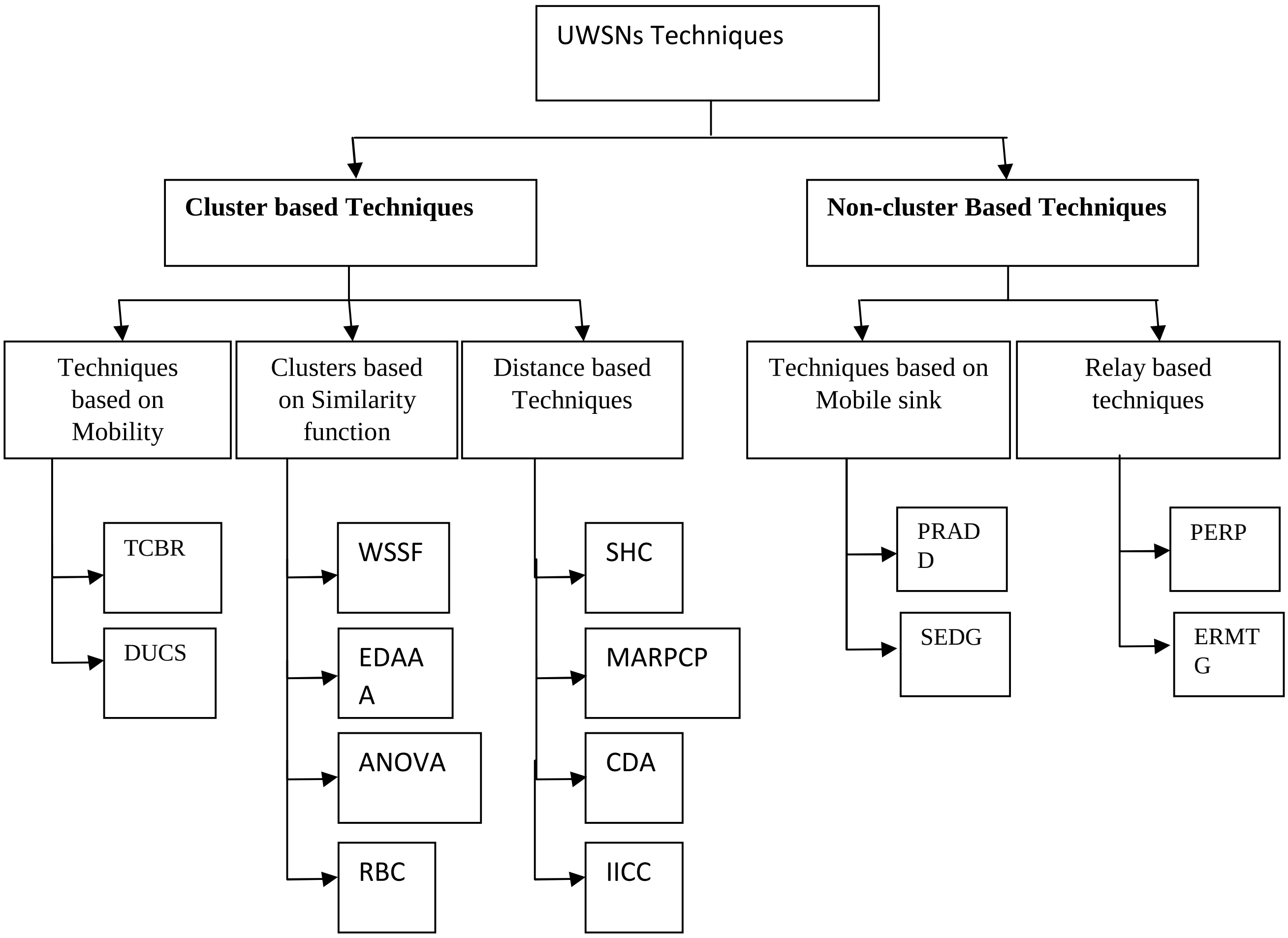


Figure 2.1: UWSN Routing Techniques to maximize network lifespan

2.4 Limitations

Some of the primary discovered limitations after doing an in-depth literature study include:

1. Cluster formation in most protocols is irregular, resulting in energy waste and a high packet loss rate.
2. Overhead rises as a result of imbalance grouping, structural changes, and re-election.
3. As the literature study demonstrates when packet forwarding mechanisms are developed and network lifespan is increased, the issue of longer routing paths and increased energy consumption arises.
4. In compared to terrestrial networks, energy consumption in underwater networks is not a major concern; nonetheless, certain traditional methods of battery charging have limits.

Chapter 3: Methodology

This chapter provides a detailed explanation of the proposed methodology used for this research. Two cluster formation techniques are utilized; skipping of fast moving node and skipping of close neighbor node. The chapter is divided into two sections; the first section provides the working of existing LEACH algorithm and the second section includes the adopted proposed smart clustering methodology to prolong network lifespan.

3.1. LEACH Algorithm Description

LEACH follow dynamic clustering algorithm and it means selection of cluster heads rotates among all nodes randomly for the sake of equal energy distribution among all the sensor nodes. Each of the node have same probability to get selected for cluster head. In the start of each iteration new cluster heads are been chosen. In broad perspective working of LEACH protocol is based on iterations and each iteration have two phases: Set-up phase, is the initial phase to select cluster heads and form clusters around them; Steady-state phase, is the second phase in which data is being collected and passed to sink node.

In the initial phase, a "P" percentage is considered to start the procedure of cluster head selection and its is the percentage which decides number of cluster heads in one iteration. During the selection process every node is denoted by "i" and its value is less than 1 and greater than 0. For example, the threshold T(i) is greater than the number, role of CH will be assigned to that node for that specific iteration. Soon quickly after the selection of CHs, the selected CH will broadcast a message to neighbor nodes about its role as CH, neighbor nodes will choose to join the closest CH.

In second phase, all the members of a CH will collect and pass the data to CH, which further transmit the data to sink node after aggregation. Time Division Multiple Access (TDMA) is used to avoid collisions during the transmissions. LEACH makes use of TDMA and allocates frames to each transmission. After the successful transmission nodes participated in transmission will go to idle state and wait for next frame allocation.

Every sensor which is being used in UWSN environment consumes power when transmitting, receiving and processing some data. Processing of data consumes less energy as compare to consumption of energy in used in communication.

3.1.1 Detailed Functioning

As mentioned above "P" is the percentage for number of clusters in a network at an instant "t". LEACH is based on rounds/iterations which made of 1/p rounds.

Each round "r" is organized as follows:

1) Each node "i":
   a. computes the threshold T(i) such as:

$$1.\quad T(i) = \begin{cases} \dfrac{p}{1-p*(r \bmod 1/p)} & \text{if i has not elected as CH yet} \\ 0 & \text{if i has elected as CH earlier} \end{cases}$$

   b. chooses a pseudo-random number $0 \le xi \le 1$.
   c. If $xi \le T(i)$ then "i" designates itself as a CH for the current round. T(i) is computed in such as every node becomes CH once in every cycle of 1/p rounds we have T(i) = 1, when r = 1/p - 1.

2) The selected CH sends a broadcast message to neighbors in order to inform them about its role as CH and it make use of CSMA MAC.
3) After receiving the broadcast message all nodes choose nearest suitable CH on the basis of signal strength. Then, all nodes will reply with the information of their cluster ID and CH ID. Reply message will use the same CSMA MAC as it was initially used to send the message.
4) All CHs make efficient use of TDMA to avoid the collision within clusters and make a schedule of all the expected transmissions by nodes of a cluster and assign their respective time slots to each node member of the cluster.
5) Cluster Heads are always expecting transmissions from its members. Every node waits for its slot to make the transmission else it remains in sleep mode and save their energy.
6) Aggregation functions are being performed at CH level after receiving data and data will be compressed too before passing it to sink. The transmission between CH and sink node could be direct transmission if sink node is in range, else multi-hop transmission will be made in which some nodes act like relay nodes.

7) Last two steps will continue moving till last round.

3.2. Proposed Approach

In this section, the detail of our proposed routing scheme is discussed.

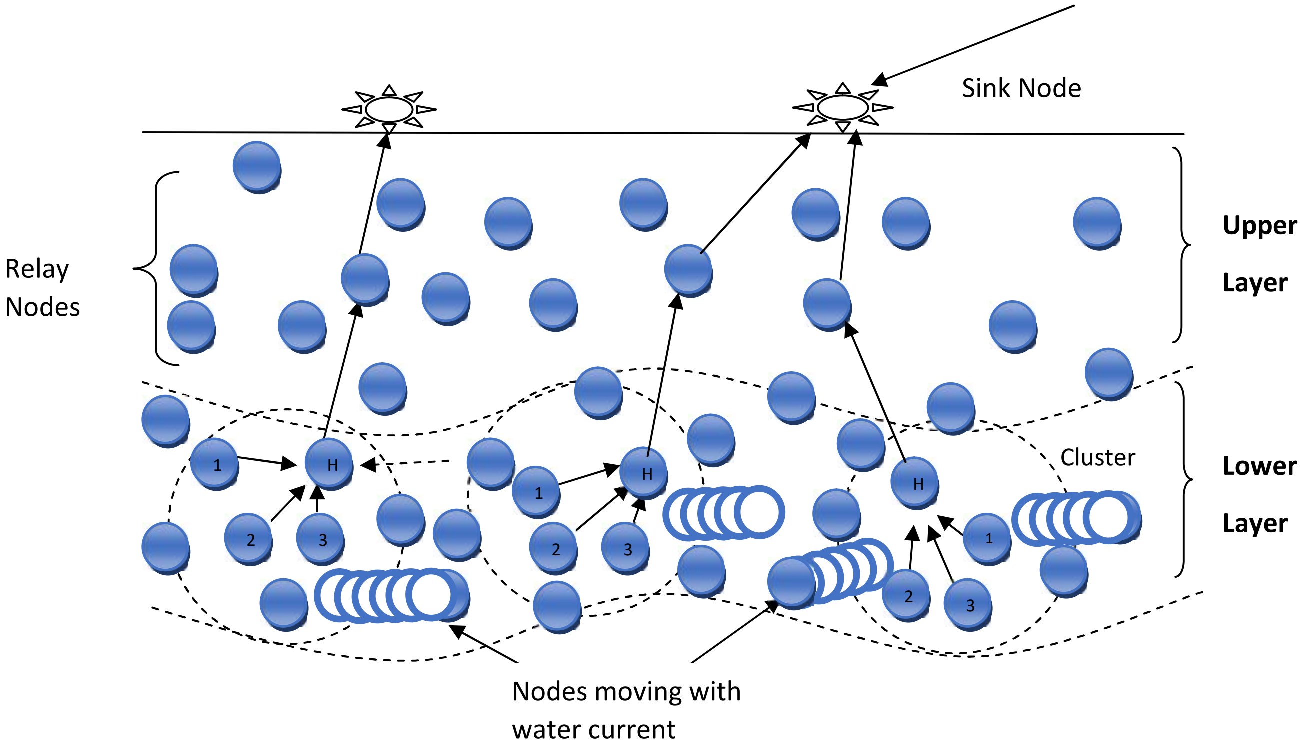


Figure 2: Proposed Scheme Architecture

3.2.1 Network Architecture

As was already indicated, we are using the RBC protocol and assuming that the nodes are placed in three dimensions. All sink node sensors placed at the water's surface are outfitted with acoustic modems to transmit data to on-shore stations and radio antenna to receive data from underwater sensors. Two different types of modems for optical and audio communication are also included with underwater sensor nodes placed in three dimensions. Each of them has the potential to serve as a data source or relay node that sends data to a sink node. All sink nodes can effectively communicate with one another and with base stations on the ground by using radio antennae. Furthermore, in our situation, it is assumed that every sensor that has been put underwater has a depth sensor and can determine its precise depth from the sink node above the sea. We have separated the network into two layers: the bottom layer is used to organize data sources into clusters, and the upper layer is used to select the best forwarders for sending data to sink nodes. Each sensor's residual energy level is continually changing.

3.2.2 Depth Threshold

We'll adhere to the depth barrier set forth by Depth Based Routing (DBR). To discover the relay or forwarding nodes, we first set the depth threshold (dth) option, which was introduced in [30]. Any node will only choose the subsequent node as the forwarder if the distance between the two hops exceeds the threshold value. Residual energy will be the determining factor if the resulting value is equal to the threshold.

3.2.3 Cluster Formation

Our network is divided into clusters, which are discrete, non-overlapping groups of nodes. Only one cluster head (CH) and a certain number of cluster nodes are permitted in each cluster. To steady and fine-tune a large network, clustering technology is applied. To communicate both within and across clusters, each node has two different types of modems installed. Source nodes are those nodes in a cluster that actually gather data and communicate it to their respective CHs, which then broadcast it to sink nodes on the surface.In the suggested technique, we use the RBC model to recreate clusters whenever the network changes. We have created an algorithm to choose the cluster head in order to establish a cluster formation. The full cluster will be formed by the algorithm. Increased data redundancy and energy consumption are caused by high data rate transmission from source nodes. We are employing data aggregation techniques on the CH level to lower the bulk of the data that needs to be delivered to the sink node and ultimately to base stations on the ground in order to address these problems. These methods are frequently used in conjunction with routing protocols to assist energy conservation, decrease delay rates and data redundancy etc. Because aggregation procedures are carried out at the CH level, CH should be the strongest node and the nearest to the sink node. A CH is in charge of gathering data, doing aggregation, and then transmitting the data to the sink node. All of these procedures use a lot of energy, and a node's chances of getting chosen for CH again in the second round are extremely slim if it serves as CH once in the first round. To choose CH, we are taking into account the following two fundamental criteria:

1. Choose a node within a cluster that has the least depth of all the nodes.
2. Evaluate each node's remaining energy, and if many nodes share the same energy level, evaluate the deepness of those nodes.

The algorithms described below demonstrate the cluster creation process.

***Algorithm 1* - Cluster Formation**

S_n *: Sensor Node;* ***CH****: Cluster Head;*

```
for each S_n
        create an empty cluster C_k
        for (m=1; m<CH; m++)
        CH broadcast cluster join message to S_n
        End for
        for (m=1; m<=num; m++)
        Distance cost = sensor node to CH distance + distance from CH to sink;
                If (distance cost < previous distance cost)
                S_i join with CH by sending reply message
                End if
        End for
End
return formed clusters
```

Algorithm 2 - *Cluster Head Selection*

Node = N_i; Cluster = C_k; Depth = D

```
for each S_n
        create an empty cluster C_k
        N_i is the first node member of C_k
        for each N_i
                find depth and residual energy of N_i
                If (D_ij> within threshold area)
                        N_i is a member of C_k
                end if
        end for
end for
return no of CHs
```

3.2.3.1 Skipping Nodes

When a cluster is forming, our algorithm is set up to skip any inappropriate nodes. In the first phase, we defined a threshold distance D_{th} between any two cluster nodes. If any two nodes got near enough to one other and the distance decreased to less than the threshold, we would have to skip one node. We have taken into account the following factors while deciding whether to add or skip a node in a cluster.

1. There should be no nodes within D_{th} of the threshold distance.
2. If a second node exists with that particular range, It should have more remaining energy than that node.
3. The node's movement shouldn't exceed the threshold speed S_{th}.

Algorithm 3 - Skipping Nodes during Cluster Formation

Node=N_i; Cluster=C_k; Distance=D Residual Energy = E_R ; Threshold Distance= D_{th}

for each S_n
create an empty cluster C_k
S_i *is the first node member of* C_k
for each N_i
Measure distance D from N_i *to* N_{i+1} *and*N_i *to* N_{i-1}
if $(D_{i,i+1} > D_{th}$ && $D_{i,i+1} < D_{th})$
Compare residual energy E_R *of* N_i *to* N_{i+1} *and*N_i *to* N_{i-1}
if $(E_i > E_{i+1}$&& $E_i > E_{i-1})$
add N_i *to* C_k
else
skip N_{i+1}
end if
end if
end for
end for
return N_i *is suitable for* C_k *or Not*

3.2.4 Inter-Cluster and Intra-Cluster Communication

We will employ acoustic communication inside the cluster to convey data from the nodes to the cluster head because it is a low-energy approach used for underwater communication over short distances. In order to convey data from CH to sink node, using the optical approach, we shall apply similarity functions of aggregation. However, the optical approach uses more energy and is only suited for long distance communication. Because data must be sent over a great distance via optical technology, CH's energy will be depleted quickly.

3.1.6 Flow Chart

The flow diagram for our proposed strategy is shown in Figure 3. Nodes are initially distributed at random in three dimensions before being sunk onto the surface. The information of all deployed nodes will be obtained by sink nodes by broadcasting a control message. The depth information, remaining energy level, and movement speed of each node will be returned in response to that control message. Logically, the network is split into two layers: the source node layer is at the bottom and the higher layer is made up of relay nodes. To begin with, a few cluster heads in the lowest layer are chosen to create a cluster around. Initially when energy of all nodes is same, the nodes closer to sink node will be selected as CHs. In the next round energy of previously selected CHs will be decreased, so they have less chance to get selected as CH again. Again the energy of all the nodes will be compared and the nodes with higher energy level and closer to sink will be selected as CH. Hence this process will continue until required number of CHs got selected. After that cluster will be formed around each selected CH. Threshold distance between two adjacent nodes and Threshold speed of nodes is set to choose the best suitable nodes to form a cluster. If two adjacent nodes are closer than threshold distance; only one node with higher energy will be selected to form a cluster, second node will left idle to conserve energy for next round. Reason behind skipping closer node is they transmit redundant data which will be discarded later at aggregation level. Water current in UW environment cause movement of nodes; if any node is moving faster than the threshold speed it means that node will get out of transmission range from CH, so it will not be made part of cluster. Source nodes gather data and send it to the appropriate CH, which aggregates it and transmit the data to sink node. If sink node is not in the range of CH, it will find relay node/ forwarder from the upper layer to deliver the data to sink node. In the next round, process of CH selection and cluster formation is repeated. After each successful data transmission, energy level of CH, source node and relay node is decreased, and the idle nodes will have more chances to be selected in next round because their energy level is higher than the nodes performed in previous round.

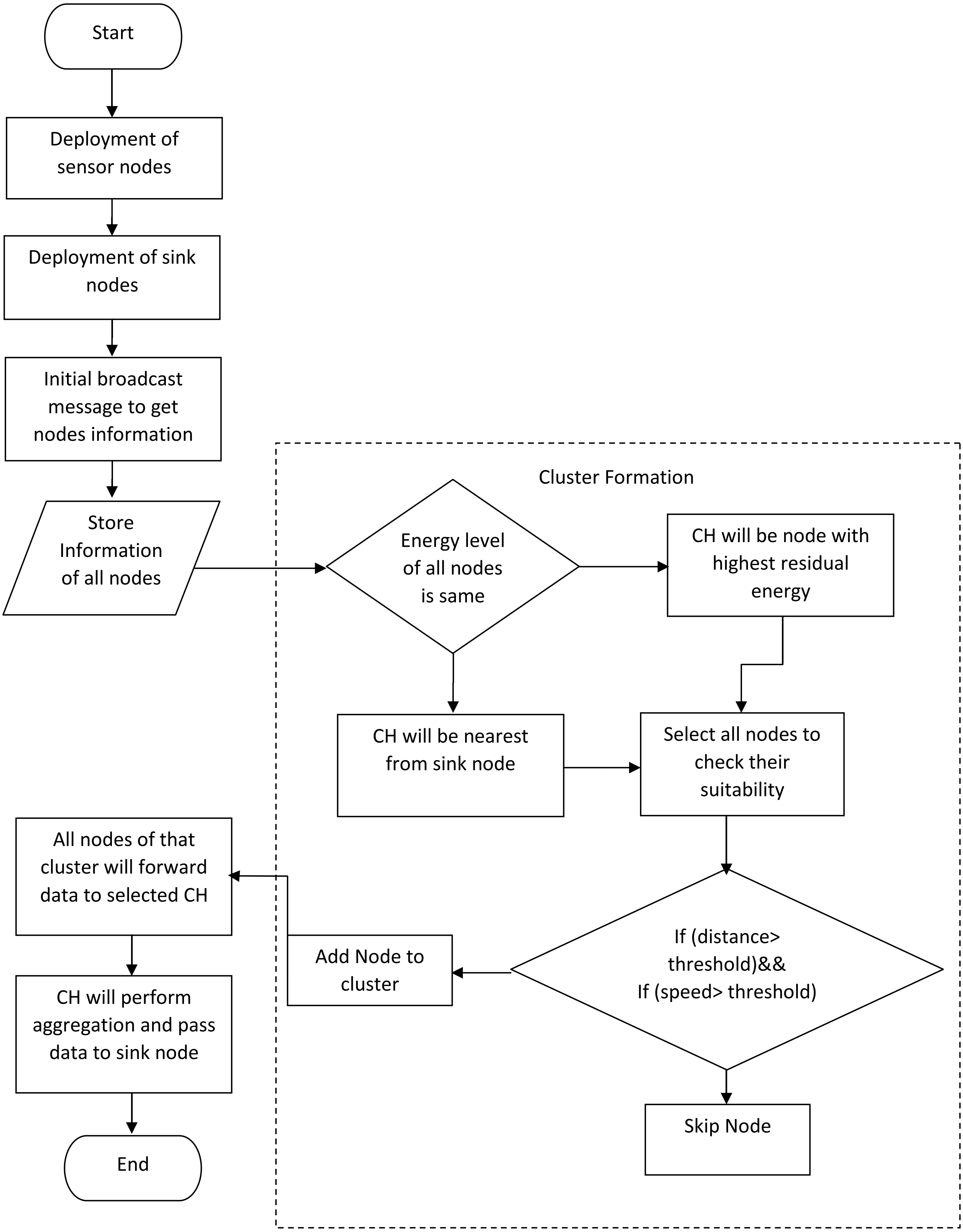


Figure 3: Flow Diagram of Proposed Scheme

3.2.4 Acoustic Energy Dissipation Model

The moment dilations and compressions passed by propagation acoustic waves are generated. Generally, this medium comes under properties of elastic propagation. An acoustic propagation model is proposed by Jurdak*et al.* [58] and derived the formulae in [57], [59]

$$SL = TL + 85$$

Transmission loss is denoted by TL and Source level is denoted by SL. All the parameters present in the equation are in *dB re* μ*Pa*, and value of 1μ*Pa* is equal to 0.67×10^{22} *Watts*=*cm*2. Signal shape directly affects the transmission loss. For Values of cylindrical shape signals is calculated by

$$TL = 10 \log d + C\alpha d \times 10^{3}$$

In this equation absorption coefficient is denoted by α and it is dependent on two things; Frequency and distance between sender and recipient.

3.1.2 Balanced Energy consumption

In [60] we can balance the energy dissipation within a cluster if and only if data incoming in a cluster is somehow balanced. Balanced Energy consumption for Cmcan be calculated by:

$$(a) = E(b) \; \forall a \epsilon Cj \forall b \epsilon Cj \; 1 < j \leq m$$

If:

$$E(a) = DT(a) * \varepsilon t(r) + MT(a) * \varepsilon t(rh) + R(a) * \varepsilon r$$

For any node a belonging to Cj, E is the total energy used, R is receiving energy by a in T rounds, $(a) * \varepsilon t(r)$ is the energy spent in DT, $MT(a) * \varepsilon t(rh)$ is the energy spent in MT and $R(a) * \varepsilon r$ is sum of energy dissipated while reception. In any zone, We can balance power usage if we can balance the incoming data.

3.1.5 Data Transmission

The particular frequency f is calculated by the Thorp's expression as,

$$(f) = 0.11f21 + f2 + 44f24100 + f2 + 0.003$$

If a node is within the $Ropt$ then, directly communicates with sink, else transfer the packet to the neighboring node. For example, The result of $Ropt$ is 250 meter after calculation. Up to 250m all nodes in network perform mixed transmission, after that performs the MT. No matter, if the pi generate the direct ratio.

3.4.1 Simulations Parameters

We have used MATLAB for simulations and to evaluate the efficiency of proposed protocol. The area supposed for transmission is 1500m^3 and each node can transmit up to 250m. To check the performance of proposed protocol in sparse and dense network sensor nodes varies from 50-200. Furthermore, detail of all parameters is added in Table 2.

Simulation Parameters	**Values**
Network volume	1500x1500x1500 (m3)
Transmission range of nodes	250 (m)
Nodes	50-200
V	1500 (m/s)
Data rate	16 (kbps)
Payload	100 (bytes)
Frequency	10 (kHz)
Idle power	0.01 (W)
Receiving power	0.1 (W)
Transmission power	2 (W)

Table 3: Simulation Parameters

Chapter 4: Results

This chapter provides seismic evaluation results obtained from MATLAB simulation.

4.1 Performance Metrics

1. ***Network lifetime:*** It is the life of a network or the duration in which network can perform transmissions. It starts from the start of the network, nodes continuously performing their jobs and draining out of energy according to their work load and it will last 5% nodes are active in the network. The nodes who can't participate in network process because of less energy are considered dead nodes.

2. ***Network End-to-End Delay:*** Its kind of delay which a packet takes to travel from source to destination.

3. ***Average energy consumption:*** It is average energy consumed by the network in one complete cycle when all nodes complete a transmission.

4.2. Performance Comparison

Table 4: Comparison of Network lifetime in LEACH and Proposed

Round (s)	LEACH	Proposed
5	90	90
10	65	88
15	24	87
20	9	80
25	2	27
30	2	4
35	2	0
40	2	0
45	0	0

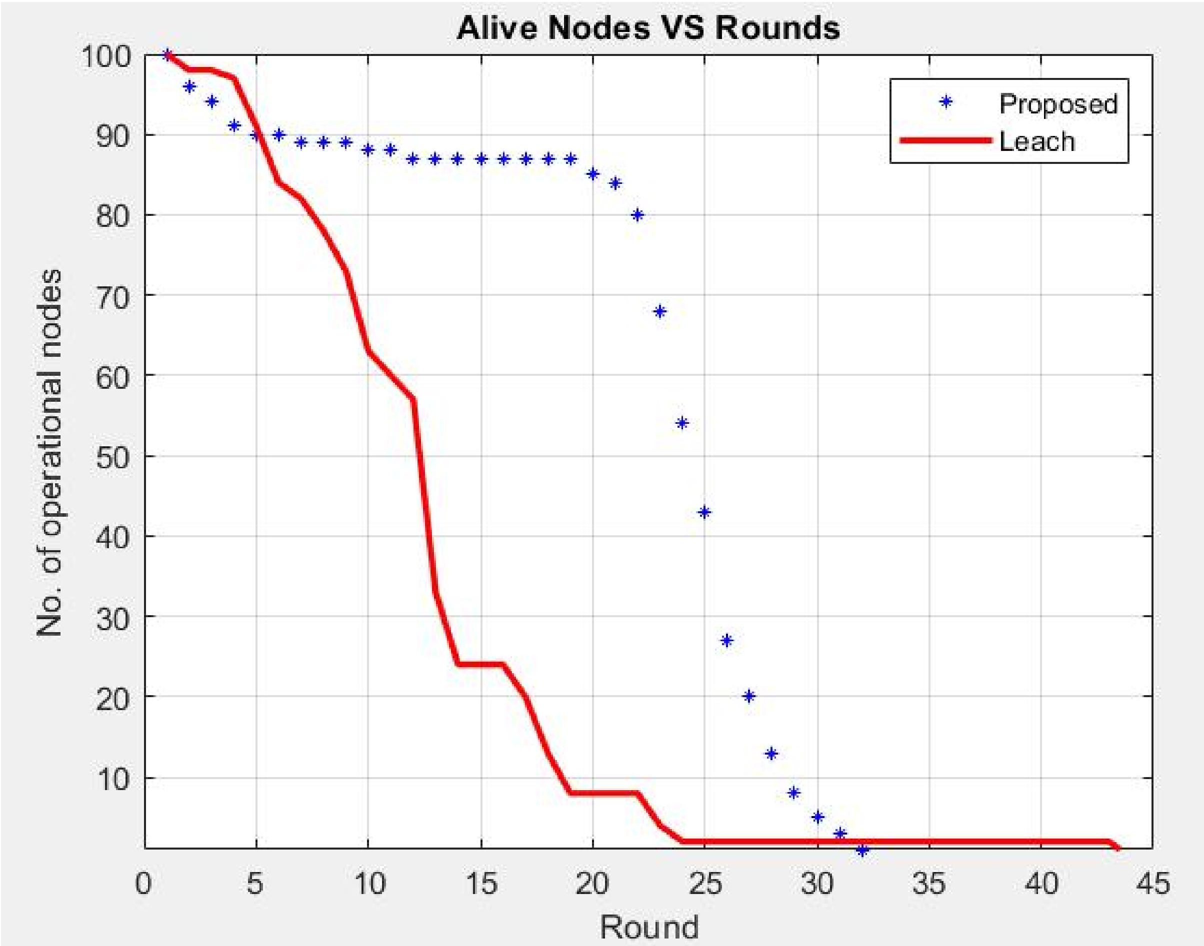


Figure 4: Network lifetime in LEACH and Proposed

Figure 4 have shown the comparison graph for existing LEACH protocol and proposed smart clustering approach with respect to network lifetime. The two major advancement in the smart clustering approach are; (1) skipping unsuitable nodes (i.e fast moving & very close neighbor nodes) and conserve their energy (2) not reforming clusters after each iteration. Clusters will be reformed once residual energy of CHs goes below 50% and in the next reformation skipped/idle nodes may become suitable to be part of clusters because of variation in their moving velocity.

Table 5: Comparison of end-to-end delay (sec)

Round (s)	LEACH	Proposed
5	0.8	1.5
10	0.7	0.3
15	0.8	0.4
20	0.8	0.3
25	1	0.2
30	0.9	0.1
35	0	0

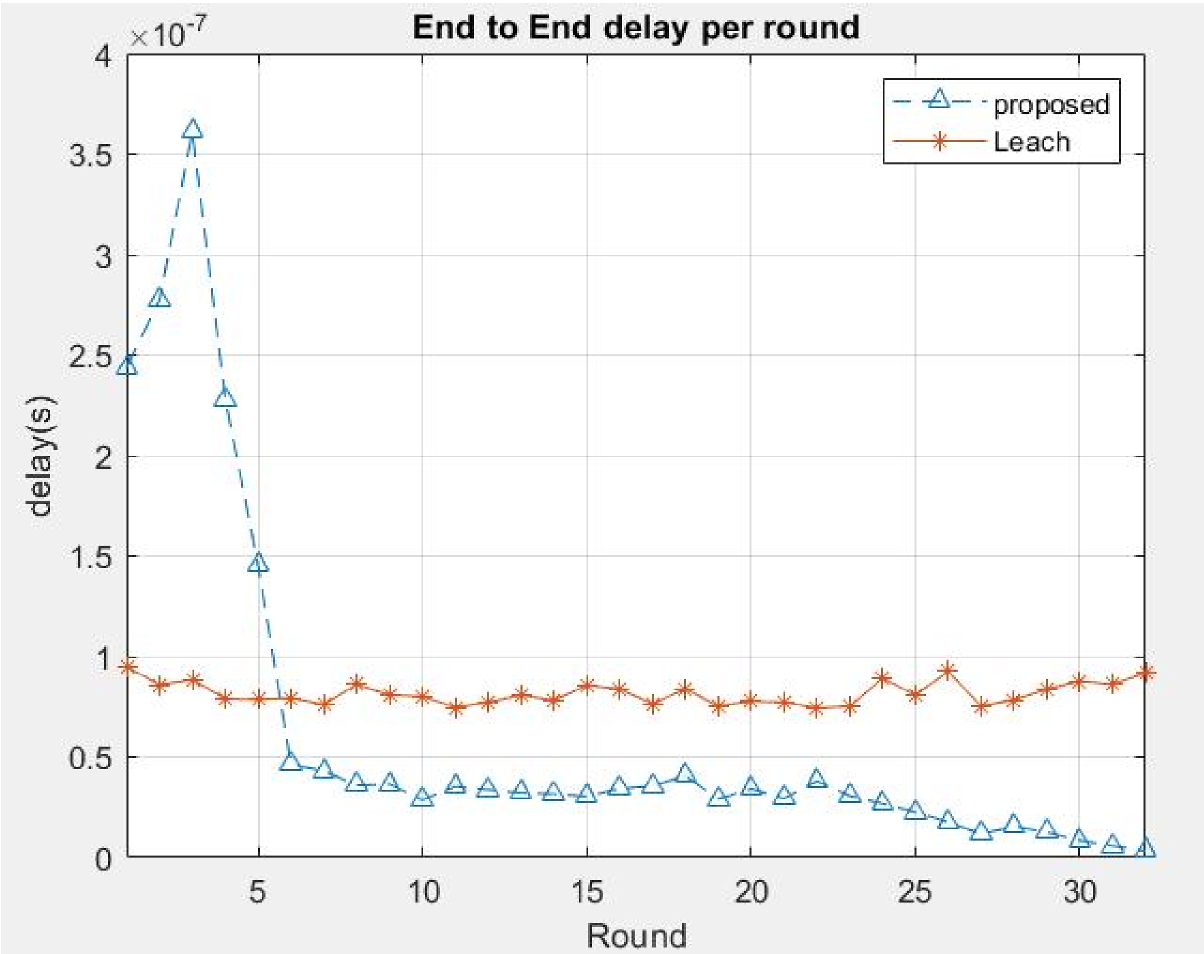


Figure 5: End-to-end delay in LEACH and Proposed

Table 5 shows comparison of LEACH with proposed with respect to end-to-end delay. In LEACH, nodes with low depth drained out quickly in comparison to all the other nodes having more depth level because the nodes with low depth are transmitting data and sometimes being selected as data forwarder. Figure 5showing end-to-end delay in LEACH and Proposed Scheme. Proposed Scheme have lower delay than LEACH protocol despite of increased traffic. The nodes with lower depth level are not required to transmit data directly to sink node which consumes more energy; they just pass the data to their respective CHs and conserve energy.

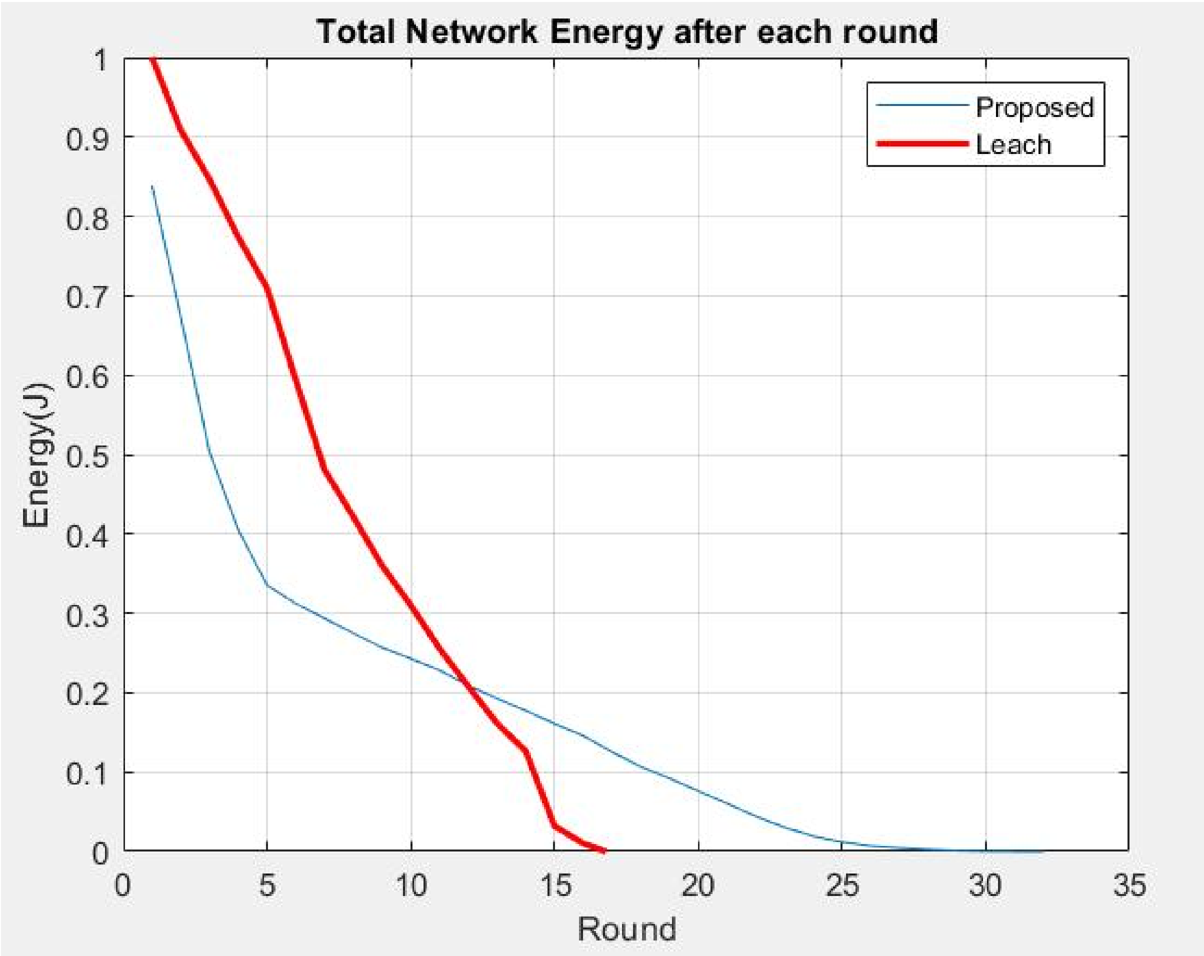


Figure 6: Average energy consumption in LEACH and Proposed

Table 6: Comparison of average energy consumption (joule)

Round (s)	LEACH	Proposed
5	0.8	0.5
10	0.5	0.4
15	0.3	0.3
20	0	0.2
25	0	0.1

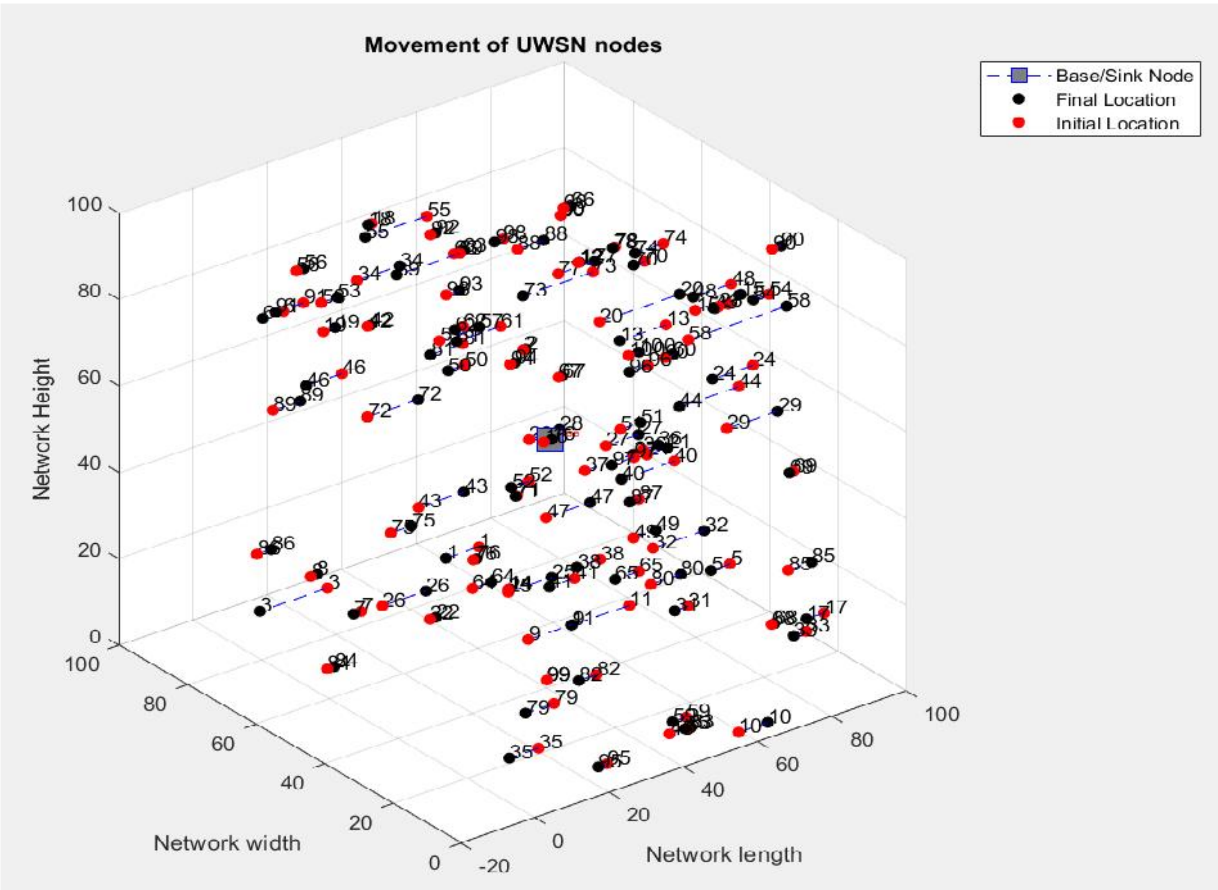
Table 6 shows the comparison of average energy consumption of network. Total energy is assumed 1J and after completion of first 5 rounds, LEACH network consumes 0.2J and proposed approach consumes 0.5J. After 15 rounds both networks have consumed 0.7J and left with only 0.3J. The network which was following LEACH protocol completely drained out after 20rounds but the proposed network was still alive till 30rounds.

Fig. 6 depicts the comparison of both approaches. In Smart Clustering approach, wastage of energy is controlled and prolongs network lifespan. Only the involved nodes are active rest all are in idle mode and conserve energy for next utilization. Cluster Heads consumes more energy because they receive data from cluster members and make aggregation functions and then pass the data over long distance to sink node. In LEACH the network drained out completely after 20rounds but in smart clustering approach network lasts till 30rounds.

4.3. Nodes Movement

During the entire life of network all nodes changed their locations with water current. In figure, 7we can see the initial and final position of each node denoted by red and black dots respectively. Not every node needs to change their position equally. The speed of movement for every node will be different from its neighbor nodes. The node N_{29} traveled more as compare to $N_{86.}$

Figure 7: Nodes Movement with Water Current



Chapter 5: Discussion

UWSN is being considered a sub-domain of Wireless Sensors Networks in which monitoring of underwater happenings are performed. In comparison to terrestrial networks nodes in UWSN are deployed in 2-Dimensions or 3-Dimensions.Secondly, radio signals are not appropriate for underwater communication due to their high attenuation. Acoustic signals are used for communication purpose. One of the major challenges which are being faced by networks in underwater averment is water current. It affects bandwidth of acoustic communication and networks are to be composed again and again which cause a new challenge of energy consumption. In contrast with WSN, recharging of sensors batteries in UWSN is not possible using traditional mechanisms which results in early death of sensors and ultimately the entire network. Many protocols are proposed in the past to reduce consumption of energy in UWSNs in order to deal with challenge. The LEACH (Low Energy Adaptive Clustering Hierarchy)is one of those protocols which efficiently make use of limited energy and prolongs network lifespan. LEACH protocol works in rounds and each round have two phases; setup phase and transmission phase. In setup phase of ach round old clusters are destroyed and new clusters are formed which balance energy consumption of all nodes but consumes extra energy in repeating the cluster formation process. In smart clustering approach we are not forming clusters in each round, we continue with same formation of previous round until energy of CH goes below 50%. Skipping nodes during the cluster formation found helpful to avoid wastage of energy in redundant data transmission. It is proved from simulation results that proposed smart clustering approach save more energy in comparison to actual LEACH protocol and increased network life.

Chapter 6: Conclusion

In our research we have devised a smart approach to form clusters which ultimately make protocols more energy efficient and maximize a network lifespan. Before we formed the clusters, we assessed the nodes' rates of movement. In cluster formation, we considered three key node parameters: node residual energy, current movement speed, and length from neighbor nodes. We have established a threshold speed for nodes moving quickly as well as a threshold distance from neighboring nodes. Any node that is sufficiently near to its neighbors to reduce their distance to a threshold will be skipped from the cluster. If a node is travelling quick enough and has passed the speed barrier, it is not deemed appropriate for cluster formation in the case of fast-moving nodes. In this thesis, simulation results shows that our proposed smart clustering scheme can prolong network life span by balancing energy dissipation.

6.1 Future Work

In future, I will explore and implement this smart clustering approach with some other clustering based routing protocols to improve their efficiencies. Presently, I have enhanced the efficiency of basic LEACH protocol by using smart clustering approach which is taking the movement of nodes into account and made the protocol learn about the suitable and unsuitable sensor nodes. Further research may be carried out on how we can have maximum benefit from understanding behavior of sensor nodes in underwater environment to counter rest of the challenges which UWSN face.

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