ENERGY EFFICIENT ADAPTIVE ROUTING MECHANISM FOR WIRELESS SENSOR NETWORK

BY

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in partial fulfilment of the requirement for the degree of MS(EE)

CERTIFICATE

We accept the work contained in this report as a confirmation to the required standard for the partial fulfilment of the degree of MS (EE).

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Head of Department	Supervisor
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Internal Examiner	External Examiner

DEDICATION

This thesis is dedicated to my wonderful parents and family who have been always a great source of love, encouragement and support.

DECLARATION OF AUTHORSHIP

I hereby declare that content of this thesis is my own work and that it is the result of work done during the period of registration. To the best of my knowledge, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgement has been made in the text.

Parts of this thesis appeared in the following publications, to which I have made substantial contributions:

- Enhanced three layer hybrid clustering mechanism for energy efficient routing in IoT – Accepted in Sensor Journal.

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(Student Signature)

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Muhammad S/O Faizan Ullah

ABSTRACT

Recently different routing techniques are proposed for three layer clustering topology in Wireless Sensor Network (WSN), which outperform the basic two layer clustering hierarchy. The problem remains in these approaches is the heavy control packet exchange between nodes after every round in order to choose efficient lower layer heads. Among these techniques; Hybrid Hierarchical Clustering Approach (HHCA) in which distributed approach is proposed. According to HHCA, the upper layer heads are centrally selected by base station, while sensor nodes only have to select lower layer heads distributively. In this work, enhanced three layer hybrid clustering mechanism is proposed that limits the exchange of control packets between nodes after every round for lower layer head selection. Energy of nodes are divided into levels upon which it is decided when nodes of a cluster need to enter into new cluster head selection phase. The proposed mechanism helps to limit control packet exchange between nodes to large extent, at the same time keeping energy consumption between nodes balanced. Moreover, it is focused that higher layer heads are selected by base station in a manner that reduce backward transmission in the network as much as possible. Simulation results show that nodes in the proposed mechanism stay alive for longer time as compared to other approaches, and it outperforms HHCA technique in network lifetime based on Half of the Nodes Alive (HNA) by 18 percent.

TABLE OF CONTENTS

Certificate ii

Dedication iii

Declaration of Authorship iv

Acknowledgements v

Abstract vi

Table of Contents vii

List of Figures ix

List of Tables x

Abbreviations xi

CHAPTER 1. Introduction 2

1.1. Thesis Background/Overview 2

1.2. Problem Description 5

1.3. Thesis Objectives 7

1.4. Thesis Organization 8

CHAPTER 2. Literature Review 11

2.1. Some overview 11

2.1.1. Some more overview 13

CHAPTER 3. Methodology 17

3.1. Proposed System 19

3.2. Details 21
CHAPTER 4. Evaluation 26
4.1. System Setup 26
4.2. Evaluation 27
CHAPTER 5. Conclusions and future work 34
5.1. Contributions 34
5.2. Future Works 34
References 35

LIST OF FIGURES

Figure 1.1 Three layer clustering topology 7

Figure 3.1 Energy consumption in transmitting and receiving data packet in first order radio modele [28] 20

Figure 3.2 Cluster joining and CH selection process in the proposed mechanism 24

Figure 4.1 Network lifetime of proposed mechanism is increased by limiting wasteful operations 28

Figure 4.2 Total number of received data packets at base station 30

Figure 4.3 Network lifetime of proposed mechanism with different energy Total Level (TL) 31

Figure 4.4 Network lifetime based on First Node Dies (FND) and Half of the Nodes Alive (HNA) 32

LIST OF TABLES

Table 1: Simulation parameters and their values. 27

ABBREVIATIONS

CH	Cluster Head
EL	Energy Level
ETLHCM	Enhanced Three Layer Hybrid Clustering Mechanism
EEEAC	Enhanced Energy Efficient Adaptive Clustering
FCM	Fuzzy C-means Clustering
FND	First Node Dies
GH	Grid Head
HNA	Half of the Nodes Alive
HHCA	Hybrid Hierarchical Clustering Approach
ISM	Industrial Scientific and Medical
IoT	Internet of Things
LEACH	Low Energy Adaptive Clustering Hierarchy
LND	Last Node Dies
MIMO	Multiple Input Multiple Output
RBCR	Relay selection Based Cooperative Routing
RF	Radio Frequency
SDN	Software Defined Network
SDWSN	Software Defined Wireless Sensor Network
SEECH	Scalable Energy Efficient Clustering Hierarchy

TL	Total energy levels
TDMA	Time division Multiple Access
UWSN	Underwater Wireless Sensor Network
WSN	Wireless Sensor Network

Chapter 1

Introduction

CHAPTER 1. INTRODUCTION

1.1. Thesis Background/Overview

Wireless Sensor Network (WSN) which is also called ear and eyes of Internet of Things (IoT), becomes an important research topic due its increasing role and usage in many applications. WSN as a connecting bridge between real and digital worlds, is a fast growing field of IoT that provides the required data from the field accurately with low cost.

The common perception of different IoT wireless systems is usually related with same concept, use of networked embedded devices to achieve intelligent monitoring and management. Devices are interconnected to transmit useful measurement data and control packets via distributed sensor networks.

WSN is widely used in both delay tolerant and real time applications. Some of well-known usage of WSN are: smart cities and smart homes applications, area monitoring, wildlife monitoring, enemy intrusion detection, indoor smoke detection, motion detection in high secure premises, soil movement detection before or during landslide, detection of fire in forest and public places. Underwater Wireless Sensor Network (UWSN) are used to constant monitor water amount and quality in dams, large water storing facilities, rivers, and even underground water reserve. UWSN also used for exploring natural resources such as oil and gas in deep oceans. It also used to monitor enemy activities in deep ocean water. WSN are widely used in industries for multi purposes including real time machines monitoring, auto production monitoring, and temperature measuring in data centres. It is useful in monitoring health status of patients remotely, measure and monitor air and water pollution levels, used for earth and environment sensing and others [1]. The application area of WSN is enlarging day by day with rapid development in the fields of low power consuming wireless communication [2] and digital electronics [1].

WSN consists of one or more sink nodes, and many sensor nodes. Usually homogeneous sensor nodes in extensive and large number are deployed randomly in the field of interest to collect required attribute and transmit them towards sink node which in turn forward these data packets to nearest station.

A sensor node is typically tiny electronic device usually equipped with: low cost micro controller with very low power consumption, one or more sensors that gather data of the interest from the surrounding, limited battery which assumed neither be replaced nor recharged as the power source, flash memory, and transceiver that uses Radio Frequency (RF) for communication with other nodes. Laser and infrared are also can be used for communication instead of RF in some WSN applications but they are sensitive to atmospheric conditions, and also require line of sight.

RF based communication is most popular in WSN applications. License free Industrial Scientific and Medical (ISM) frequencies radio band such as 433 MHz, 915 MHz and 2.4 GHz are mostly used in WSN.

It is obvious that these small low cost sensor nodes are neither accurate nor powerful as compared to the expansive macro sensor nodes, but a good quality sensor network still can be made by using large number of these sensor nodes together. Normally these nodes are deployed randomly in remote areas where deployment of large expansive nodes are not possible due to high cost or harsh environment.

Sensor nodes have limited source of power. Their batteries in most scenarios cannot be recharged or replaced due to many reasons such as: large number of deployed sensor nodes, random deployment of sensor nodes, remote location of the sensing region, harsh environment, and high cost of manual changing of deployed sensor nodes batteries.

Therefore, energy of sensor nodes in WSN remains one of the main issue and there is always need for algorithms and mechanisms that reduce network energy consumption and balance consumption of power between all deployed sensor nodes, in order to prolong the network life time. Unlike sensor nodes, the sink node is assumed to have no power constraints. In some cases Sink is deployed in the centre of the coverage areas, while in other topologies it is placed in a corner or outside of the sensing region. Sink node can be mobile and it can be static, but in the proposed mechanism, it is assumed along with sensor nodes that they are static after deployment and are not changing their physical locations. The main task of sink is to collect sensed information from the deployed sensor nodes and forward them to the nearest base station, for processing the collected information from the coverage area.

The energy utilization of a sensor node mainly take place in two conditions. The first condition is when a sensor node performs tasks such as transmitting data packets, receiving data packets, or processing requests received from either neighbouring sensor nodes or from the sink; which are called useful tasks. While operations such as transmission and reception of control packets with neighbouring sensor nodes for upper or lower layer head selection or for choosing better forwarding and data transmission path toward sink, or energy consumption due to retransmissions, overhearing of data packets from other sensor nodes, processing redundant packets, and similar other operations are all come in second condition which are considered as wasteful operation and waste of energy.

1.2. Problem Description

Network lifetime is considered a major factor in performance evaluation of routing protocols for WSN when sensor nodes have limited power source. Many techniques and protocols are proposed in past few years to reduce energy consumption of sensor nodes for getting longer network lifetime. One of less energy consumption technique in WSN is formation of clusters and routing data packets toward sink via Cluster Heads (CHs).

The basic Low Energy Adaptive Clustering Hierarchy (LEACH) protocol [3] is a two layer clustering technique in which CHs are chosen randomly after every round. At the beginning of every new round, a random number is generated and assigned to the deployed sensor nodes, and the one with higher random value is assigned as CH at that round, giving priority to those nodes which are not selected as CH previously. Many improvements are proposed in the choice method of CH in LEACH protocol such as in [4], [5], [6] and [7].

Recently few three layer clustering hierarchy are proposed for energy efficient data routing in WSN, which have longer network lifetime as compared to the basic two layer clustering techniques. Hybrid Hierarchical Clustering Approach (HHCA) protocol [8] is an adaptive three layer clustering protocol for WSN. Every sensor node in this protocol first of all sends its location along with the residual energy information toward sink. Sink based upon the received information from the sensor nodes selects upper layer heads which are named as Grid Heads (GH). Sensor nodes using Fuzzy C-means Clustering approach FCM [9] join grid, and then exchange control packets with each other for selection of CH using the same distributive procedure as used in LEACH with taking residual energy of sensor nodes into account too.

The three layer approach and combination of centrally selection of upper layer GHs via sink and distributive selection of lower layer CHs via sensor nodes shows better result as compared to fully distributive clustering techniques. The problem remained in this approach is waste of excessive amount of energy by transmitting and receiving of control packets after every complete round for assigning role of GH and CH to different sensor nodes. Besides this approach maintain energy consumption along with all deployed sensor nodes balance, but on the other hand a significant amount of energy is wasted due continuous communication of sensor nodes with their neighbouring sensor nodes which are within their transmission range.

In Figure 1.1, a typical three layer clustering topology in WSN is shown.

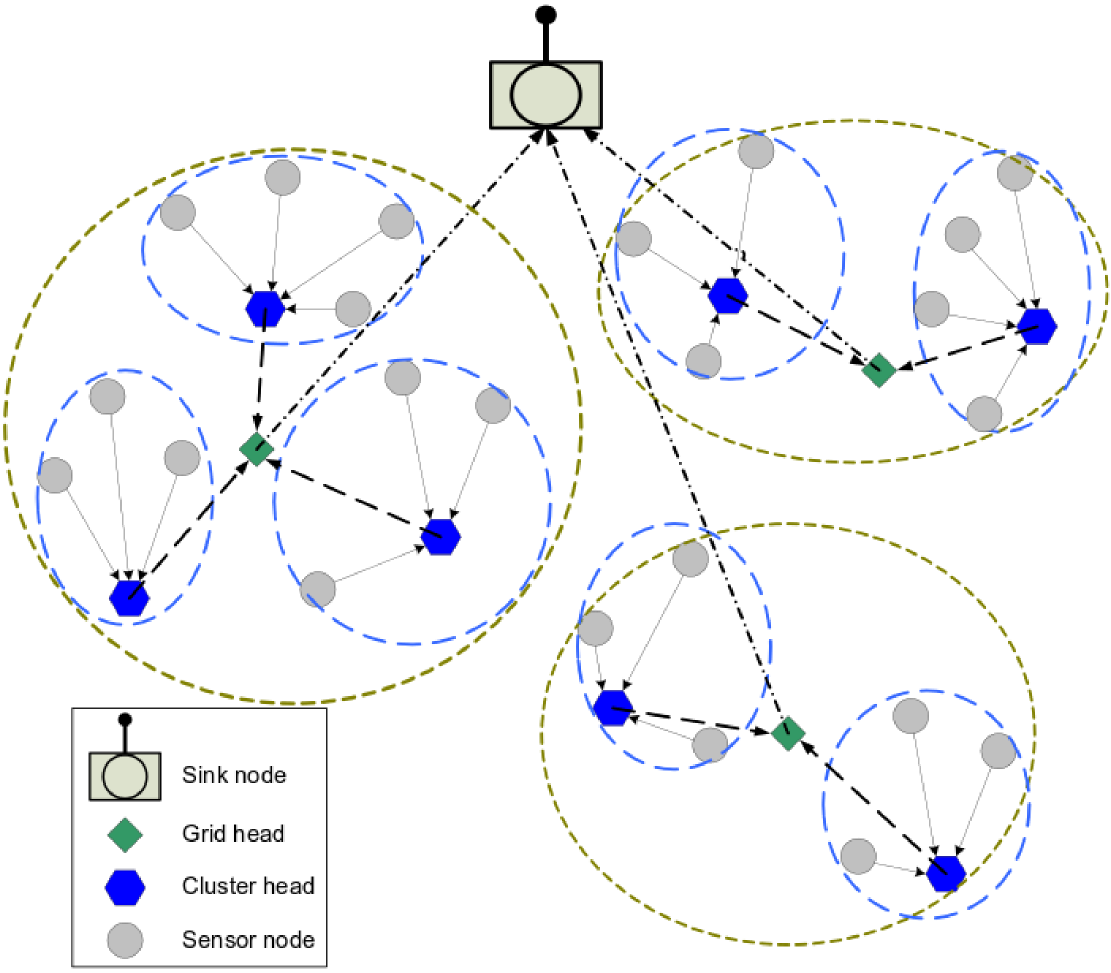

Figure 1.1 Three layer clustering topology

1.3. Thesis Objectives

In this thesis, Enhanced Three Layer Hybrid Clustering Mechanism (ETLHCM) is proposed that tackles to some extent issue of large wasteful operations in previous three layer clustering techniques.

Energy Levels (EL) for sensor nodes are designed in this thesis to limits the exchange of control packets after every round for CH selection and route formation purpose. At the same time EL also used to balance energy consumption between deployed sensor nodes so that to prevent creation of network holes in some parts of the network. Nodes that are selected as upper or lower layer heads change their role back to normal sensor node only when their residual energy drops by at least 1 EL. The proposed mechanism reduces burden of election and selection of lower layers heads in every round, as well as reduces to large extent the control packet exchange overhead. At the same time, the proposed technique does not overload sensor nodes, and switch the role of forwarding from one to other but in slow and cotrolled manner.

By reducing wasteful operations, ETLHCM shows better results in form of long network lifetime and high number of data packets received to sink. Details of the proposed mechanism is presented in chapter 3.

Moreover we added Euclidian distance to sink as another prioritizing parameter besides the residual energy metric of sensor node in the fuzzification process for selection of GHs via FCM approach. Thus sensor nodes with greater residual energy, and less Euclidean distance to sink have more priority to be selected by the sink as GH. This results in reducing backward transmission of data packets from lower layer to upper layer to some extent. The proposed mechanism can be used to increase the efficiency of IoT devices by reducing unnecessary communication overhead that not only saves the bandwidth but also save power.

1.4. Thesis Organization

Introduction chapter explains importance of WSN, its rising role in the daily life, as well as its working procedure. The rest of the thesis is organized as follows. Some previous well known energy efficient routing techniques and algorithms are mentioned in chapter 2. In chapter 3 issues of existing recent work in three layer cluster based routing algorithms in WSN are explained in details. Chapter 3 also explains the proposed mechanism briefly. Simulation results are evaluated and compared with recent existing works in chapter number 4. Conclusion and future work is presented in chapter 5.

Chapter 2

Literature Review

CHAPTER 2. LITERATURE REVIEW

Hierarchical transmission in WSN is considered one of the preferred ways for energy efficient routing of data packets toward the destination. In this kind of architecture, sensor nodes are divided into different layers with different tasks.

Clustering is a technique where different sensor nodes divided into groups and sub groups, they transmit their sensed data to the CH node and they in turn forward these packets toward the sink in hierarchical fashion.

Sensor nodes based upon Time division Multiple Access (TDMA) modulation or any other type modulation (depends upon the nature of application), transmit their data packets to their perspective CH. These collected data packets are compressed and forwarded to upper layer heads or sink.

2.1. Some overview

Low Energy Adaptive Clustering Hierarchy (LEACH) protocol [3] is considered one of the basic and simple two layer cluster routing technique in WSN, in which single hop communication is used between base station and CH. In LEACH, the CH role is circulated over all nodes one by one randomly; prioritizing those nodes to be selected as CH that were not been selected in earlier rounds. The approach proposed in LEACH lacked of efficiency in many aspects especially in selection process of CH among the deployed homogenous sensor nodes.

Authors in "Hybrid Energy-Efficient Distributed clustering approach for ad hoc sensor networks" (HEED), [10] take two other factors in consideration before assigning CH role to any sensor node, which are the communication cost and the residual energy of the sensor nodes.

Enhanced Energy Efficient Adaptive Clustering (EEEAC) protocol [11] is also based on residual energy of sensor nodes and uniformly distributes the CH overload in the network between all deployed sensor nodes.

While most of energy efficient routing techniques extend the network lifetime on the cost of end to end delay or other network parameters; authors in "A constrained shortest-path energy-aware routing algorithm for wireless sensor networks" [12] propose an energy aware routing protocol that maintains good end to end delay and throughput as well.

Authors in "distance aware intelligent clustering protocol for wireless sensor networks" [13] prolong the network lifetime by dividing the entire network region into tiers. Sensor nodes of high amount of energy and shortest distance to the sink are selected as CHs in this protocol. In "energy efficient opportunistic routing protocol for WSNs" [14], opportunistic multi path routing mechanism is proposed with aim to minimize the energy consumed due to the selection process of forwarding nodes in order to prolong the network lifetime.

A distributed algorithm called Scalable Energy Efficient Clustering Hierarchy (SEECH) is proposed in [15]. SEECH selects low degree nodes as relays while high degree nodes are selected as CHs separately using distance based algorithm.

In "geographical multi layered energy efficient clustering scheme for ad hoc distributed WSN" [16], the size of clusters are chosen to be variable instead of being fixed. Thus clusters with maximum distance to sink have larger size as compared to those that are nearer to sink. Sub tree mechanism is proposed in this protocol so that some parents nodes gather data packet from their neighbouring sensor nodes and forward them to CH, which in turn transmit them toward the base station.

Cooperative communication improves capacity of transmission and achieves spectral efficiency by taking advantage of the broadcast nature of communication in WSN [17]. Cooperative communication is basically developed from Multiple Input Multiple Output (MIMO) mechanisms, in which multiple sensor nodes share their resources to cooperatively reach data packet from source to destination without need to equip each and every sensor node with multiple antennas.

Relay selection Based Cooperative Routing (RBCR) is defined in [18] which is a relay selection based cooperative technique. Decode and forward without redundancy check strategy is adopted in RBCR with selection of best paths according to the information of channel state. At the receiving node, all receiving signals are combined again to retrieve the actual sent data packet.

2.1.1. Some more overview

Recently, researchers are working on using controllers that are used in the Software Defined Network (SDN) to perform all computational task of WSN. Software Defined Wireless Sensor Network (SDWSN) play important role in reducing energy consumption and prolonging network life time of WSN. SDN model also helps in adding many other functionalities and more intelligence to the WSN.

A centralized SDWSN model is described in [19]. The main problem in fully centralized WSN or SDWSN is that it is totally dependent over controller, which makes the network less responsive in some conditions. For example, if a CH node dies, the data packets from its neighbouring should be re-routed, but it cannot be happen in fully centralized mechanism until the new schedule is not updated by the central controller. On the other hand in distributive case, sensor nodes can handle re-routing locally by themselves very quickly [20]. Combination of centralized and distributive approaches have better outcome.

Authors propose a traffic deduction algorithm in [21] that reduce the overall data packets volume by exploring intra correlation of data packets generated by the sensor nodes. This algorithm prioritizes the unusual detected data packets and guarantee its delivery to the base station.

Geographic routing also broadly used in WSN due to its efficiency and simplicity. However it suffers from routing holes where there is no eligible node to forward data packets further and thus data packets are stopped at the hole boundary. Authors in [22] propose a distributed hole bypassing mechanism that tackles the load imbalance as well as routing path enlargement issues in WSN.

In [23] a Distributed Learning Automation (DLA) based algorithm is proposed to improve network lifetime by taking many routing constraints such as end to end delay and reliability into consideration in selection process of routes for data forwarding toward base station.

A traffic minimization mechanism is proposed in [24] in order to reduce the data required for communication by exploring the intra correlations and similarities of the sensors data. This mechanism which is proposed to detect landslide, decreases the energy utilization of WSN without degrading the detection performance of sensor nodes.

Authors in [25] define a topology control protocol in which the deployed sensor nodes learn and choose proper transmission range from the reinforcement signals of neighbouring sensor nodes. The network lifetime is increased by adopting lower transmission range for every deployed sensor node. Authors in [26] propose algorithm that provides certain level of security and protection to each sensor node with minimum energy consumption.

Chapter 3

Methodology

CHAPTER 3. METHODOLOGY

In this chapter, recent work over three layer clustering routing in WSN is discussed, their issues are highlighted and motivation for the proposed mechanism is explained. This chapter also includes detail explanation of the proposed technique and how it tackles the problem stated.

Recently in "an improved three-layer low-energy adaptive clustering hierarchy for wireless sensor networks" [8] paper, a new Hybrid Hierarchical Clustering Approach (HHCA) is proposed for three layer clustering routing, to improve the network lifetime of WSN. According to HHCA, all deployed sensor nodes in the first step transmit their location information along with their energy status to sink node. By applying centralized Fuzzy C-Means (FCM) clustering approach [9], every sensor node determines whether it is selected by sink as GH. In case a sensor node is selected as GH, it broadcasts a control packet announcing its selection. If the sensor node is not selected as GH, it joins the grid that is selected to it by sink via FCM approach.

The second step in HHCA is that all sensor nodes exchange control packets with each other and distributively select lower layer heads which are also called cluster heads in the same way as proposed in LEACH with addition of taking residual energy of nodes in consideration too, so that giving priority to sensor nodes with higher residual energy during CH selection process. Sensor nodes that are selected as CHs broadcast control packet announcing their assigned role, while other sensor nodes send join requests to nearest CH.

Both first and second steps in HHCA protocol are repeated after every round. Finally all sensor nodes that are not selected as CH and GH, transmit their data packets to CHs, and CHs in turn forward these data packets to GHs and they then forward them to sink.

It is noticed that the operations which are categorized as wasteful in chapter 1 are taking place in large amount after every round in aforementioned protocol. The repeated exchange of control packets between sensor nodes in HHCA and other routing techniques is for best lower layer heads selection and energy balancing purpose, which results in waste of significant amount of network energy.

As stated in [27], the high power consuming operation in WSN is communication, i.e., sending and receiving packets, that takes about two third of the total power consumption of a wireless module. The communication part of WSN is further categorized into two categories. Receiving of instructions and Transmission of sensed attributes by the deployed sensor nodes toward base station are enrolled in first category which is important. The second category as already explained in chapter number 2, consists of communication process that can be reduced if not avoided at all. This process includes retransmission of data packets, over hearing of data packets by sensor nodes that are broadcasted from other sensor nodes which are located near them, and most importantly the heavy control packet exchange between all deployed sensor nodes for efficient data routing purpose.

To save this excessive amount of energy that is wasted by exchanging of control packets between sensor nodes, ETLHCM mechanism is proposed in this thesis to limits exchange of control packets after every round and at the mean time keeps energy consumption between sensor nodes balanced. Balancing energy consumption between the deployed sensor nodes is important due to many reasons, the most important one is if certain sensor nodes are overloaded, they will die fast and thus network holes are created in the network. This leads to remain some regions in the network uncover.

3.1. Proposed System

In this mechanism, the first order radio model is adapted from [28]. It is used to calculate the energy that is consumed in transmitting E_{TX} and receiving E_{RX} of data packets size l bits over distance d by each of the deployed sensor node in the network.

$$E_{TX} = \begin{cases} l * \left(E_{elc} + \varepsilon_{fs} * d^2\right), & d < d_0 \\ l * \left(E_{elc} + \varepsilon_{mp} * d^4\right), & d \geq d_0 \end{cases} \tag{3.1}$$

In Equation (3.1), distance threshold d_0 is the normal transmission range of the sensor node, E_{elc} and ε_{fs} are the energy dissipation to run the radio and free space model of transmitter amplifier and their values are 50 nJ/bit and 10 pJ/bit/m^2 respectively. l is the data packet size and ε_{mp} is the multi path model of transmitter amplifier and its value is 0.0013 pJ/bit/m^4.

The receiving energy E_{RX} can be calculated as shown in Equation (3.2).

$$E_{RX} = l * E_{elc} \tag{3.2}$$

Figure 3.1 explains the aforementioned E_{TX} and E_{RX} consumption process in first order radio model [28].

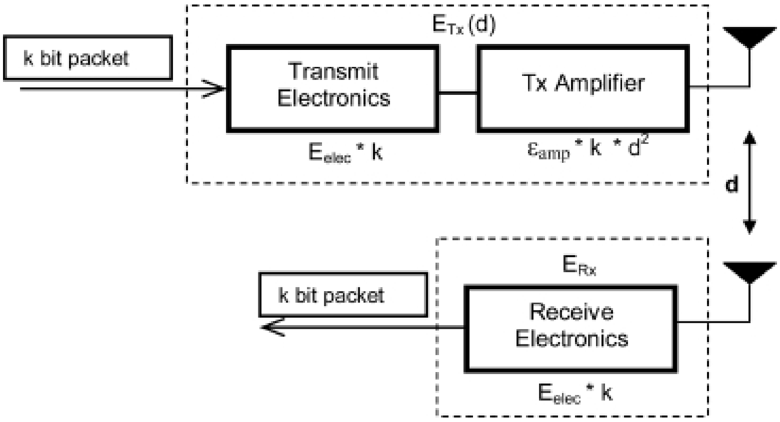

Figure 3.1 Energy consumption in transmitting and receiving data packet in first order radio modele [28]

It is assumed in this thesis that all sensor nodes are randomly deployed in the field of a fixed dimension. The deployed sensor nodes are homogenous and all have same capabilities and limited power source of same initial energy that cannot be recharged or replaced. Some reason regarding why it is not easy to change power sources of sensor nodes are explained in chapter number 1. Sink node is assumed to have no energy constraints and is deployed outside the coverage area.

All sensor nodes are assumed to know about location of the sink node and are able to find their own location information after the deployment. Sensor nodes are static and do not change their locations once they are deployed in the field. Sensor nodes determine distance between each other based upon the received signal strength.

In initial round, all deployed sensor nodes transmits their location and energy information hop by hop to sink. Sensor nodes join grid or upper layer in the same mechanism as explained in [9]. Nodes which are selected as grid head broadcast their assigned role, and pause the sensing role. Other sensor nodes after joining upper layer, start exchange of control packets between each other for cluster head or lower layer head selection.

Each sensor node share its residual energy and location information in control packet. Fuzzification process of shared parameters by sensor nodes taken place distributively. Node of higher residual energy and less Euclidean distance to both sink and grid head is chosen to be cluster head. The Euclidean distance between any two sensor nodes a and b is calculated from the following two dimension Euclidean distance Equation (3.3).

$$d(a,b) = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \qquad (3.3)$$

where x_1 and x_2 are the width dimensions, y_1 and y_2 are length dimensions of sensor nodes a and b respectively.

Nodes with CH role collect data from sensor nodes, compress it, and transmit it toward grid head which in turn forward them toward sink. While rest of sensor nodes sense the environment, collect data, and transmit it to their CH.

3.2. Details

Unlike HHCA and other previous three layer routing techniques, sensor nodes are not required to repeat the cluster head selection process and exchange of control packets between each other after every round. In the proposed mechanism, the main goal is to minimize the wasteful operations in every round and save nodes energy. Equation (3.4) shows the objective function of the proposed mechanism.

$$Min \sum_{r=1}^{r=max} WE_{consumed}(r) \quad \forall r \in R \qquad (3.4)$$

$WE_{consumed}$ is calculated using Equation (3.5).

$$WE_{consumed} = \sum_{i=1}^{N} d_0(i) \times (E_{TX} Control\ Packet + E_{RX}\ Control\ Packet) \qquad (3.5)$$

Where $WE_{consumed}$ is the amount of energy consumed per round in the exchange of control packets between all deployed sensor nodes N for CHs selection, d_0 is the maximum distance between two neighboring sensor nodes. $E_{TX} Control\ Packet$ and $E_{RX}\ Control\ Packet$ are the energy consumed in transmitting and receiving control packets. Their values can be calculated using Equation (3.1) and Equation (3.2) respectively, given that *l* is equal to the control packet size.

For achieving the objective function which is described in Equation (3.4), we split the total energy of sensor nodes into different equal portions called energy levels (EL). EL is calculated from Equation (3.6).

$$EL = E_0 \ / \ TL \qquad (3.6)$$

Where E_0 is the fixed initial energy of sensor node and TL is the total energy levels. The value of TL depends upon the frequency of energy consumption by a node, density of the network, and data packet size. As TL is inversely proportional to EL, so the lower value of TL will results in higher value of EL. The reason that we cannot set very low value to TL is due to its tradeoff with balance energy consumption between all deployed sensor nodes. The value of TL in this paper is set to 10 based on different simulation experiments.

Unless the residual energy of a sensor node that is selected as CH is not decreased by EL, it remains as CH, and no reselection process of CH take place. Whenever the CH residual energy decreased by EL, it broadcasts a control packet announcing end of its CH role. Thus new CH selection process start. The working procedure of the proposed mechanism is further explained in a flow chart which is shown in Figure 3.2.

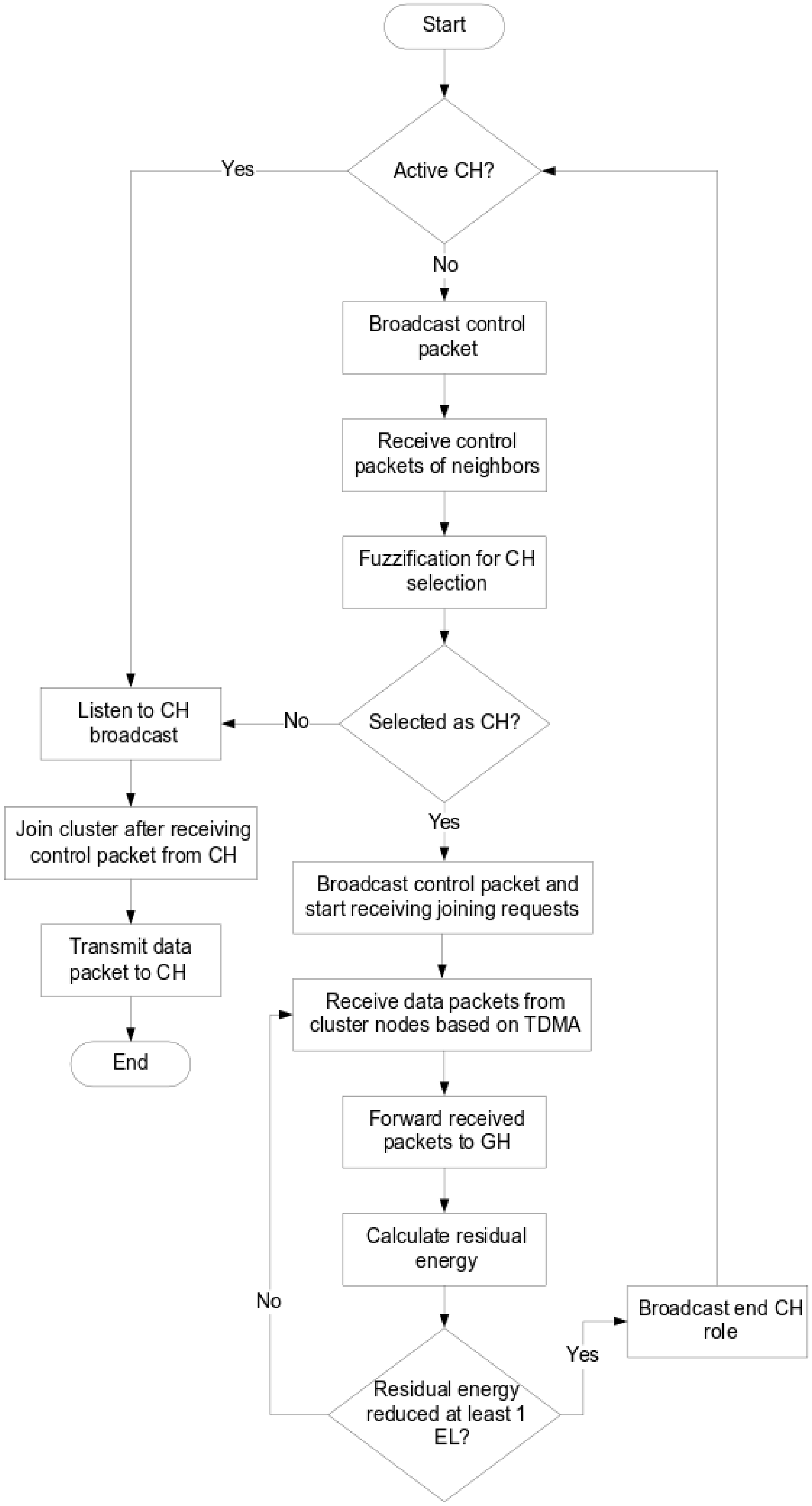

Figure 3.2 Cluster joining and CH selection process in the proposed mechanism

Chapter 4

Evaluation

CHAPTER 4. EVALUATION

Here in this chapter we evaluate the simulation results of the proposed technique, and compare the results with previous work.

4.1. System Setup

Simulation parameters are given in Table 1.Simulations are conducted using MATLAB/Simulink. 100 nodes of same initial energy are randomly deployed over a network of 100m * 100m. The Sink node is placed outside the covered area at (50 m, 175 m) in the 2D network. The main goal of the proposed technique is to prolong the network life time by avoiding retransmissions and heavy control packet exchange between sensor nodes every round.

Table 1: Simulation parameters and their values.

Parameters	Values
Network area	100 m * 100 m
Initial node energy	2 J
Number of sensor nodes	100
Data packet size	500 bytes
Packet header size	20 bytes
Control packet size	8 bytes
Bandwidth	1Mbps
$\boldsymbol{E_{elc}}$	50 nJ/bit
$\boldsymbol{\varepsilon_{fs}}$	100 pJ/bit/m^2
$\boldsymbol{\varepsilon_{mp}}$	0.0013 pJ/bit/m^4

4.2. Evaluation

Figure 4.1 shows the network lifetime of the proposed technique compared with other recent schemes. The shorter network lifetime of HHCA technique is due to the heavy control packet exchange between sensor nodes after every round for selection of efficient CH at lower layer.

HHCA results are improved from the basic clustering technique LEACH and its improved version for three layer clustering routing TL-LEACH scheme which are fully distributive clustering techniques. The main cause of low performance of LEACH is the inefficiency in procedure of CH selection. TL-LEACH tackled that problem, but since it is fully distributive approach, it consumes more energy than hybrid approach.

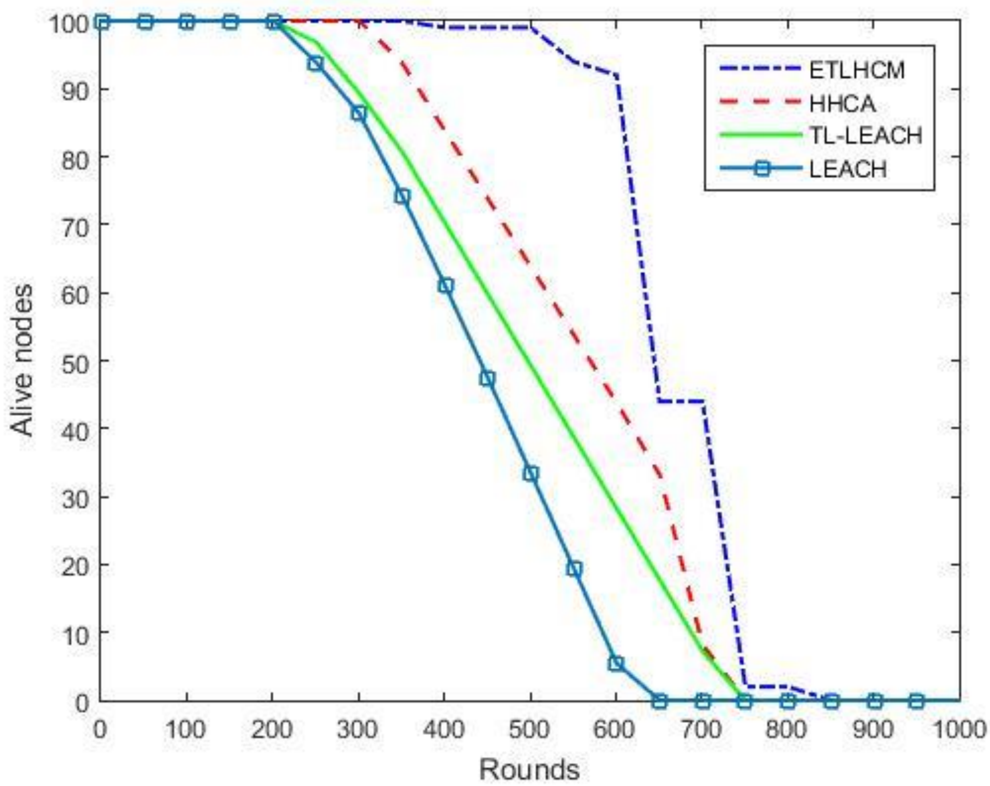

Figure 4.1 Network lifetime of proposed mechanism is increased by limiting wasteful operations

While HHCA outperforms LEACH and TL-LEACH, still it consumes high energy on selection of appropriate forwarders at lower layer. In the proposed scheme, exchanging control packets between sensor nodes are limited to large extent by defining energy levels that controls in a balanced manner the rotation of CH role among the deployed sensor nodes.

Results show that sensor nodes energy lasts for a longer time in the proposed mechanism due to minimizing wasteful operations. Sensor nodes in the proposed scheme start dying at later rounds as compared to other mentioned techniques due to limitation of control packet transmission and reception between sensor nodes over and over after every round. This help in saving energy of sensor nodes and thus prolonging their lifetime.

The overhead of the proposed algorithm is that when the batteries of sensor nodes reach to final stage, the graph of alive nodes falls sharply as you can see in Figure 4.1. The reason behind this is that nodes assigned as forwarders in the proposed algorithm do not change their state until their residual energy falls from a certain limit which is comparatively much larger than that of HHCA and other protocols as explained in chapter 3. Once all nodes batteries in the cluster reach to final stage, they start dying out frequently.

In Figure 4.2, the total number of data packets transmitted and successfully received at base station are shown. The proposed scheme appears to have better result from HHCA, TL-LEACH and LEACH protocols due to longer network lifetime. The good amount of energy that is used in other schemes during selection of CHs are saved to large extent in the proposed scheme, and thus nodes remain alive for longer period of time.

This results directly in increasing total number of successfully delivered data packets from sensor nodes to the base station. As much nodes die out in the network, that much probability of data packet drop increases. In the proposed mechanism, sensor nodes remains alive for longer time and thus the ratio of data packet drop is reduced.

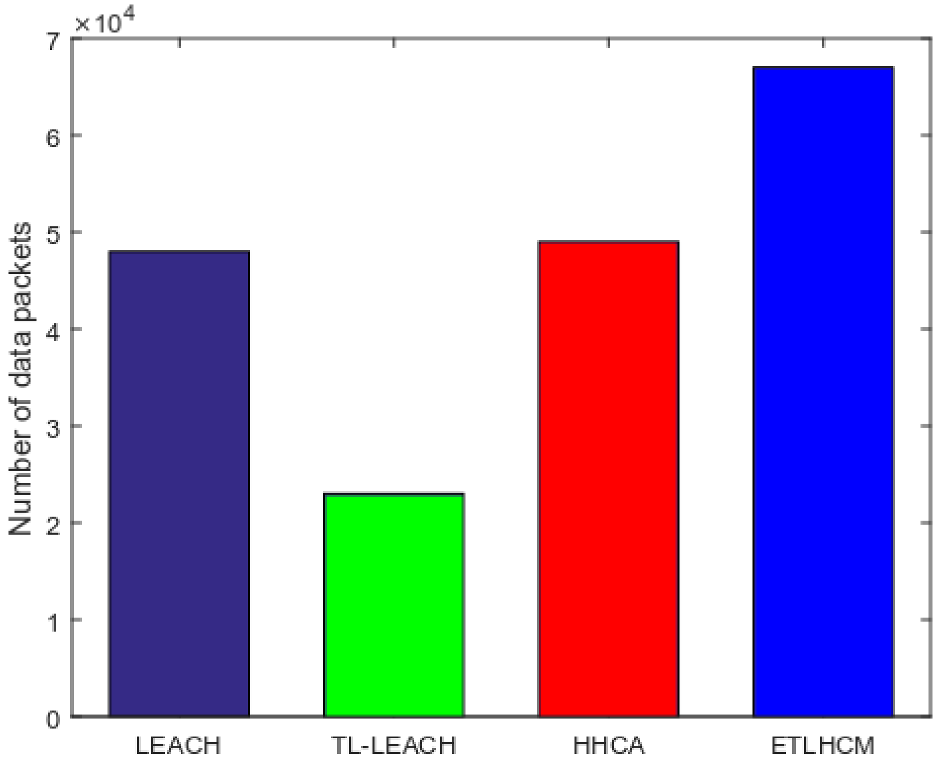

Figure 4.2 Total number of received data packets at base station

Figure 4.3 shows network lifetime of the proposed scheme with different total energy levels *TL* which is defined in Equation (3.6). As explained in chapter 3, higher value of *TL* results in more balanced energy consumption of sensor nodes in the network, but on the cost of higher energy consumption due to frequent control packet exchange. As shown in the Figure 4.3, the reason that we cannot set very low value to *TL* is due to its tradeoff with balance energy consumption between all deployed sensor nodes. Based upon the network parameters which are defined in Table 1, the proposed scheme outperforms with value of *TL* =10.

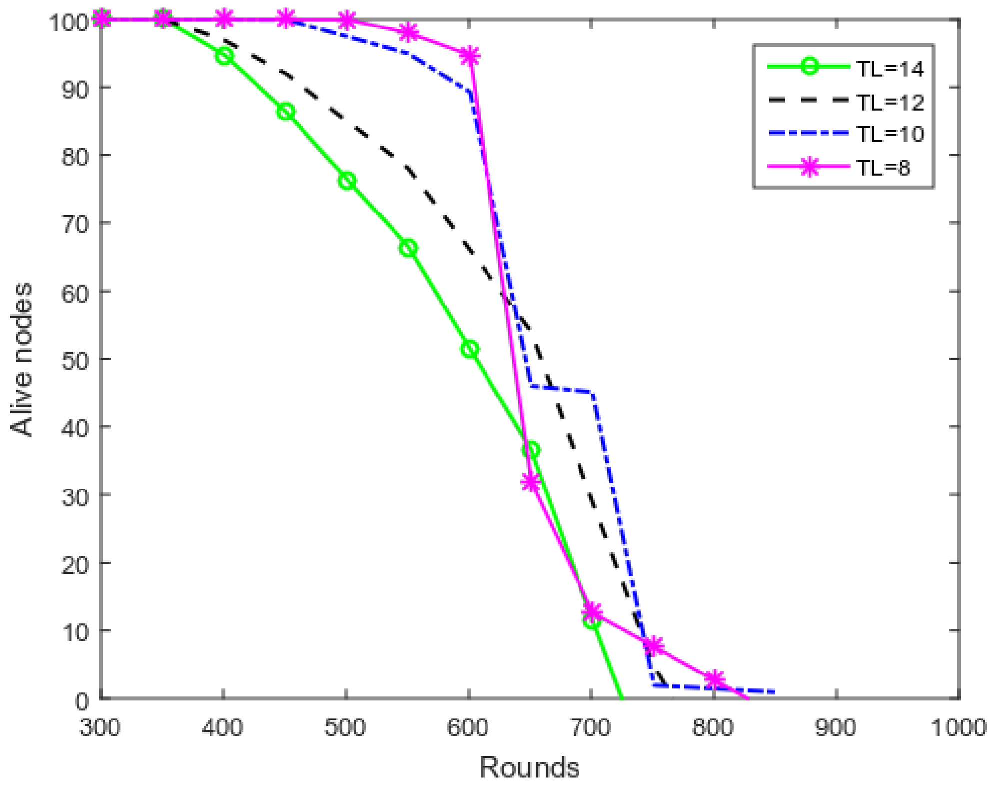

Figure 4.3 Network lifetime of proposed mechanism with different energy Total Level (TL)

Figure 4.4 shows the network life of WSN based on two metrics called First Node Dies (FND) and Half of the Nodes Alive (HNA), which are proposed in [29]. FND metric shows the number of rounds in which energy of first sensor node is exhausted and is considered dead. HNA metric on other hand shows number of rounds in which at least 50 percent of the deployed sensor nodes are functional.

As WSN becomes almost useless after dying out half of the deployed sensor nodes, therefore we focus more on HNA metric rather than Last Node Dies (LND) metric. HNA is also more useful metric in denser WSN as compared to FND metric, as network performance is not effected by dying out of single sensor node. As shown in Figure 4.4, the proposed scheme outperforms rest of techniques based on FND and HNA metrics.

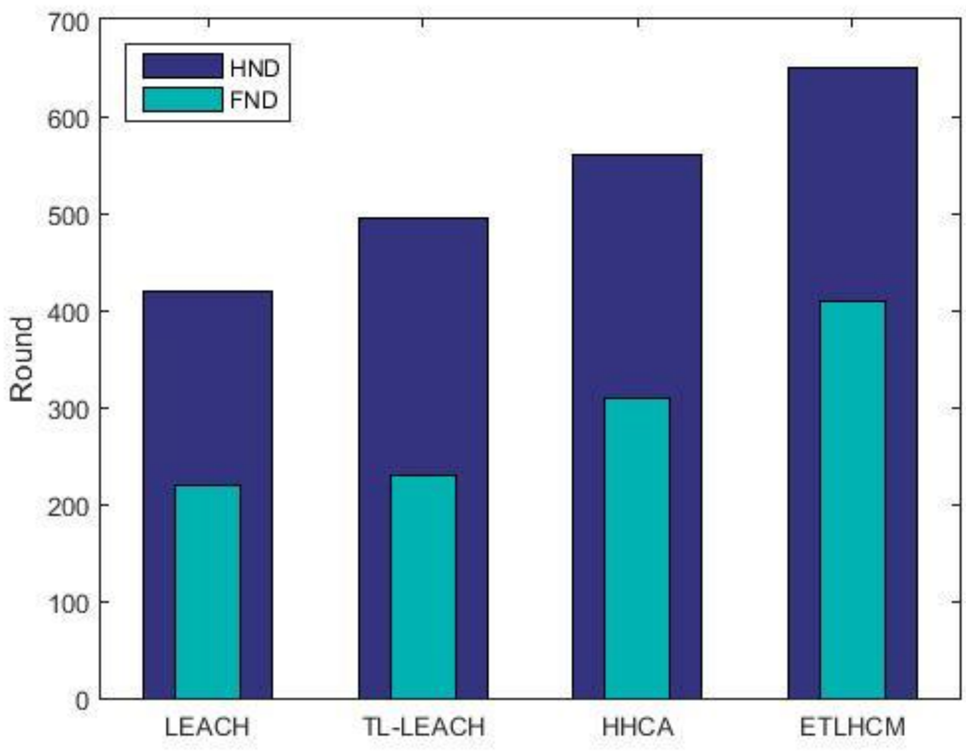

Figure 4.4 Network lifetime based on First Node Dies (FND) and Half of the Nodes Alive (HNA)

Chapter 5

Conclusions and Future Work

CHAPTER 5. CONCLUSIONS AND FUTURE WORK

5.1. Contributions

Heavy control packet exchange between sensor nodes for obtaining efficient forwarding route to base station results in reducing overall network lifetime. This work affirms that limiting wasteful operations in randomly deployed WSN are of paramount importance besides efficient selection of CHs in cluster based routing techniques.

The wasteful operations are defined and reduced on the basis of energy consumption of all deployed sensor nodes. The heavy control packets exchange between all deployed sensor nodes is reduced to a large extent in the proposed mechanism, and thus the overall network lifetime is improved.

The proposed mechanism, evaluated in simple homogenous small scale network, limit wasteful operation in three-layer hybrid clustering routing protocol for WSN and in the mean time balance the energy consumption between the deployed sensor nodes and results in 18 percent improvement in the network lifetime based upon HNA metric as compared to the recent three layer clustering routing protocol HHCA.

5.2. Future Works

In future, we aim to implement the proposed mechanism in some application specific heterogeneous network and also to design and test it for large scale networks.

REFERENCES

[1] Akyildiz, Ian F., et al. "Wireless sensor networks: a survey." *Computer networks* 38.4 (2002): 393-422.

[2] Sohrabi, Katayoun, et al. "Protocols for self-organization of a wireless sensor network." *IEEE personal communications* 7.5 (2000): 16-27.

[3] Heinzelman, Wendi B., Anantha P. Chandrakasan, and Hari Balakrishnan. "An application-specific protocol architecture for wireless microsensor networks." *IEEE Transactions on wireless communications* 1.4 (2002): 660-670.

[4] Xiangning, Fan, and Song Yulin. "Improvement on LEACH protocol of wireless sensor network." *2007 International Conference on Sensor Technologies and Applications (SENSORCOMM 2007)*. IEEE, 2007.

[5] Junping, Hu, Jin Yuhui, and Dou Liang. "A time-based cluster-head selection algorithm for LEACH." *2008 IEEE Symposium on Computers and Communications*. IEEE, 2008.

[6] Xu, Jia, et al. "Improvement of LEACH protocol for WSN." *2012 9th International Conference on Fuzzy Systems and Knowledge Discovery*. IEEE, 2012.

[7] Fu, Chunyao, et al. "An energy balanced algorithm of LEACH protocol in WSN." *International Journal of Computer Science Issues (IJCSI)* 10.1 (2013): 354.

[8] Lee, Jin-Shyan, and Tsung-Yi Kao. "An improved three-layer low-energy adaptive clustering hierarchy for wireless sensor networks." *IEEE Internet of Things Journal* 3.6 (2016): 951-958.

[9] Hoang, D. C., R. Kumar, and S. K. Panda. "Fuzzy C-means clustering protocol for wireless sensor networks." *2010 IEEE international symposium on industrial electronics*. IEEE, 2010.

[10] Younis, Ossama, and Sonia Fahmy. "HEED: a hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks." *IEEE Transactions on mobile computing* 4 (2004): 366-379.

[11] Misra, I. Saha, Sudipto Dolui, and Ambarish Das. "Enhanced energy-efficient adaptive clustering protocol for distributed sensor networks." *2005 13th IEEE International Conference on Networks Jointly held with the 2005 IEEE 7th Malaysia International Conf on Communic*. Vol. 1. IEEE, 2005.

[12] Youssef, Moustafa A., Mohamed F. Younis, and Khaled A. Arisha. "A constrained shortest-path energy-aware routing algorithm for wireless sensor networks." *WCNC*. Vol. 2. 2002.

[13] Gautam, Navin, and Jae-Young Pyun. "Distance aware intelligent clustering protocol for wireless sensor networks." *Journal of communications and networks* 12.2 (2010): 122-129.

[14] Mao, Xufei, et al. "Energy-efficient opportunistic routing in wireless sensor networks," *IEEE transactions on parallel and distributed systems 22.11*, pp. 1934-1942, 2011.

[15] Tarhani, Mehdi, Yousef S. Kavian, and Saman Siavoshi. "SEECH: Scalable energy efficient clustering hierarchy protocol in wireless sensor networks." *IEEE Sensors Journal*14.11 (2014): 3944-3954.

[16] Siavoshi, Saman, et al. "Geographical multi-layered energy-efficient clustering scheme for ad hoc distributed wireless sensor networks." *IET Wireless Sensor Systems* 6.1 (2016): 1-9.

[17] Hedayat, Ahmadreza, T. E. Hunter, and A. Nosratinia. "Cooperative communication in wireless networks." *IEEE Communications Magazine* 42.10 (2004): 74-80.

[18] Nacef, Ahmed Ben, et al. "A combined relay-selection and routing protocol for cooperative wireless sensor networks." *2012 8th International Wireless Communications and Mobile Computing Conference (IWCMC)*. IEEE, 2012.

[19] Gude, Natasha, et al. "NOX: towards an operating system for networks." *ACM SIGCOMM Computer Communication Review* 38.3 (2008): 105-110.

[20] Song, Jianping, et al. "Centralized control of wireless sensor networks for real-time applications." *IFAC Proceedings Volumes* 40.22 (2007): 25-32.

[21] Liu, Zhi, Toshitaka Tsuda, and Hiroshi Watanabe. "Traffic deduction exploring sensor data's intra-correlations in train track monitoring WSN." *2015 IEEE SENSORS*. IEEE, 2015.

[22] Le Nguyen, Phi, et al. "Distributed hole-bypassing protocol in WSNs with constant stretch and load balancing." *Computer Networks* 129 (2017): 232-250.

[23] Mostafaei, Habib. "Energy-efficient algorithm for reliable routing of wireless sensor networks." *IEEE Transactions on Industrial Electronics* 66.7 (2018): 5567-5575.

[24] Liu, Zhi, et al. "Data driven cyber-physical system for landslide detection." *Mobile Networks and Applications* (2018): 1-12.

[25] Javadi, Mahmood, et al. "Learning automaton based topology control protocol for extending wireless sensor networks lifetime." *Journal of Network and Computer Applications* 122 (2018): 128-136.

[26] Mostafaei, Habib, and Mohammad S. Obaidat. "Learning automaton-based self-protection algorithm for wireless sensor networks." *IET Networks* 7.5 (2018): 353-361.

[27] Estrin, Deborah. "Wireless sensor networks tutorial part IV: sensor network protocols." *Mobicom*. 2002.

[28] Wang, Jin, et al. "Hop-based energy aware routing algorithm for wireless sensor networks." *IEICE transactions on communications* 93.2 (2010): 305-316.

[29] Handy, M. J., Marc Haase, and Dirk Timmermann. "Low energy adaptive clustering hierarchy with deterministic cluster-head selection." *4th international workshop on mobile and wireless communications network*. IEEE, 2002.