An Enhanced Routing Technique for Wireless Sensor Networks

A Thesis Submitted in Fulfillment of the Requirement for the Award of the Degree of

DOCTOR OF PHILOSPHY

IN

COMPUTER SCIENCE AND ENGINEERING

By

Kalpna

(Registration No. 951003013)

Under the Supervision of

Dr. Anil K. Verma

Professor, Computer Science and Engineering Department,
THAPAR INSTITUTE OF ENGINEERING & TECHNOLOGY
PATIALA – 147004

COMPUTER SCIENCE AND ENGINEERING DEPARTMENT

December 2018

Certificate

I hereby certify that the work which is being presented in the thesis entitles " An Enhanced Routing Technique for Wireless Sensor Networks" in partial fulfillments of the requirements for the award of the degree of Doctor of Philosophy and submitted in the Department of Computer Science and Engineering of Thapar Institute of Engineering and Technology, Patiala is an authentic record of my own work carried during the period from Jan 2011 to Dec 2018 under the supervision of Dr. Anil K. Verma, Professor, CSED, Thapar Institute of Engineering and Technology, (Deemed to be University), Patiala.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other institute/ university.

KALPNA

(Registration No. 951003013)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Prof. (Dr.) Anil K. Verma

Abstract

In recent years, wireless sensor networks (WSNs) have emerged as one of the most promising technology in our day to day life. WSNs have played a major role in applications such as tracking and monitoring in remote environments. There are various open issues in WSNs such as limited network lifetime, higher energy consumption, handling mobility of SNs, link failures and lower network performance due to dynamicity of operations. Designing energy efficient protocols for routing of data events is a major challenge due to the dynamic topology and distributed nature of WSNs. Route selection is a critical activity while transmitting messages from source to destination. Major amount of energy is consumed during the data transmission. Hierarchical routing architecture has proved to be extremely effective in solving the problem of excessive energy consumption. In cluster based routing protocols cluster heads are overburdened with the task of data forwarding to BS which causes unbalanced energy consumption. Novel cluster head selection is an important task which needs emphasis in order to reduce energy consumption and network lifetime enhancement.

Hardware restrictions necessitate the requirement of energy efficient design and development of hierarchical routing protocols. This thesis is an effort towards this direction. In this thesis three protocols have been proposed which are: “An energy efficient load balanced cluster based routing using ACO (LB-CR-ACO)”, “An Unequal clustering using meta-heuristic Ant Colony Optimization (MHACO-UC) and An Enhanced Energy Proficient Clustering (EEPC) Algorithm for relay selection in heterogeneous WSNs.

The first protocol “An energy efficient load balanced cluster based routing using Ant Colony Optimization (LB-CR-ACO)” is an effort to enhance network life time. It performs optimal clustering based on

cluster head selection weighing function. The cluster formation utilizes various parameters like remaining energy of the nodes, received signal strength indicator and node density. The priority weights are assigned among these parameters. The presented protocol also performs a dynamic selection of optimal cluster head periodically which conserves energy, thereby utilizing network resources in an efficient and balanced manner. The optimal route construction is done using ACO in steady state phase for multi hop data transfer. It has been observed through simulations that proposed protocol exhibits better performance for number of alive nodes, energy consumption per round than its peer protocols.

The second protocol is “Meta-heuristic ant colony optimization based unequal clustering (MHACO-UC) for wireless sensor networks". The protocol's main focus is to deal with the issues related to unbalanced energy consumption, network performance dynamics. Apart from the optimal cluster head selection this protocol emphasizes on unequal clustering to maintain a fair balance between intra and inter cluster communication load. The initialization of nodes nearer to Base Station (BS) as relay nodes increases the performance. Meta-Heuristic Ant Colony Optimization approach selects the optimal path between the nodes which increases the packets delivered to destination. Unequal clustering, novel CH selection, prediction of optimal path using meta-heuristic ant colony optimization reduces the energy consumption effectively. The simulation and comparative analysis of proposed Meta-Heuristic Ant Colony Optimization based Unequal Clustering (MHACO-UC) with the existing unequal clustering approaches on the basis of various performance parameters such as packet delivery ratio (PDR), number of packets sent to the BS, energy consumption and residual energy shows the effectiveness of proposed work in WSN applications.

The third protocol is "An Enhanced Energy Proficient Clustering (EEPC) algorithm for relay selection in heterogeneous WSNs". It reduces the energy consumption in the field of sensor tracking events. The main focus of the presented work is to handle mobility of SNs and to deal with link failures. In this work, network is constructed with both static and mobile nodes, which are placed in grid structures, and deployed randomly. The nodes select their cluster head (CH) on the basis of their associated placement and energy level. The mobile nodes transmit the data to the CH. Generally, CH transmits the sensing information to the base station. The proposed approach introduces the concept of finding relay nodes, which are static nodes. The EEPC algorithm selects the relay nodes based on its velocity and location by calculating particle fitness value. The selected intermediate relay static nodes transmit the collected sensing information to the Base Station (BS) using sensor data fusion technique. The link fault could be predicted based on the deviation value. The simulation results show that the proposed approach minimizes the energy depletion and hence enhances the network lifetime.

Acknowledgements

"God is there where the tiller is tilling the hard ground and path maker is breaking stones. He is with the Sun and Shower".

This dissertation could never have been complied in its present from and seen the light of the day without constant courage and blessing received by me from the unseen hands of the divine grace.

First and foremost I would like to commend and thank **"God –The Supreme Power"** for my life through all tests in the past years.

My deepest gratitude goes to parents my Dad Ji (**Sh. Ranjit Singh**) and Mumma (**Smt. Sarla**) who brought me to this world and have been beside me, helping me psychologically, emotionally, morally and materially to overcome all the obstacles I faced during my life. I am grateful for their unflagging love and support throughout my life. They stood behind me like a pillar of success, motivation and has always been one of my best counselors.

I am sincerely grateful as well as indebted to express my deep sense of gratitude of appreciation and profound personal regard to my esteemed Supervisor **Prof. (Dr.) Anil Kumar Verma** for his expert, invaluable and tireless guidance and encouragement. He was always accessible and willing to help in research work. As a result research life became smooth and rewarding for me. This achievement is simply impossible without his help and guidance.

I am indeed beholden to **Prof. (Dr.) Maninder Singh** Head, department of Computer Science & Engineering for his invaluable suggestions and providing me the necessary research facilities.

The formal acknowledgement will hardly be sufficient in expressing my deep sense of gratitude to members of my advisory committee **Prof. (Dr.) Rajesh Khanna** (Department of ECE), **Dr. Neeraj Kumar** (Associate Professor, CSE), **Dr. V.P. Singh** (Associate Professor, CSE) and **Prof. (Dr.) Rafat Siddique (**Dean of Research & Sponsored Projects) for their meaningful comments and useful suggestions throughout this research work.

My successful accomplishment of the task at hand also owes much to my maternal uncle (Mama Ji) **Prof. (Dr.) A.L. Sangal** who is the driving force behind this work. Furthermore, the blessings of my maternal parents **Sh. S.R. Sangal** (Babu Ji) and **Smt. Shanti** (Mata Ji), who have always been a constant source of encouragement in my life. They are like my spiritual father and mother who drew me close to the Lord.

I will always remain indebted to my father-in-law ***Sh. T. R. Verma*** *and mother-in-law* ***Smt. Urmila*** *and express my deep sense of gratitude for their kind cooperation and constant support throughout this work.*

*I express my heartiest thanks to my elder sister (**Mrs. Sheetal**) and Jiju Ji (**Mr. Tarun**) for their blessings and inspirational words. I cherish all the prayers and best wishes rendered by them.*

I greatly acknowledge and appreciate my sister ***Neha*** *for the motivational advice, encouragement and constant support she has rendered throughout this period. She has been my mentor throughout this work. I also thank my younger Jiju* ***Mr. Manoj*** *for his help and support.*

It's my pleasure to extend a special thanks to my brother ***Ashish*** *who has done an incredible job of a reviewer throughout the publication of work and shown great patience during the proofreading process.*

Mere words cannot express my feeling of debt and gratitude to my daughter ***Airish*** *and son* ***Aarav****, for allowing me the time for my work, which was meant for them. I also commend their sacrifice and place on record my heartfelt affection towards both of them, as their prayers and blessings worked on me. I would like to appreciate the best wishes of my nephew* ***Rishab*** *and niece* ***Elish*** *whose love and affection is an adorable gift.*

Language seems to be an inadequate medium to express my appreciation to my husband ***Mr. Ashok Kumar*** *whose inspirational advice, encouragement and affection has always been my strength and which acted as a premium to my accomplishments. I feel inadequacy of words that can describe his everlasting affection and care for me.*

Good friends are hard to find, harder to leave but impossible to forget. Such a caring and jolly natured friend I have ***Sushil****. He was always my first thought for help throughout the preparation of this manuscript and undoubtedly, he did so. I treasured all the precious moments we shared and I cherished the prayers and support between me and him. I have no suitable words that can fully describe his unconditional help and support.*

Last but not the least, I take pleasure to acknowledge the best wishes and support rendered by my friends ***Latika, Vanita*** *and* ***Garima****. I feel privileged to have them in my life.*

Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

The latest developments in the area of wireless networks have brought revolution in the field of communication technology (Elgala et al., 2011). In earlier times, the exchange of information was a very difficult task, especially in the remote areas. However, in today's scenario, it has become an easy task, with the usage of latest technologies and electronic gadgets available. Internet acts as communication backbone by virtue of which various heterogeneous networks can connect, communicate and transfer information to any part of the world. The communication among different network entities is made possible through various networking devices which follow certain sets of software rules known as protocols. The networks can be exclusively branched into two broader categories namely wired and wireless.

In wired networks, cables are the prime medium to connect different networking devices and they utilize fixed infrastructure. However, in wireless networks radio waves act as communication medium to build up connection among various networking devices. Characterization of wireless networks on the basis of their coverage area can be drawn as Wireless Personal Area Networks (WPAN), Wireless Local Area Networks (WLAN), Wireless Metropolitan Area Networks (WMAN), Wireless Wide Area Networks (WWAN) (Crow *et al.*, 1997; Callaway *et al.*, 2002; Zhang and Chen, 2007; Dravida *et al.*, 2012). Figure 1.1 illustrates the details about wireless communication technologies.

Wireless networks can be categorized as infrastructure-less and infrastructure-equipped. The infrastructure-less wireless networks are classified as ad-hoc networks which can be further branched into

Mobile Ad-hoc Networks (MANET's) (Akyildiz *et al.*, 2009; Govindan and Mohapatra 2012), Vehicular Ad-hoc Networks (VANET's) (Kumar and Verma, 2015), Wireless Sensor Networks (WSNs) (Akyildiz *et al.*, 2002).

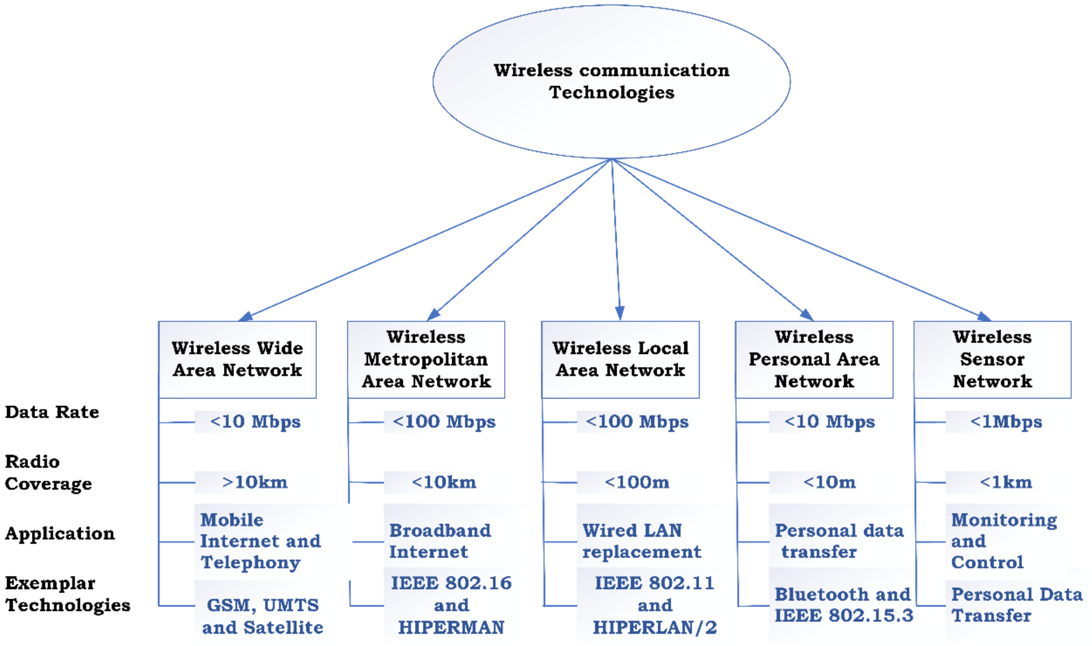

Figure 1. 1 Wireless Communication Technologies

1.1 Wireless Sensor Networks

The wireless sensor networks (WSNs) are comprised of a large number of nodes which allow accumulated data transfer through the network to sink or base stations (BSs) (Suryadevara *et al.*, 2015). These networks find numerous attractive applications in fields such as business, healthcare, military surveillance, air pollution control, river level variation monitoring, intelligent highway designing and remote health assistance etc. While establishing such applications, the sensor nodes utilize huge amount of energy for communication, data processing and sensing (Bai *et al.*, 2012). Nowadays industry wide, research is going on with a special focus on energy consumption, network topology maintenance and finding a better route for data transmission to maximize the network life time. Energy efficient routing (Yadav et al., 2017; Guleria and Verma, 2018 a; Khabiri and Ghaffari, 2018), query optimization (Chen *et al.*, 2012; Jindal *et al.* 2015), security advancement (Prasanna and Rao, 2012, Garg *et al.*, 2016), 3D sensing and coverage (Huang and Tseng, 2005) are some of the major research areas in WSNs. Wang *et al.*, 2016a; Wang *et al.*, 2016b have made a significant contribution for improving energy efficiency in WSNs through green computing. The authors have proposed an energy efficient Industrial Internet of Things (IIoT) architecture (Wang *et al.*, 2016a).

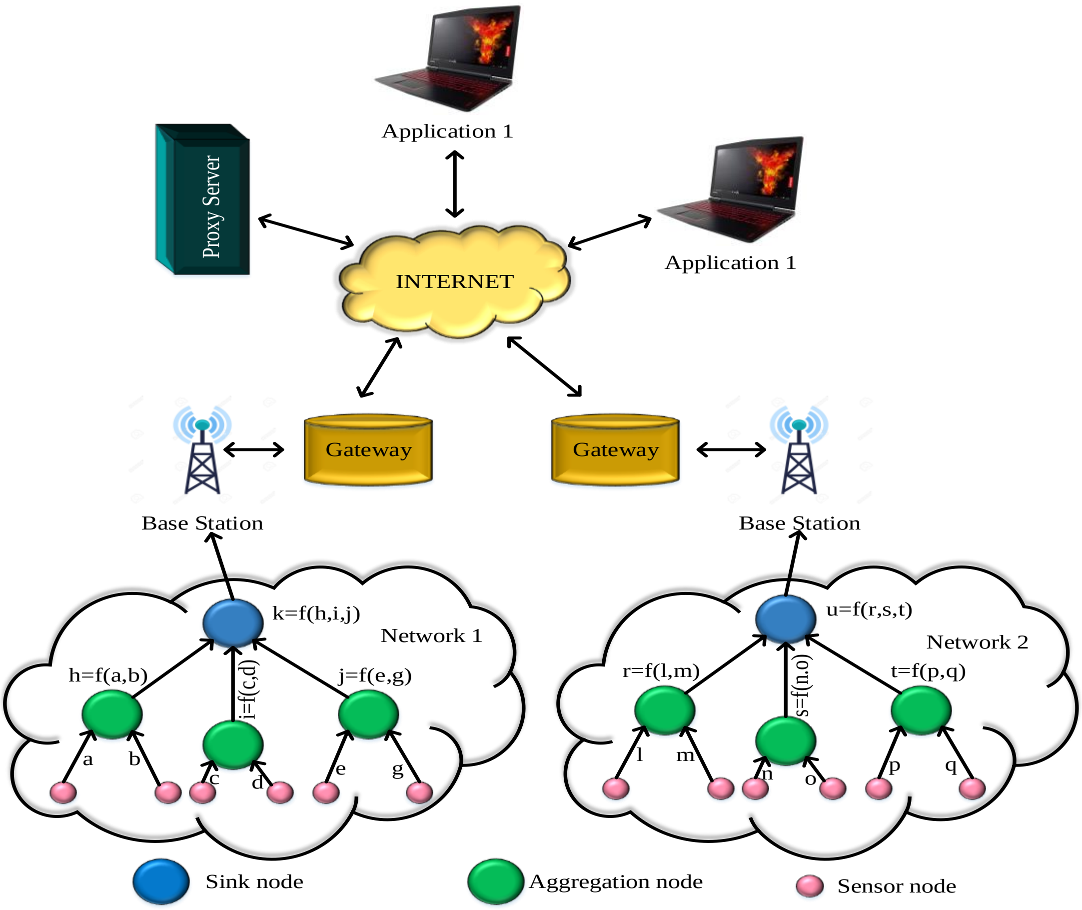

Figure 1. 2 Architecture of WSNs

The proposed hierarchical framework is a three-layered architecture comprising of sense layer, gateway layer and control layer which contributes to load balancing and enhances the network lifetime as well. Further, Wang *et al.* 2016b have proposed an efficient, fault tolerant and reliable interest based reduced variable neighborhood search (RVNS) queue-based architecture (IRQA) to alleviate the issues related to data collection, processing and analysis for mobile eHealth networks. The authors have used the concept of Big data (Provost and Fawcett, 2013) for rapid processing of large volumes of data in mobile.

Sensor Nodes (SNs) gather the environmental information and transfer it from source to sink node in a multi hop communication as illustrated in figure1.2. The collected information is further transferred from sink node to end user through internet.

1.2 Characteristics of WSNs

The characteristics of WSN play an important role for energy efficient deployment and operation of the network. Therefore, they must be considered for routing protocol design and implementation. The characteristics of WSNs are shown in figure 1.3 and explained below:

- **Data Centric Communication Paradigm**
  WSNs follow a data centric communication paradigm, which implies that data communication is based on the SNs in a defined location or data values. However, communication paradigm in traditional networks is address centric.
- **Application Specific Nature**
  WSNs are deployed to execute a specific application and thereby exhibit an application specific behavior.
- **Dynamicity of operations**
  Communication links' connectivity in WSNs is unstable due to dynamicity of network nodes and node errors/failures in mobile environments.
- **Higher Node Density**
  WSNs are having a very high node density as compared to other infrastructure-less wireless networks such as ad-hoc networks.

- **Resource constraint**

  The WSNs are resource constrained due to the smaller size of SNs which leads to limited battery power, lower processing and storage capabilities.

- **Random Deployment**

  SNs deployment is usually performed in a random manner due to which the maintenance/replacement is a tedious task. This characteristic also gives stimulus to runtime reconfiguration and reprogramming through routing protocols.

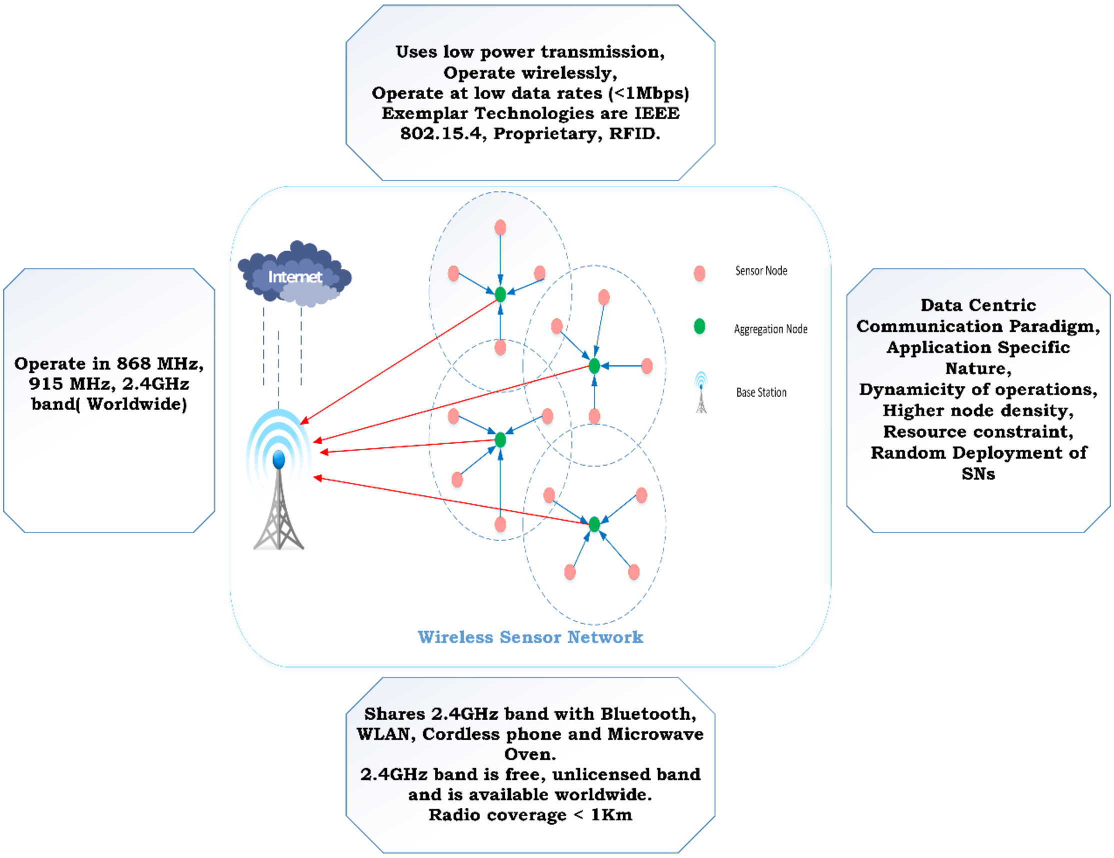

Figure 1. 3 Characteristics of WSNs

1.3 Applications of WSNs

In today's scenario, WSNs are used in a wide variety of application domain. The main application domains for WSNs are listed below and shown in figure 1.4.

- **Military surveillance and monitoring**

  One of the major application areas of WSNs is military surveillance and monitoring (Oracevic et al., 2017). In the border areas and in battle fields SNs form an indispensable part of command, control, intelligence and surveillance-based systems.
- **Environmental Monitoring**

  Fire detection in forest areas, earthquake monitoring, planetary exploration, volcano prediction and pollution level detection are some of the important environmental monitoring applications of WSNs (Badescu and Cotofana, 2015).
- **Precision Agriculture**

  WSNs are deployed to keep track of parameters such as temperature and humidity in order to maintain/control the required level of moisture contents for precision agriculture.
- **Patient Health Monitoring**

  The Wireless Body Area sensor Networks (WBANs) have emerged as one of the promising technologies for e-Health networks. It administers patients' health, drugs and tracks or monitors patients/doctors in a hospital.
- **Structural Health Monitoring**

  WSNs are used to improve the public safety by monitoring and performing structural health checks of critical infrastructures like high rise buildings, bridges and stadiums.
- **Home Automation**

  Building smart homes means, Heating Ventilation & Air Conditioning (HVAC) which is possible through the usage of smart sensor technology. SNs allow users to control their smart home appliances from locally/remotely through internet or satellite.
- **Industrial monitoring and control**

  WSNs play an integral role in industrial monitoring applications where human beings cannot be subjected for tracking monitoring activities like chemical processes in chemical plants/ boilers.

- **Traffic Monitoring in Smart Cities**

  The sensor technology has made it possible to monitor and control traffic conditions during peak hours in smart cities which avoids accidents and instructs vehicle drivers not to take route from the area where traffic jams or road works are going on.

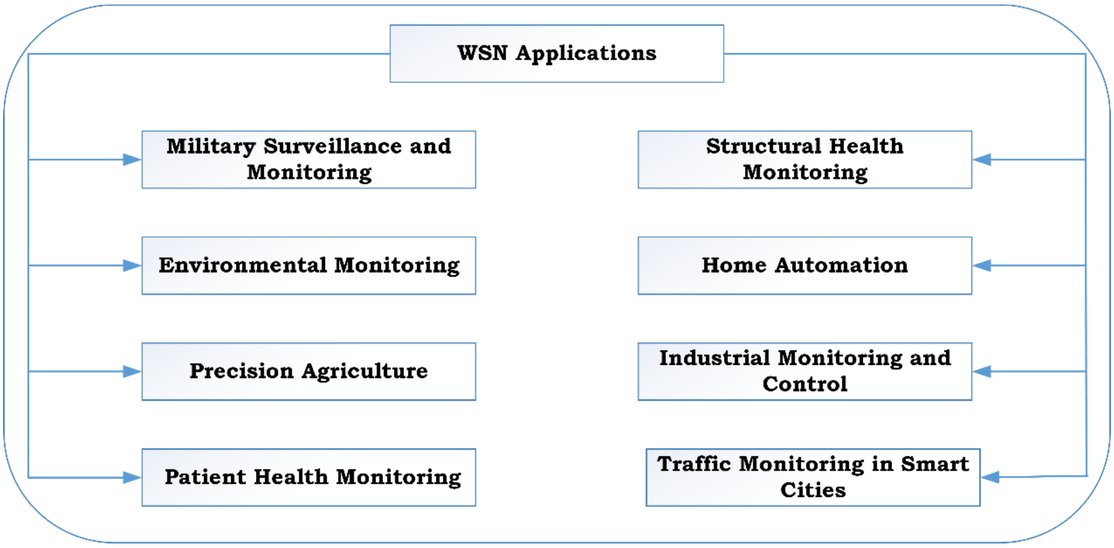

Figure 1. 4 Applications of WSNs

1.4 Routing challenges in WSNs

The design and development of routing protocols are affected by different challenging aspects. The effective communication is achieved by overcoming these challenges. This section describes various routing and design challenges in WSNs.

- **Restricted energy capacity**

  Sensor nodes have limited battery power and they are randomly positioned in the difficult regions. Mostly, it is quite difficult to recharge the battery or to exchange the dead battery.

- **Data Aggregation**

  To effectively utilize network bandwidth, redundant data packets generated by SNs are required to be aggregated which results in reduced data size and less communication load. Data aggregation is the collection of data from various sources and it is performed with the help of suppression, max, min and average operations.

- **Scalability**

  Routing protocols designed must have the capability to scale with the size of the network. A trade off should be maintained between scalability and latency measure of a protocol.

- **Network Dynamics**

  The topology of a WSN keeps on changing because of sensors addition, node failures and energy depletion. Moreover, the SNs are connected by a wireless medium, and this medium is noisy, fault prone, and time bound. So, pathways for routing must reflect good network performance dynamics.

- **Delay**

  Delay is an utmost important factor for time bound/critical applications. The real time applications require information to be sent immediately in a time bound manner else it will be of no use. So, the delay control is the primary objective of the routing protocols in the network.

- **Limited hardware resources**

  The storage abilities, computational functionalities and processing capability of SNs are limited. Due to the hardware restrictions, there is a need for better design of network protocols and software algorithms.

- **Fault Tolerance**

  Physical damage and intrusion of WSNs environment, results in failure of SNs. These defects in SNs should not disrupt the WSNs operation. Fault tolerance is the capability to keep functionalities of the network running without any disruption.

- **Data Delivery Model**

  This model is used to find, how the information is composed and delivered. The data delivery model may be continuous, query-driven, event-driven, and hybrid. In the continuous delivery model, every sensor transmits information periodically. However, in query-driven model, the data transmission is activated when sink generates the query. Additionally, in event-driven model, when an event occurs the transmission of data is triggered. Some networks also employ a hybrid model by utilizing a combination of event-driven, continuous and query- driven models.

- **The quality of Service (QoS)**

  It is defined as the desired quality attributes required by an application. It could be the length of error rate, protection, data consistency and transit delay etc. These factors affect the choice of routing protocols for an application.

1.5 Thesis Organization

This thesis is structured into six chapters. A brief outline of every chapter is presented in the subsequent sections.

The first chapter presents introduction about Wireless Sensor Networks. It gives a detailed discussion about communication architecture of wireless sensor networks with a special focus on hierarchical architecture. The chapter also elaborates characteristics of WSN's and its routing challenges. An effective illustration of these concepts is outlined through diagrammatic representation.

The second chapter presents a comprehensive review of various routing protocols. These protocols are classified based on network structure and properties. The Structure based routing protocols are classified as data-centric, hierarchical and location based. Further, the hierarchical protocol characterization has been categorized as classical and swarm intelligence based. Additionally, the detailed analysis of routing protocols with their objective, methods, key metrics, strength and future scope has been presented. This chapter summarizes routing protocols on the basis of energy efficiency, data aggregation, QoS, Scalability, load balancing, fault tolerance and location awareness.

In third chapter, "An Energy Efficient Load Balanced Cluster - based Routing using Ant Colony Optimization (LB-CR-ACO)" is presented. The proposed protocol is an effort to enhance network life time. It performs optimal clustering based on cluster head selection weighing function. The cluster formation utilizes various parameters like remaining energy of the nodes, received signal strength indicator and node density. The priority weights are assigned among these parameters. The presented protocol also performs a dynamic selection of optimal cluster head periodically which conserves energy, thereby utilizing network resources in an efficient and balanced manner. The optimal route construction is done using ACO in steady state phase for multi hop data transfer. It has been observed through simulations that proposed protocol exhibits better performance for number of alive nodes, energy consumption per round than its peer protocols which shows higher network lifetime.

The fourth chapter presents "Meta-heuristic ant colony optimization based unequal clustering (MHACO-UC) for wireless sensor networks". The main focus in this protocol is to deal with the issues related to unbalanced energy consumption, network performance dynamics. Apart from the optimal cluster head selection this protocol emphasizes on unequal clustering to maintain a fair balance between intra and inter cluster communication load. The initialization of nodes nearer to Base Station (BS) as relay nodes increases the performance.

The Meta-Heuristic Ant Colony Optimization approach selects the optimal path among the nodes which increases the number of packets delivered to the destination. Unequal clustering, novel CH selection, prediction of optimal path using meta- heuristic ant colony optimization reduces the energy consumption effectively. The simulation and comparative analysis of proposed protocol with the existing unequal clustering approaches on the basis of various performance parameters such as packet delivery ratio (PDR), number of packets sent to the BS, energy consumption and residual energy shows the effectiveness of proposed work.

Chapter 5 presents "An Enhanced Energy Proficient Clustering (EEPC) Algorithm for Relay Selection in Heterogeneous WSNs" in order to reduce the energy consumption in the field of sensor tracking events. The main focus of the presented work is to handle mobility of SNs and to deal with link failures. In this work, the network is constructed with both static and mobile nodes. The static nodes are placed in grid structures and mobile nodes are deployed randomly. The nodes select their cluster head (CH) on the basis of their associated placement and energy level. The mobile nodes transmit the data to the CH. Generally, CH transmits the sensing information to the base station. The proposed approach uses the concept of finding relay nodes, which are static nodes. The EEPC algorithm selects the relay nodes based on its velocity and location by calculating particle fitness value. The selected intermediate relay static nodes transmit the collected sensing information to the Base Station (BS) using sensor data fusion technique. During the data transmission if link fault occurs then it could be predicted based on the deviation value. The simulation results show that the proposed approach minimizes the energy depletion and enhances the network lifetime.

The chapter 6 finally presents the conclusion of thesis work along with its future work outlines.

Chapter 2

Literature Survey

The energy efficiency (Hsiung *et al.*, 2007; Rault *et al.*, 2014) is a major cause of concern during the network design phase, as the sensors are manufactured with non-rechargeable batteries. Route selection (Hayajneh *et al.*, 2014) is a critical activity while transmitting messages from source to destination and the major amount of energy is consumed during the data transmission. The hierarchical routing architecture has proved as extremely effective in solving the problem of excessive energy consumption. During data transmission process, the intermediate sensor nodes assist the source node to send data packets to the destination through routing paths (Villas *et al.*, 2013; Shokouhifar and Jalali, 2015). The concept of data aggregation results in efficient use of limited resources of WSNs.

Nowadays, cluster based routing protocol are attaining greater importance. In clustering (Li et al., 2013; Lio et al., 2013; Wu and Taun, 2015) the network is divided into multiple clusters. In this type of routing protocols sensor nodes form clusters, which contains one main node called as Cluster Head (CH) (Nayak and Devulapalli, 2016).

Conventional protocols are called as classical protocols. Self-organized or biologically inspired protocols are called as swarm intelligence based protocols. Classical and swarm intelligence approaches utilize their resources which result in efficient solution for energy consumption. Swarm intelligence based clustering protocols have a major objective of minimizing the energy consumption by performing dynamic clustering on sensor nodes during the setup phase.

Low-Energy Adaptive Clustering Hierarchy (LEACH) was the first protocol used for decreasing the network energy consumption by arranging nodes into clusters (Lu *et al.*, 2014; Arioua *et al.*, 2016). Every round of LEACH operation is divided into setup phase and steady state phase. Active and passive clustering are performed in separate rounds which results in energy aware behavior of LEACH to some extent (Jin *et al.*, 2013; Yan *et al.*, 2013). It has been proved through simulative and analytical technique that a MAC protocol can be used for reducing the network power consumption based on the duty cycle of the node (Anchora *et al.*, 2014). Ant colony optimization based fuzzy system is one of the basic protocols in swarm intelligence based approach, used for enhancing the network lifetime (Jan *et al.* 2015; Tomar *et al.*, 2015).

This chapter illustrates recent research and developments for hierarchical protocols in classical and SI category. It emphasizes on analytical comparison of routing protocols considering various metrics such as energy efficiency, data aggregation, location awareness, QoS, scalability, load balancing, fault tolerance, multipath, query based. Further, the detailed illustration of protocols classification, objective, methods, advantages and future scope has been presented.

In recent years, WSNs have used many routing protocols for enhancing the network performance. The taxonomy of routing protocols classification is represented in figure 2.1. These protocols are classified based on network structure and properties. Network structure performs a significant role in the routing protocols. The node uniformity has been used to categorize the network structure. The primary characteristic of network structure based routing protocols is how nodes connect and transmit the data based on the framework of interconnections.

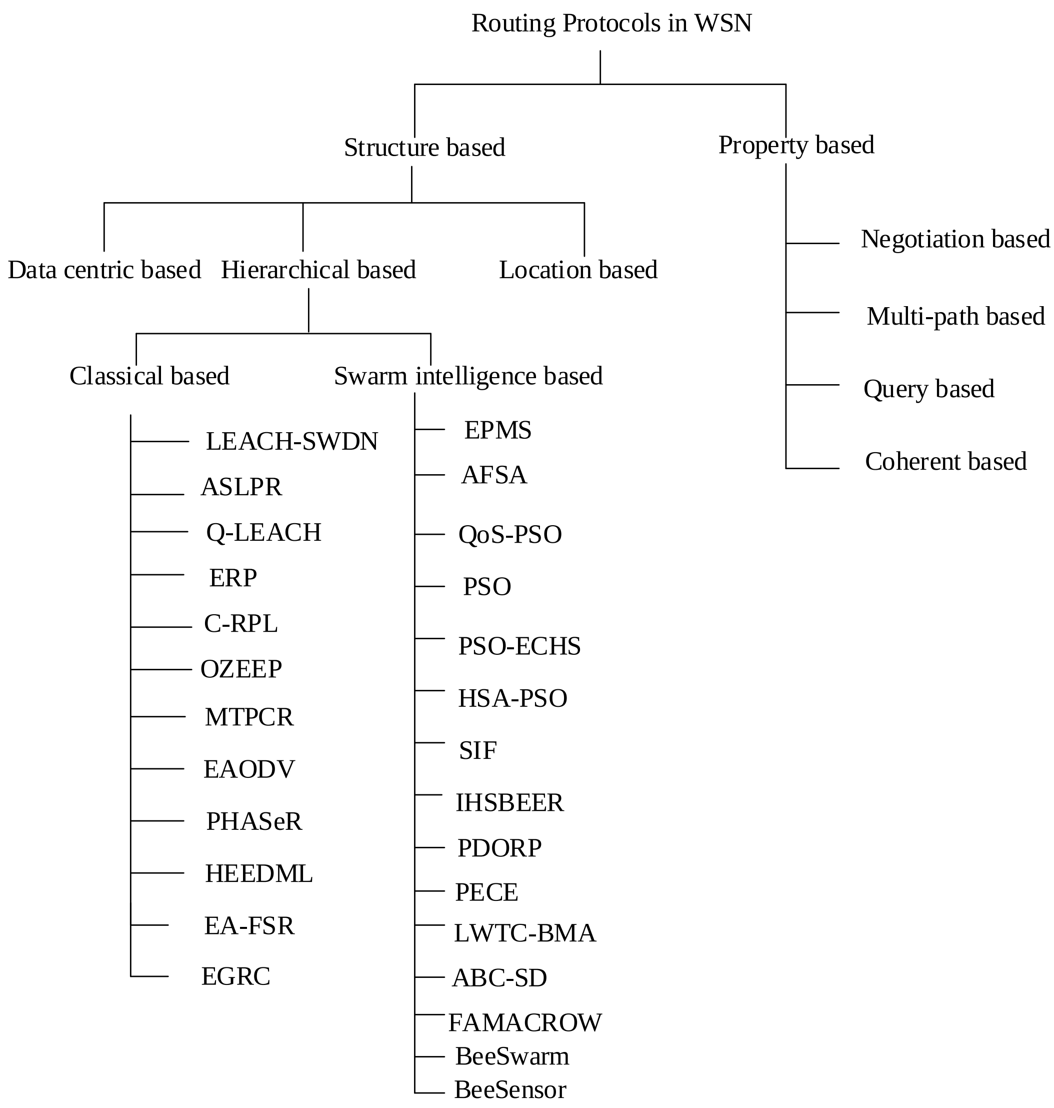

Figure 2. 1 Taxonomy of Routing Protocols

Data-centric, hierarchical and location based are the arrangements of the structure based protocols (Pantazis *et al.*, 2013; Arora *et al.*, 2016). In data-centric communication when source node sends information to sink node the intermediate sensors execute several structures of aggregation on the information created from multiple sources of the sensor network and transmit the aggregated information in the direction of sink. This process results in energy saving by eliminating redundant data. These types of protocols have limited memory storage for data caching. Figure 2.2 illustrates the data centric routing.

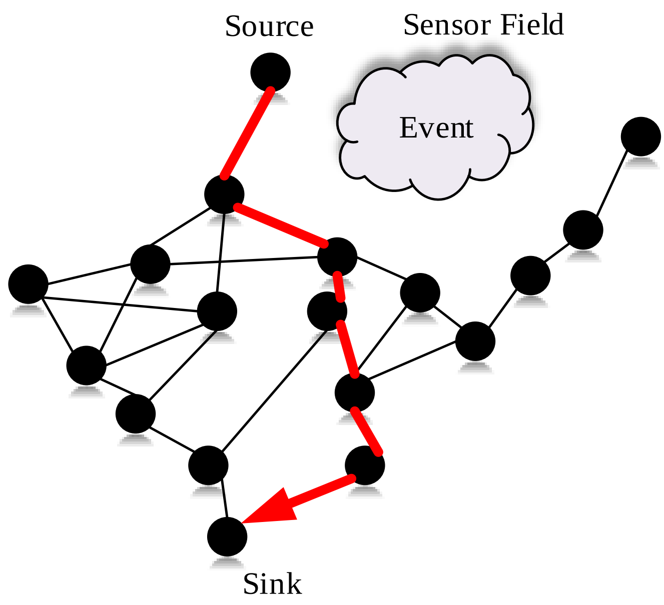

Figure 2. 2 Data Centric Communication with Minimum Energy Consumption Path

In hierarchical routing protocol, the nodes are not identical and they perform various performance based functions. The nodes which have high energy level, can be used for processing and transferring the information. However, the nodes which have lower energy levels are used for sensing the information. These protocols have been further classified into classical and SI. These protocols exhibit convenient topology management, high efficiency energy usage, simple data fusion, simple topology structure, less energy consumption, good load balancing and maximum network lifetime (Baradaran and Navi, 2017; Darabkh et al., 2017). Figure 2.3 illustrates arrangement of nodes and sink in hierarchical manner.

In location based routing SNs are identified by their geographic position. Location based protocols utilize this knowledge for calculating distance metric between SNs and their neighbors or SNs and sink. SNs location database makes it convenient for location based protocols to diffuse a query in a defined region which results in reduced number of transmissions, ultimately leading to energy saving.

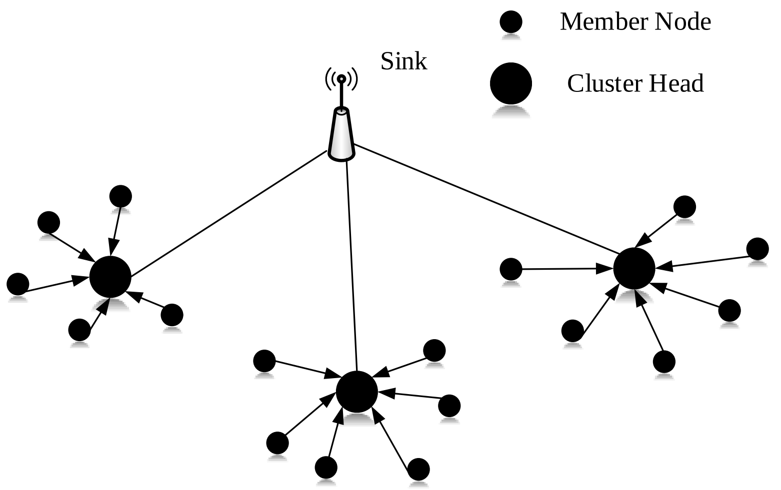

Figure 2. 3 Hierarchical Structure

The operations of WSNs are classified as per their functionalities. The objective of property based routing is to attain optimum performance and protect the insufficient resources of the sensor network (Arora *et al.*, 2016). Negotiation based, multi-path based, query based, and coherent based routing protocols are classified under the property based routing protocols.

The aim of negotiation based routing protocols is the removal of transmission of redundant information by high-level data descriptors. It prevents the dummy data and controls the redundant information directed to the subsequent sensor network or BS by operating a list of negotiation messages ahead of the initiation of real data transmission.

Multi-path based routing attains higher network reliability at the cost of higher network control traffic for preserving multiple pathways to the destination. Sensor networks improve the performance by multiple pathways instead of a single path. If there is any interruption in the primary path, then an alternate pathway is established between the source and the destination node. The fault tolerance is enhanced by conserving multiple pathways between the sender and receiver node at the cost of network control packet overhead and consumed energy. Control messages are generated periodically to keep alternate paths alive.

In query based routing (Yang *et al.,* 2007; Jindal et al., 2015), a query is initiated by receiver node for the information retrieval from the sender. High-Level languages are used to express queries over the network.

In coherent based routing protocol, the information is directed to aggregators after minimum processing. It normally covers time stamping, duplicate suppression etc. This coherent process is mainly used in the energy efficient routing.

It has been observed that hierarchical routing protocols have an edge over other categories for large networks because energy consumption and end to end delay is reduced to a great extent. Hierarchical network structure also provides good scalability and load balancing. However, the point of worry is issues associated with node connectivity and topology maintenance. Data centric protocols use redundant data elimination method to save energy and they are not well suited for large networks because of increased end to end delay, as data is sent by multi hop transmission. Data centric communication is good for small network scenarios. Control message overhead is reduced in location aware routing protocols which leads to lower energy consumption. It is possible due to region attributed query diffusion which lowers the number of transmissions. Location aware protocols have limited scalability especially while handling node mobility. Major point of concern with property based protocols is that they do not provide guaranteed data delivery due to lower throughput and delivery ratio.

2.1 Classical Hierarchical Routing Protocols

Classical hierarchical routing protocols were principally designed for Mobile Ad hoc Networks (MANETs) (Zungeru *et al.*, 2012). However as per researcher's observations, it is a good match for WSNs as well, but it has some major constraints concerning energy and scalability. Clustering performs a critical role in saving the energy of sensor nodes

(Chamam and Pierre, 2010; Sabet and Nazi, 2016; Naeem et al., 2017). Effective utilization of sensor nodes energy is the central focus of cluster based routing in multi-hop communication. The SNs are energy constrained due to their limited battery power. The energy is depleted in SNs while transmitting the information from SNs to the base station. This section investigates a few typical hierarchical routing protocols based on classical (conventional) approach

2.1.1 Protocol Enhancements over LEACH

Low Energy Adaptive Clustering Hierarchy (LEACH) is a classical and adaptive hierarchical routing protocol which considers mainly the energy consumption during its operation (Xiangning and Yulin, 2007). Wang *et al.*, 2017 had proposed Low Energy Adaptive Clustering Hierarchy with Sliding Window and Dynamic number of Nodes (LEACH-SWDN) protocol for enhancing the LEACH outcome. In this protocol, the sliding window generates a random number to make an interval. Average energy of non-CH nodes and initial energy of nodes is utilized to calculate sliding window interval. The size of sliding window determines the selection probability of a CH and expected number of CH. The optimal cluster head is adjusted dynamically based on number of alive nodes (Hayashi *et al.,* 2009, Kumar *et al.*, 2018). Thus, the number of cluster heads are optimally placed and the energy is balanced with the reduced energy consumption in comparison to LEACH, Advanced Low Energy Adaptive Clustering Hierarchy (ALEACH) (Ali *et al.*, 2008), Low Energy Adaptive Clustering Hierarchy-Deterministic Cluster Head Selection (LEACH-DCHS) (Liu *et al.*, 2008) protocols.

Shokouhifar and Jalali, 2015 had introduced an Application-Specific Low Power Routing (ASLPR) protocol which extends the network lifetime as per specified application. Due to complexity of control parameters of proposed algorithm it becomes extremely important to tune them. The hybrid optimization based on simulated annealing and genetic algorithm is utilized for optimizing control attributes which enhances the lifetime of network. The outcome of simulation gives enhanced lifetime and minimum utilization of energy compared to LEACH, Energy Aware LEACH (LEACH-EP) (Jia *et al.*, 2010), LEACH with Distance based Threshold (LEACH-DT) (Kang and Nguyen, 2012) protocols.

Manzoor *et al.*, 2013 proposed Quadrature-LEACH (Q-LEACH) protocol for enhancing the throughput, stability period and network lifetime for homogeneous networks. Optimal clusters are formed by partitioning the network into four quadrants and further into subsectors which provides better node distribution. It solves the problem of higher energy depletion of farthest nodes in the cluster. Optimal clustering leads to good distribution of nodes in a particular field. This protocol achieves better coverage of the entire network and energy efficient operation in comparison to Distributed Energy Efficient Clustering (DEEC) (Qing *et al.*, 2006), Stable Election Protocol (SEP) (Smaragdakis *et al.*, 2004) and LEACH protocols.

Bara'a and Khalil, 2012 had proposed enhancements over LEACH protocol for providing the energy efficiency and improved stability period for heterogeneous sensor networks. Authors named it as Evolutionary Routing Protocol (ERP). Evolutionary Algorithm (EA) or meta-heuristic approach with modified fitness function is utilized to introduce compactness (cohesion) and separation error for improved clustering. Evolutionary approach function along with improved fitness function helps the protocol to achieve energy efficiency and better stability period than Hierarchical Clustering Routing algorithm (HCR) (Sudevalayam and Kulkarni, 2011) protocol. ERP fails to achieve better stability period than SEP protocol whereas energy efficiency is better than SEP.

2.1.2 Cooperative Routing Protocol for Low-Power and Lossy Networks (C-RPL)

WSNs are used for performing various functions which execute different tasks like sensing, collecting the required information from various sensing areas and finally processing it. These heterogeneous data sets may require different processing functions as well. Hence, conventional tree-based routing will not suffice the job. The network is divided into numerous RPL instances in IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL) (Winter et al., 2012). RPL does not explain any mechanism for selecting the node that belongs to an instance. Marc Barcelo *et al.*, 2016 had developed Cooperative-RPL (C-RPL) protocol which is a collaborative and collected mechanism for creating several instances among the nodes. C-RPL facilitates the coordinated effort among RPL Instances. In C-RPL, the aim of each instance is to increase the performance with decreased energy consumption. In RPL, both the instances and their constructions operate independently from each other. The nodes belonging to each instance must be defined earlier to enhance the flexibility of routing procedure.

In C-RPL, predefining of nodes is not needed, as it is constructed according to the objective function of each occurrence, their locations, and particular system conditions. Using coalitions, a larger C-RPL instance maximizes the performance of the system but consumes a lot of power. A new fairness analysis is used in sensor networks for attaining good trade-off in terms of consumption of energy and performance using the cooperation parameter α. Performance comparison of C-RPL and RPL with heterogeneous traffic done using MATLAB. Simulations in MATLAB platform reveals that a better trade-off among performance parameters and energy efficiency is achieved in C-RPL protocol than the RPL protocol for heterogeneous traffic.

2.1.3 Optimized Zone-based Energy Efficient Routing Protocol (OZEEP)

WSNs face some problems like connectivity, bandwidth usage, coverage of network and these problems may affect performance of the network. The clustering ensures network scalability but it requires careful setting up. Srivastava and Sudarshan, 2015 introduced the Optimized Zone-based Energy Efficient Routing Protocol (OZEEP). Two stages of clustering procedures are used in this algorithm. Fuzzy Inference System is used during the primary stage. This system uses Fuzzy Logic Controller (FLC) for selecting the CH by narrowing down on best nodes as contenders. FLC is comprised of fuzzifier, de-fuzzifier, fuzzy interference system, and fuzzy decision rules. The input specifications of the system include energy of each node, distance of the node from BS, node density and the mobility of each node. To promote the best node as CH, a genetic procedure is used. Furthermore, an ideal number of such CHs are computed in the system for acknowledging complete scope and hence adjusted further. The fuzzy module performs first level of screening which specifies nodes that can battle for becoming CH. In second stage genetic algorithm is applied which provides optimal balanced distribution of CHs. OZEEP achieves better energy efficiency and very less packet loss in comparison to Zone – based Energy Efficient Protocol (ZEEP)(Srivastava *et al.*, 2013).

2.1.4 Minimum Transmission Power Consumption Routing (MTPCR)

The Received Signal Strength Indicator (RSSI) measure of a received packet and contentions occurred during Media Access Control (MAC) layer are two factors which can influence the transmission bandwidth. Chen and Weng, 2012 proposed Minimum Transmission Power Consumption Routing (MTPCR) protocol for power - aware routing. This protocol identifies the preferred pathway for routing which reduces the energy consumption. MTPCR protocol also considers that transmission bandwidth is decreased due to higher energy consumption in applications handling mobility of nodes. Power consumption analytics are obtained by maintaining neighboring nodes information. The bandwidth of good pathway is sustained by using a pathway maintenance mechanism. Node density is used to decide whether to activate pathway maintenance procedure or not. The simulation results give reduced power consumption and better network bandwidth than Ad-hoc On Demand Distance Vector(AODV)(Feng and Zhu, 2009), Dynamic Source Routing (DSR) (Johnson and Maltz, 1996), Min Max Battery Cost Routing (MMBCR) (Toh, 2001), Improved Minimum Battery Cost Routing (xMBCR) (Vergados *et al.,* 2008; Rai *et al.*, 2009), Power Aware Multiple Path (PAMP) (Yang *et al.*, 2008). MTPCR also reduce the breakages in pathways.

2.1.5 Extended Ad hoc On-Demand Distance Vector (EAODV) routing protocol

In this protocol WSN is assumed as a scale-free weighted network. Multicast communication minimizes bandwidth, cost, and energy. Zhang *et al.*, 2015 had developed a multicast routing protocol based on Distributed Minimum Transmission (DMT) called Extended Ad hoc On-Demand Distance Vector (EAODV). Every sensor node has a similar communication range and fixed transmitting power. If the threshold of the received power is smaller than the accepted signal, then the data packets are successfully accepted. To provide route optimization solution EAODV protocol selects forwarding routes which connect multicast receivers. EAODV exhibits better performance in terms of package loss rate, delay, throughput and energy consumption as compared to AODV (Perkins *et al.*, 2003), LEACH protocols.

2.1.6 Proactive Highly Ambulatory Sensor Routing (PHASeR)

The robust and dynamic routing of data is enabled in mobile WSNs by several methods. Proactive Highly Ambulatory Sensor Routing (PHASeR) is a protocol proposed by (Hayes and Ali, 2015) for the purpose of radiation mapping by unmanned automobiles.

As per proposed protocol, in mobile environments, a global Time Division Multiple Access – Media Access Control (TDMA-MAC) layer does not need any dynamic scheduling for sustained gradient measure. The blind forwarding method is used by this protocol to send messages in multipath manner. A stable time slot will generate collision-free TDMA MAC layer. The cycle length is determined using the sensors sampling frequency, where there exists a predefined length for each time slot. Hop-count gradient is used to execute blind forwarding by PHASeR. All neighboring nodes hear about the communication and it is the receiving node which independently finalizes the need to send any received information further in the network based on hop count gradient value. The PHASeR method is mathematically analyzed for scalability, traffic load, and mobility. This protocol gives better performance measures for a wide range of applications. PHASeR shows reduced energy consumption in comparison to AODV, Optimized Link State Routing (OLSR) (Yang *et al.*, 2009).

2.1.7 Multi-Level Hybrid Energy Efficient Distributed Clustering protocol (HEEDML)

Singh *et al.*, 2016 had developed a hybrid energy efficient distributed clustering protocol (HEED) to deal with multiple levels of heterogeneity, and this protocol is also called as HEED MultiLevel (HEEDML). Residual energy and intra-cluster communication cost are the two parameters used for CH selection to improve the network lifetime in HEED (Younis and Fahmy, 2004). Residual energy is used for initial CH selection. When the range of a node falls in multiple CHs, there occurs a tie and intra cluster communication cost is utilized to remove this conflict. Distance and node density are two additional parameters used for CH selection procedure in fuzzy implementation. After CHs selection the data aggregation is performed and data is transferred through multi-hop transmission. In fuzzy logic based and non-fuzzy based implementations the protocol executions are illustrated as HEEDML-0/1/2/3/4. Protocol deals with five levels of heterogeneity for energy.

The difficulty of imprecise data and uncertainties are easily handled using this method. The proposed protocol provides better performance in terms of total energy consumption, throughput, packet delivery, average delay, and transportation load in comparison to its earlier variants.

2.1.8 Energy-Aware Fisheye State Routing (EA-FSR)

Kumar *et al.* 2013 had developed an Energy-Aware Fisheye State Routing (EA-FSR) protocol. It considers energy as the basic parameter for selecting a neighboring node rather than distance. The energy of all the neighboring nodes is compared to find a node with highest remaining energy. An energy aware path selection algorithm is utilized along with basic Fisheye State Routing (FSR) (Pie *et al.*, 2000) mechanism. Packets are forwarded using the nodes selected on the basis of the most efficient parameters of energy. Distance between nodes and sink is considered during this process. The simulation is performed under different parameters using QualNet 5.0. (Garg *et al.*, 2013). This protocol attains better performance with reduced energy consumption than FSR protocol.

2.1.9 EGRC (Energy - Efficiency Grid Routing based on 3D Cubes) for UASNs

Wang *et al.*, 2016 have proposed a novel energy efficient protocol for reliable data transmission for environmental monitoring in Underwater Acoustic Sensor Networks (UASNs). Energy consumption is considered as one of the most challenging issue in underwater environmental monitoring applications like submarine oil pipeline monitoring. Therefore, authors proposed Energy - Efficiency Grid Routing based on 3D cubes (EGRC) for UASNs. EGRC considers complex attributes of underwater medium which are 3D dynamics of topology change, node density, node mobility, higher propagation delay and CH rotation mechanism.

The system is modeled as a big 3D cube which utilizes multi-hop architecture, MAC layer duty cycle mechanism to maintain sleep/wake up schedule for energy saving and an energy efficient routing protocol for network layer. 3D underwater network is configured as a collection of 3D Small Cubes (SCs) which are assumed as clusters. Node density depends upon size of SCs. EGRC proposes a novel cluster head selection approach on the basis of higher residual energy and smaller distance to BS. Further, a dynamic cluster head selection mechanism is introduced where SC's becomes cluster heads on rotation basis for a predetermined time period. An efficient search algorithm is introduced for next hop selection during optimal route construction which considers end to end delay, distance and energy metrics as selection parameters. Simulation of EGRC is performed on NS-2 with Aqua-Sim package (Pereira *et al.*, 2015) which proves that EGRC exhibits an enhanced network lifetime and better energy efficiency in comparison to LEACH, Energy and load-balance LEACH (EL-LEACH) (Quynh *et al.*, 2012), Energy efficient Routing Protocol based on Physical distance and Residual energy (ERP^2 R)(Wahid *et al.*,2011), Vector Based Forwarding (VBF)(Xie *et al.*, 2006) and Layer by Layer Angle- Based Flooding (L2-ABF)(Ali *et al.*, 2014) protocols. EGRC also exhibits less end to end delay in comparison to VBF and L2-ABF protocols.

The following observations have been made about the reviewed classical hierarchical routing protocols:

Optimum selection of CHs with respect to number of SNs, is the ideology of LEACH-SWDN to conserve energy whereas the compromising factor is the increased network load due to control packet overhead in each round. However, authors insist that it has a nominal effect on network performance. The novelty of ALSPR lies in extending the network lifetime based on specific application by optimizing control attributes using Genetic Algorithm and Simulated Annealing. However, protocol fails to deal with large scale network topologies. Q-LEACH achieves better network coverage and energy efficiency through optimal distribution of SNs by performing optimized sub sectoring using randomized clustering algorithm. Q-LEACH needs further enhancements to deal with mobility in dynamic network scenarios. ERP approach function and improved fitness function (cohesion, separation) leads to balanced clustering mechanism which in turns provides energy efficiency for heterogeneous networks. However, ERP fails to achieve better stability period than SEP. C-RPL protocol achieves an optimum balance between performance parameters and network energy efficiency than RPL. Future enhancement of the protocol is required to implement its operation in decentralized network scenarios. OZEEP protocol is better a choice for real time applications and deals with SNs mobility as well. It achieves higher energy efficiency, low packet drop rate than ZEEP. MTPCR utilizes an optimal path discovery and maintenance mechanism which provides improved transmission bandwidth and reduced path breakages. It is a good choice for mobility based applications. EAODV protocol provides QoS awareness and handles mobility of SNs. However, robustness of protocol needs further enhancement. The PHASeR protocol can effectively handle mobility in dynamic network scenarios. It is well suitable for applications like radiation mapping by unmanned vehicles. The PHASeR shows robust operation as well. HEEDML provides very high energy efficiency by utilizing fuzzy and non-fuzzy implementations of protocols. Protocol enhancements are required to handle mobility in dynamic environments. EA-FSR fails to deliver in high mobility based applications. EGRC protocol is the best choice for applications requiring reliable and energy efficient data transmission in UASNs.

2.2 Swarm Intelligence based hierarchical routing protocols

Swarm intelligence (SI) based protocols have an essential idea of self-association, self-organization which incorporates positive feedback, negative feedback and cooperative behavior in decentralized manner.

Ant colony optimization (ACO) (Singh *et al.*, 2012; Singh *et al.*, 2014; Ye and Mohammadian, 2014) particle swarm optimization (PSO) (Saleh *et al.*, 2014; Kulia and Jana, 2014), bee colony optimization (BCO) (Fei *et al.*, 2016) are various SI based meta-heuristic algorithms used for routing. In ACO, the activity of laying pheromone by ants is a real feedback instrument to enroll more ants with the end goal that more pheromone is arranged on the shortest path to destination. Additionally, ant uses an indirect coordination mechanism called stigmergy which is utilized in the combined problem-solving practices. The ants have a nature of leaving pheromone, a compound substance, which is left for other ants to perform their stigmergic communication.

PSO is one of the swarm intelligence approach in which swarm is represented as a group of particles. During transmission, the swarm will move in the search space to discover the minimum distance path. Each particle has current position, pbest (personal best) position, gbest (global best) position and velocity. Current position specifies the position of a particle in current time. Pbest represents the best position of each particle till that time. Gbest is the best position of any particle among all in search space. The velocity means the personal velocity of each particle. In this algorithm, each and every particle tries to move towards the particle having solution. If movement is completed by following the particle having solution, that is considered as an optimal solution.

In Artificial Bee Colony (ABC) (Fei, *et al.*, 2016), the possible solution for routing is the position of food source and quality corresponds to the nectar amount. There are three kind of bees which are employed bees, onlooker bees, scout bees and they are used to solve the optimization problem. The food source count is equal to the number of employed bees. So every employed bee has a food source around the hive. Onlooker bees continuously keep an eye on the dances of employed bees and select food source accordingly. Scout bees appear if the food source of employed bees is forbidden. There are a number of protocols proposed by the researchers with the help of the swarm based optimization algorithms. A few of those protocols are discussed below.

2.2.1 Energy efficient PSO based routing algorithm with Mobile Sink (EPMS)

Wang *et al.*, 2016 introduced a clustering algorithm based on particle swarm optimization using a portable sink. Virtual clustering and PSO is collectively used in EPMS to attain energy efficient operation. A virtual clustering method utilizes information about a node's location and residual energy parameters of SNs to find CHs. EPMS routing algorithm defines three formats of data packets which are Hello packet, Message-s packet, and Message-h packet. The Hello packet is used to find which cluster area has sent information to the mobile sink. Message-h packet is used for sending information to the cluster head. Finally, Message-s packet is used for sending information to the sink node. The simulation results exhibit that energy consumption of the overall network has decreased to almost 12%, ensuring longer network lifetime than LEACH, Two-Tier Data Dissemination (TTDD) (Luo *et al.*, 2005). However, there is only a slight improvement in the jitter values and end-to-end delay.

2.2.2 Artificial Fish Swarm Algorithm (AFSA)

Helmy *et al.*, 2015 developed a hierarchical routing protocol called Artificial Fish Swarm Algorithm (AFSA) which is a SI based optimization protocol for minimizing the usage of energy and enhancing the network lifetime. This approach selects the optimum CH by using Preying, Swarming and Following. A fitness function is utilized to select a better CH based on the swarm behavior. Simulation results in MATLAB show that the protocol exhibits energy efficient operation in comparison to LEACH (Heinzelman *et al.*, 2000) and PSO (Siew *et al.*, 2012).

2.2.3 PSO based routing algorithms

Liu *et al.*, 2012 proposed a QoS based agent-assisted routing algorithm QoS-PSO. In this algorithm, synthetic QoS is selected and this QoS is an adaptive value of PSO algorithm for enhancing the entire network performance. The flow of network communication, routing state of each node and network topology changes were examined by intelligent software agents. These agents were used for network maintenance and routing. QoS-PSO protocol exhibits excellent QoS measure for latency and packet loss in comparison to AODV, Energy Efficient Ant Based Routing (EEABR) (Camilo *et al.*, 2006). The protocol performance is better for larger networks in terms of scalability whereas network control packet overhead is raised with large route discovery.

Kulia and Jana, 2014 found solution for two most commonly known optimization problems which are energy efficient routing and clustering. Authors presented linear and non-linear formulations for these two important optimization problems using PSO algorithm. Efficient particle encoding scheme with its multi-objective fitness function is better suited for routing and clustering solution using weighted sum approach. A routing trade-off is created between delay in forwarding data packets and transmission distance. PSO based optimization algorithm selects a route from all the gateways to base station which has comparatively lower overall distance as well as less number of data forwards. The encoding scheme and the multi-objective fitness function is applied using weighted sum approach. The protocol exhibits a better performance for total data sent to BS, network lifetime, inactive SNs in comparison to GA based Routing (GAR)(Gupta et al., 2013), Minimum Hop Routing Protocol for Home Security (MHRM) (Chiang et al., 2007) protocols.

Rao *et al.*, 2016 implemented a PSO based Energy efficient Cluster Head Selection algorithm (PSO-ECHS). The fitness function and particle encoding are used in PSO-ECHS. Selection of cluster head is done by considering various parameters like sink distance, residual energy and intra-cluster distance to calculate weight function which leads to energy efficient operation of protocol. The protocol attains better performance for network lifetime and energy consumption in comparison to LEACH, Centralized LEACH (LEACH-C) (Heinzelman *et al.*, 2002) and Energy-LEACH (E-LEACH) (Xiangning and Yulin , 2007).

Shankar *et al.*, 2016 had developed an energy efficient hybrid Harmony Search Algorithm (HSA) and PSO based algorithm known as HSA-PSO. CH selection is based on the criteria of distance and residual energy. This algorithm attains better convergence and higher search efficiency. In HSA-PSO, it first initializes the network parameters and assigns values to velocity, position of particle fitness function and hybrid matrix. These parameters describe Particle Harmony Memory (PHM). PHM generates a new improved harmony. An update about hybrid harmony memory, particle position and velocity is maintained. The hybrid HSA- PSO algorithm achieves better network lifetime, First Node Die (FND), Last Node Die (LND), standard deviation values than LEACH, Harmony Search Algorithm (HAS) (Geem et al., 2001), and PSO.

2.2.4 Swarm Intelligence based fuzzy routing protocol (SIF)

The sensor nodes are battery powered and it is hard to exchange or recharge the battery. Zahedi *et al.*, 2016 developed an SI-based fuzzy routing protocol (SIF). There are two basic steps in setup phase: Cluster formation and CH selection. The entire network is divided into clusters using fuzzy c-means algorithm, which is relied upon to accomplish a balanced cluster with a worthy distribution of CHs throughout the system. A priority factor (PF) is computed after cluster framing by using Mamdani fuzzy framework to choose the CH. Three factors are considered in the SIF as fuzzy data sources which are distance from cluster centroid, distance from the BS and residual energy.

This scheme finds the required number of groups needed in the network for clustering and reduces the sum of distance between cluster centers and instances. The performance of the fuzzy scheme is affected by applying fuzzy rules (Sambariya *et al.,* 2016). A hybrid swarm intelligence algorithm is developed for optimizing the fuzzy rule base by utilizing the concept of simulated annealing and firefly. This hybrid swarm intelligence algorithm performs balanced clustering to achieve minimum overall energy consumption than LEACH, LEACH protocol using Fuzzy Logic (LEACH-FL) (Ran *et al.*, 2010), LEACH Distance based Threshold (LEACH-DT) (Kang, S. H., & Nguyen, 2012), and ALSPR.

2.2.5 Predictive Energy Consumption Efficiency (PECE) routing technique

Zhang *et al.*, 2015 introduced predictive energy consumption efficiency (PECE) based routing technique. In this technique, the proposed work is divided into cluster formation phase and stable data transfer phase. In the first phase, residual energy, degree of a node and distance between the nodes are used as parameters for CH selection. In the next phase of multi-hop data forwarding, PECE is structured by bee colony optimization. The routing pathway is computed by considering the energy consumption values, hop count, delay measure from source to sink node. Optimization structure of algorithm enhances the cluster quality and network performance by reducing power consumption and achieves the enhanced coverage as well. It prolongs the network lifetime in comparison to traditional clustering algorithm LEACH, Power-Efficient GAthering in Sensor Information Systems (PEGASIS) (Lindsey and Raghavendra, 2002; Huang *et al.*, 2009).

2.2.6 Improved Harmony Search Based Energy Efficient Routing Algorithm (IHSBEER)

Zeng and Dong, 2016 proposed IHSBEER protocol. The harmony search algorithm has a simple concept and strong global search capability. The important stages of traditional HS algorithm are initializing the algorithm parameters, initialization of harmony memory (HM), improvising harmony memory, update the HM and repeat till termination condition is met. The continuous optimization problem is solved using this algorithm but WSN routing is a discrete optimization issue because of uncertain behavior of SNs. So, the traditional HS algorithm is not useful for addressing routing problem of WSNs.

Moreover, a number of improvements are needed in traditional HS algorithm in accordance with attributes of routing problem. In harmony search algorithm, the pathway to forward the message from a source to sink is denoted as harmony. Initially, the enhancement to the encoding of HM is proposed as per the attributes of WSN routing. Next, the dynamic adaption avoids prematurity and supports local search capability. Lastly an efficient local search approach for improving the local search capability, accuracy, and convergence speed of routing algorithm was applied. The protocol achieves enhanced network lifetime in comparison to EEABR, Ant Colony Optimization Router Chip based routing (ACORC) (Okdem and Karaboga, 2009) and Energy Efficient Harmony Search Based Routing (EEHSBR) (Zeng and Dong, 2014) protocols.

2.2.7 PEGASIS-DSR Optimized Routing Protocol (PDORP)

Energy consumption is the most significant factor in WSN. The routing protocols are used to find a solution to the issues associated with energy efficiency and Quality of Service (QoS). Dynamic Source Routing (DSR) protocol enhances the network performance by utilizing sleep/wake up scheduling mechanism. It leads to reduced energy consumption. However, it increases the waiting time. Brar *et al.*, 2016 had developed an energy aware routing protocol mentioned as PDORP with a directional transmission. This protocol has the features of both DSR and PEGASIS routing protocols, and the optimal pathway of routing is identified by hybridization of Bacterial Foraging Optimization (BFO) and GA (Genetic Algorithm).

The sensor nodes are deployed arbitrarily and node distance from neighboring nodes is calculated and compared with a threshold value. The optimal route is selected in the large coverage set of nodes using path finding algorithm. The proactive and reactive qualities of routing model are used in PDORP. To attain the better results of QoS and increased network lifetime, an advanced hybridization technique is used. The hybrid features of BFO and GA are utilized in PDORP to achieve better QoS measure and enhanced network lifetime.

2.2.8 Light Weight Trust Based Secure and Energy Efficient Clustering using Honey Bee Mating Algorithm (LWTC-BMA)

The procedure of honey bees mating is a swarm intelligence based technique, where the search algorithm simulates the true honey bees mating process. Sahoo *et al.*, 2013 developed LWTC-BMA protocol which utilizes a model of pragmatic energy consumption used for evaluating the network lifetime. This protocol is divided into Cluster setup and steady state phases. CH selection is carried out in set-up phase. Protocol builds up a trust method to avoid any malicious node to become a CH. The system discovers trustworthy and energy efficient cluster head. The steady-state phase is utilized for multi-hop data forwarding. This protocol performs better in terms of a total energy consumption, alive nodes, average residual energy in comparison to LEACH, Time Constrained Bee's Mating approach (TCBMA) (Senthil Kumar et al., 2011) protocols.

2.2.9 Cluster based Artificial Bee Colony (ABC-SD) routing protocol

Ari *et al.*, 2016 developed a cluster based power efficient routing protocol named as ABC-SD. This protocol utilizes search features of Artificial Bee Colony (ABC) which is used to design the low power consumption cluster. A Linear Programming formulation which utilizes a multi objective fitness function is accomplished at the sink using centralized control mechanism. The fast convergence characteristics and efficient features of meta-heuristic ABC are used for building clusters. The choice of CHs in clustering defines routes for inter-cluster communication. A trade-off between energy and hop count is taken to compute cost based measure for optimal routing path selection. The ABC-SD technique is evaluated with various technologies in different network sizes and results illustrate the efficiency of protocol based on coverage, packet delivery ratio and network lifetime. It is better than Particle Swarm Optimization-Centralized clustering (PSO-C) (Kennedy, 2010), LEACH-C, LEACH, ABC- Centralized clustering (ABC-C) (Karaboga *et al.*, 2012). protocols.

2.2.10 Fuzzy and Ant Colony Optimization Based Combined MAC Routing an Unequal Clustering Cross-layer Protocol (FAMACROW)

Gajjar *et al.*, 2016 proposed Fuzzy and ACO based FAMACROW protocol for energy efficient routing. This protocol has network setup, neighbor search and steady-state mode of operation. In the network setup phase, all the nodes in the sensing area are arranged into layers. During neighbor discovery each and every node will transmit the NODE_DETAILS message using CSMA MAC whose signal strength is sufficient to communicate with all neighboring nodes in that layer. The distance of a node from its neighbor is computed by finding absolute difference of distance of a node to MS and distance of neighboring node to MS. The protocol utilizes fuzzy logic with remaining energy, link quality, neighboring node parameters for CH selection. After the steady state phase, neighbor finding stage is repeated to create FAMACROW protocol immune to link or node break down. Ant Colony Optimization is used in the FAMACROW for efficient and reliable routing identification from CH to MS. The hot spot problem (Ever et al., 2012; li *et al.*, 2013) affecting the permanent sink node is overcome by unequal clustering and artificial intelligence. The protocol shows better energy efficiency, throughput, network settling time and latency than Improved Fuzzy Unequal Clustering (IFUC) (Mao *et al.*, 2013), Energy Aware Unequal Clustering using Fuzzy logic (EAUCF) (Bagci and Yazici, 2013), Unequal Cluster based Routing (UCR)(Chen *et al.*, 2009) and Unequal Layered Clustering Approach (ULCA)(Zhao and Wang, 2010) protocols.

2.2.11 Bee Swarm based protocols

In hierarchical WSN, CH utilizes maximum energy because of the overload of information from SNs. Mann and Singh, 2017 had introduced a BeeSwarm protocol containing three stages which are BeeCluster construction, BeeSearch for finding route, BeeCarrier for data transmission. BeeCluster, BeeSearch, BeeCarrier add to the robustness of protocol. The cluster construction is performed by executing CHs selection and formation procedure. In the setup phase, first the CH is selected using ABC meta-heuristic. After the selection of CH, the formation of clusters is done. A join request is transmitted to all the neighboring nodes from the CH to form the clusters. The Bee Search phase determines the routes for communication through scout bees. This is carried through forward and backward search procedures. The network is examined through the forward search. The pathway among various nodes and BS is created and maintained in the backward search approach. Bee Swarm enhances the lifetime of the network by 10-15 % in comparison to Multi-path Routing Protocol (MRP) (Yang *et al.*, 2010), Evolutionary Routing Protocol (ERP) (Bara'a, and Khalil, 2012). Saleem *et al.*, 2012 introduced a bee-inspired protocol called as BeeSensor. This protocol uses Bee agent model, agent to agent communication to find optimal paths and enhances the performance of protocol. The protocol exhibits better results in terms of PDR, latency minimum energy utilization and network lifetime.

The following observations have been made about the reviewed Swarm Intelligence based hierarchical routing protocols:

EPMS protocol utilizes virtual clustering concept along with particle swarm optimization and achieves energy efficiency. However, it is not suitable for real time applications. AFSA protocol lacks QoS awareness and needs further improvements to handle mobility. QoS-PSO algorithm is a better choice for real time applications as it provides excellent QoS measure. However, protocol needs further improvement to effectively handle high mobility in dynamic scenarios. QoS-PSO exhibits very good scalability for large network topologies. PSO protocol requires further enhancements to handle mobility in dynamic network scenarios. PSO-ECHS protocol exhibits high energy efficiency. However, future enhancements are required for heterogeneous networks. HSA-PSO achieves high energy efficiency and better convergence. HSA-PSO protocol needs improvement in terms of scalability for large scale networks. SIF exhibits application specific behavior as it can be optimized as per nature of application to extend network lifetime. However, protocol enhancement is required handling sink/SNs mobility. PECE protocol performs optimal clustering which leads to balanced energy consumption as well as enhanced network lifetime. The limited scalability of protocol is still a concern. Performance of IHSBEER protocol is unmatched for small size networks and it is a better choice for applications like industrial monitoring and control, body area networks, smart homes etc. However, in large scale WSN an undesired situation may arise in which forward paths of SNs are through sink. The hybrid features of PEGASIS, DSR along with Genetic algorithm and BFO optimization in PDORP achieves better QoS and energy efficiency. PDORP protocol is well suited for real-time applications. LWTC-BMA protocol needs further enhancements to handle mobility aspect for dynamic network scenarios and its performance for very large scale networks still needs to be explored. ABC-SD protocol exhibits high energy efficiency and QoS measure. It is a good choice for real time applications. FAMACROW protocol provides a better solution to hot spot problem using unequal clustering and ACO. BeeSwarm protocol needs application specific implementation on real test beds. The scalability of BeeSensor is required to be validated for large scale networks. Table 2.1 shows the main characteristics of the different classical and SI based hierarchical routing protocols.

Table 2. 1 Relevant Literature on Classical and Swarm Intelligence based Hierarchical Routing Protocols

Protocols	**Objective**	**Methods**	**Advantages**	**Metrics**
LEACH-SWDN **(Wang *et al.*, 2017)**	To discover optimal CH count dynamically and energy efficiency	Optimal Sliding window, dynamic optimization of CHs	Balanced and reduced energy consumption per round, Enhanced network lifetime	Network life time, Energy consumption, Dynamic optimal CH count, Success rate
ASLPR **(Shokouhifar and Jalali, 2015)**	To achieve enhanced network lifetime and balanced energy consumption of SNs	Hybrid Genetic and simulated annealing, multi objective fitness function	Enhanced network lifespan, balanced energy consumption	FND (First Node Dies), HND (Half Node Dies), LND (Last Node Dies), Success rate
Q-LEACH **(Manzoor *et al.*, 2013)**	To achieve a better stability period, enhanced network lifetime and coverage	Optimal clustering by applying randomized clustering concept	Improved network coverage and energy efficient operation	Stability Period, Network Life time and Throughput
ERP **(Bara'a and Khalil, 2012)**	To achieve longer network lifespan and enhanced stability period for heterogeneous networks	Evolutionary Approach with modified fitness function (cohesion, separation)	Improved clustering and better energy efficiency, Better stability period	Average remaining energy of nodes, FND, LND, Alive nodes
C-RPL **(Marc Barcelo *et al.*, 2016)**	To attain better network energy consumption and a fair network performance	A cooperative strategy& cooperative parameter α	Trade-off between energy consumption and network performance is achieved, Avoid congestion and provides QoS measure	Average number of hops, Average expected number of transmissions (ETX), Average Packet Delivery Ratio, average energy consumption
OZEEP **(Srivastava and Sudarshan , 2015)**	To achieve optimal clustering, energy efficiency, Fault tolerance, scalability	Genetic Fuzzy System for optimal CHs selection	Reduced energy consumption, handles mobility aspect and good for time driven applications	Network Lifetime, packet drop rate

MTPCR **(Chen and Weng, 2012)**	To reduce power consumption, avoid network path breakages and to improve transmission bandwidth	Optimal path discovery algorithm, path maintenance mechanism	Better network bandwidth and enhanced network lifetime than AODV, DSR, MMBCR, xMBCR, PAMP	Control packet overhead, power consumption, hop count, average hop length, throughput, path breakage count, network connectivity
EAODV **(Zhang *et al.*, 2015)**	To ensure both energy efficiency and network performance	Multicast tree optimization, Distributed Minimum transmission	Achieves enhanced network life time and performance	Energy consumption, delay, Throughput, package loss rate
PHASeR **(Hayes and Ali, 2015)**	To enable the mobility and robustness factor in routing	Blind forwarding, gradient maintenance measure	Low overhead and better network performance	Energy consumption, packet delivery ratio, average packet delay, throughput, control overhead, Average end-end delay
HEEDML **(Singh *et al.*, 2016)**	To enhance the network lifetime and performance for heterogeneous networks	Fuzzy and non-Fuzzy based implementations	Increase in network lifetime, PDR and low control overhead	Packet delivery ratio, total energy consumption, throughput, average delay, and network traffic overhead
EA-FSR **(Kumar *et al.* 2013)**	To ensure the reduction in overall energy consumption	Improved fisheye state routing, energy aware route selection	Ensure longer lifetime and decreased energy consumption	Average energy consumption, end-to-end delay, and throughput
EGRC **(Wang *et al.*, 2016)**	To enhance reliability and energy efficiency in UASNs	Optimal clustering and Active/Sleep duty cycle mechanism	Lower end to end delay, enhanced network life time and energy efficiency	Average residual energy, %age of Alive nodes, end to end delay, FND, LND, HND
EPMS **(Wang *et al.*, 2016)**	To achieve energy efficiency and better network performance	Virtual clustering, PSO	Energy efficient operation and improvement in average delay and jitter than	Energy consumption average delay and network lifetime
AFSA **(Helmy *et al.*, 2015)**	To lower down network energy consumption	Optimized CHs selection using Artificial Fish Swarm Algorithm	Achieves better network lifetime. Less energy consumption per round	FND, energy consumption per round, Network life time, Data received by BS

QoS-PSO **(Liu *et al.*, 2012)**	To enhance the QoS level	PSO based multi agent model	Improvement in the QoS measure	Packet loss, average residual energy, QoS, mean delay
PSO **(Kulia and Jana, 2014)**	To extend lifetime of wireless sensor networks	PSO encoding, multi- objective fitness function, load balanced clustering	Energy consumption is balanced and network lifetime is improved	Network life time, energy consumption, FGD (First Gateway Dies), LGD (Last Gateway Dies), delivery of total data packets
PSO-ECHS **(Rao *et al.*, 2016)**	To attain enhanced network lifetime by conserving the energy of SNs	PSO, fitness function, weight function based balanced clustering	Better performance in terms of total energy consumption, network lifespan and success rate	Total energy consumption, Network life time
HSA-PSO **(Shankar *et al.*, 2016)**	To attain balanced energy consumption among SNs	Hybrid harmony search and PSO	Achieves better search, convergence, energy efficient operation	FND, LND, residual energy, mean throughput, standard deviation
SIF **(Zahedi *et al.*, 2016)**	To achieve balanced clustering and minimum overall energy consumption	Fuzzy c-means, Hybrid FA-SA (firefly and simulated annealing)	Energy efficient and avoid uncertainties during network operation	Maximum and standard deviation of intra-cluster distance, FND, HND, LND, success rate, round history of dead nodes
PECE **(Zhang *et al.*, 2015)**	To prolong network lifetime, balanced energy consumption	Bee colony optimization, optimal clustering	Optimal cluster formation leads to enhanced network performance and balanced energy consumption	Network lifetime and remaining energy
IHSBEER **(Zeng and Dong, 2016)**	To enhance the network lifespan	Improved harmony search algorithm	Enhanced network lifetime and reduced energy consumption	Network life time, average residual energy, minimum residual energy, standard deviation of residual energy
PDORP **(Brar *et al.*, 2016)**	To enhance the network lifetime and improved QoS measure	Hybrid optimization using GA and BFO, Hybrid features of PEGASIS and DSR, Cache DSR Integration,	Reduced network control overhead, fast response, good connectivity of SNs, Energy efficiency	Throughput, delay, and bit error rate, energy consumption

LWTC-BMA **(Sahoo *et al.*, 2013)**	To present a trust based secure and energy competent clustering	Honey Bee Mating	Enhanced network lifetime	total energy consumption, alive nodes, average residual energy
ABC-SD **(Ari *et al.*, 2016)**	To design low-power scalable network and to improve energy efficiency	ABC, Cost based function	Improved network lifetime, coverage, packet delivery ratio	Energy consumption, energy efficiency, first sensor dead, amount of packet delivered, packet loss rate and network coverage
FAMACROW **(Gajjar *et al.*, 2016)**	To increase energy efficiency and network lifetime	Unequal clustering, Fuzzy logic and ACO	Energy Efficient, good scalability	Throughput, goodput, network settling time, and latency, FND, HNA, LND
BeeSwarm **(Mann and Singh, 2017)**	To design and develop power aware protocol	ABC meta- heuristic, optimal clustering	Enhanced PDR, and Energy Efficiency	Packet delivery ratio, average energy consumption, and throughput
BeeSensor **(Saleem *et al.*, 2012)**	To develop power-aware, scalable and performance efficient routing	Bee agent model, agent to agent communication	Least energy consumption, Fault tolerant behavior	Latency, PDR, energy efficiency, lifetime, and control-overhead

2.3 DISCUSSION ON HIERARCHICAL ROUTING PROTOCOLS

This section provides detailed summary and discussion on hierarchical routing protocols based on various performance metrics as shown in Table 2.2. The performance features considered for comparison are energy efficiency, data aggregation, location awareness, QoS, scalability, load balance, multipath, query based.

2.3.1 Discussion on Classical Hierarchical Routing Protocols

Sliding window interval determines the optimal CH selection probability in each round of LEACH-SWDN. Optimal clustering leads to load balancing and balanced energy consumption in every round of LEACH-SWDN. LEACH-SWDN needs further improvement to reduce the control packet overhead which may lead to increased network load. Limited scalability of LEACH-SWDN requires an enhancement to make it suitable for large scale network topologies. However, LEACH-SWDN it not suitable for real time applications as it lacks QoS awareness. Mobility is another aspect which needs to be further explored to make it suitable for dynamic network scenarios.

Application specific behavior is one of the key aspects of ALSPR protocol which is achieved by perfect tuning and optimization of complex control attributes. Genetic algorithm and simulated annealing (GA-SA) performs hybrid optimization which enhances the network lifetime depending upon application specific needs. ALSPR protocol utilizes application specific clustering for load balancing and GA-SA optimization to attain balanced energy consumption and enhanced network lifetime. ALSPR protocol needs further enhancements in scalability to make it suitable for large scale network topologies in multi-hop environment. It fails to deal with SNs mobility in dynamic scenarios. QoS awareness of the protocol is another area which is still unexplored. ALSPR protocol is capable of selecting alternate path during primary path failures and ensures fault tolerant operation.

Q-LEACH protocol achieves enhanced network lifetime and stability period by utilizing the concept of randomized clustering for optimized sub sectoring which in turn leads to optimal distribution of SNs. Q-LEACH also provides better network coverage and optimal energy depletion of SNs. However, Q-LEACH needs enhancements to handle mobility in dynamic network scenarios. Limited scalability of protocol is another area of concern. Q-LEACH is not suitable for real time applications as it lacks QoS awareness.

Evolutionary approach applies modified fitness functions (cohesion, separation) in addition to ERP functions to attain optimal dynamic clustering which leads to a better stability period and enhanced lifetime for heterogeneous networks. Optimal clustering in ERP also ensures balanced energy utilization of SNs during its network operation. However, protocol still needs further improvement in its fitness function to prolong stability period as in its current state it fails to achieve stability in certain situations. Limited scalability, inability to handle mobility in dynamic networks requires further enhancement in the protocol. QoS awareness of the protocol is still unexplored.

A cooperative strategy and cooperation attribute build up a fairness mechanism to achieve a better trade-off between energy consumption and network performance parameters. This leads to balanced network load in C-RPL protocol. It works well for centralized networks. However, further enhancement of protocol is needed for decentralized network scenarios. C-RPL protocol is a better choice for real time applications due to its QoS awareness. It exhibits moderate scalability which needs further improvement. Further enhancements are required to deal with SNs mobility.

OZEEP protocol achieves high energy efficiency by utilizing the concept of genetic fuzzy system and attains optimal CHs. OZEEP exhibits very good level of scalability and hence it is suitable for large scale network topologies. Protocol handles SNs and sink mobility in dynamic network scenarios effectively. It is a good choice for reliability-based applications due to its fault tolerant nature and it maintains alternate path during the path failures. OZEEP protocol is also suitable for time driven applications.

MTPCR protocol exhibits high energy efficiency due to optimal path search and path maintenance procedure. It achieves better transmission bandwidth and protocol is able to handle mobility effectively. MTPCR is suitable in large network scenarios for multi-hop environment due to its very good level of scalability. MTPCR is fault tolerant as it handles path breakages effectively due to its multipath nature. MTPCR is a good choice for reliability-based applications. High guaranteed bandwidth of MTPCR protocol makes it suitable for time driven applications.

Multicast tree optimization and Distributed Minimum transmission (DMT) leads to balanced and reduced energy consumption in EAODV. EAODV is suitable for real time applications due to its QoS awareness factor which maintains guaranteed bandwidth, lower delay, improved control overhead, less packet loss, higher delivery ratio, and balanced energy operation. EAODV effectively handles mobility of SNs or sink in dynamic network scenarios. However, limited scalability of protocol needs further improvement.

PHASeR utilizes blind forwarding and gradient maintenance measure to achieve better network performance and energy efficiency. Handling mobility in dynamic scenarios and fault tolerance are the main focus in PHASeR protocol. It is able to select alternate path during path failures due to its multipath nature. Protocol needs further enhancements for QoS awareness and to study the effect of channel fading on its performance. PHASeR protocol exhibits a very good level of scalability. It is a better choice for time based applications such as radiation mapping.

Fuzzy and non-fuzzy formulations in HEEDML deal with five levels of energy heterogeneity. HEEDML achieves high energy efficient operation and better network performance by utilizing balanced clustering method and fuzzy/non-fuzzy formulations up to five levels. A further enhancement is required to deal with mobility issue and QoS awareness. HEEDML does not provide fault tolerance and is not able to select alternate path during path failures. HEEDML is more suited for small size networks due to its limited scalability.

An improved FSR (Fish eye State Routing) algorithm and energy abundant path selection method is utilized by EA-FSR protocol for less energy consumption. However, it sacrifices end to end delay and jitter for improved energy consumption. EA-FSR fails to deliver in high mobility based applications and higher control packet overhead is another major issue. Future enhancements of the protocol are required to support real time applications by embedding QoS awareness. EA-FSR fails to select alternate path during path failures. It does not exhibit fault tolerant behavior.

EGRC protocol is best suited for Underwater Acoustic Sensor Network applications where reliability of data transmission is the prime objective along with energy efficiency. EGRC exhibits fault tolerant behavior. It supports data aggregation, location awareness and shows a good level of scalability as well. EGRC supports load balancing through optimal clustering. Duty cycle mechanism and optimal clustering concept in turn leads to energy efficient operation of EGRC protocol.

Data aggregation feature is supported by LEACH-SWDN, ALSPR, ERP, C-RPL, OZEEP, EAODV, PHASeR, HEEDML, EGRC protocols. However, Q-LEACH, MTPCR, EA-FSR protocols do not perform data aggregation. Location awareness is used to enhance the energy efficiency of SNs (Jindal *et al.*, 2015; Singh and Verma 2017a; Singh and Verma 2017b). Q-LEACH, C-RPL, OZEEP, PHASeR, HEED-ML, EA-FSR, EGRC support location awareness. OZEEP, MTPCR, EAODV protocols effectively handle mobility based application due to their query based nature.

Table 2. 2 Summary of Various Hierarchical Routing Protocols

Routing protocol	**Energy efficiency**	**Data aggregation**	**Location awareness**	**QoS**	**Scalability**	**Load balance**	**Fault tolerance**	**Multi-path**	**Query based**
LEACH-SWDN (Wang *et al.*, 2017)	Good	Yes	No	No	limited	Yes	No	No	No
ASLPR (Shokouhifar and Jalali, 2015)	Good	Yes	No	No	Moderate	Yes	Yes	Yes	No
Q-LEACH (Manzoor *et al.*, 2013)	Good	No	Yes	No	limited	Yes	No	No	No
ERP (Bara'a and Khalil, 2012)	Good	Yes	No	No	Limited	Yes	No	No	No
C-RPL (Marc Barcelo *et al.*, 2016)	Good	Yes	Yes	Yes	Moderate	Yes	No	No	No
OZEEP (Srivastava and Sudarshan , 2015)	Very Good	Yes	Yes	Yes	Very Good	Yes	Yes	Yes	Yes
MTPCR (Chen and Weng, 2012)	Very Good	No	No	No	Very Good	Yes	Yes	Yes	Yes
EAODV (Zhang *et al.*, 2015)	Good	Yes	No	Yes	Limited	Yes	No	No	Yes
PHASeR (Hayes and Ali, 2015)	Good	Yes	Yes	No	Very Good	Yes	Yes	Yes	No

HEEDML **(Singh *et al.*, 2016)**	Very Good	Yes	Yes	No	Limited	Yes	No	No	No
EA-FSR **(Kumar *et al.* 2013)**	Good	No	Yes	No	Good	Yes	No	No	No
EGRC **(Wang *et al.*, 2016)**	Very Good	Yes	Yes	No	Good	Yes	Yes	Yes	No
EPMS **(Wang *et al.*, 2016)**	Good	No	Yes	No	Limited	Yes	No	No	No
AFSA (Helmy *et al.*, 2015)	Good	Yes	Yes	No	Good	Yes	No	No	No
QoS-PSO **(Liu *et al.*, 2012)**	Good	No	No	Yes	Very Good	Yes	Yes	Yes	No
PSO **(Kulia and Jana, 2014)**	Good	yes	No	No	Good	Yes	No	No	No
PSO-ECHS **(Rao *et al.*, 2016)**	Very Good	Yes	No	No	Good	Yes	No	No	No
HSA-PSO **(Shankar *et al.*, 2016)**	Very Good	Yes	No	No	Moderate	Yes	No	No	No
SIF **(Zahedi *et al.*, 2016)**	Good	Yes	Yes	No	Limited	Yes	No	No	No
PECE **(Zhang *et al.*, 2015)**	Very Good	No	No	No	Limited	Yes	Yes	Yes	No
IHSBEER **(Zeng and Dong, 2016)**	Very Good	No	No	No	Moderate	Yes	No	No	No
PDORP **(Brar *et al.*, 2016)**	Good	Yes	No	Yes	Very Good	Yes	No	No	No

LWTC-BMA **(Sahoo *et al.*, 2013)**	Good	Yes	No	No	Good	Yes	No	No	No
ABC-SD **(Ari *et al.*, 2016)**	Very Good	Yes	No	Yes	Good	Yes	No	No	No
FAMACROW **(Gajjar *et al.*, 2016)**	Very Good	Yes	No	No	Very Good	Yes	No	No	No
BeeSwarm **(Mann and Singh, 2017)**	Very Good	Yes	No	No	Limited	Yes	No	No	No
BeeSensor **(Saleem *et al.*, 2012)**	Good	Yes	No	No	Moderate	Yes	Yes	Yes	No

2.3.2 Discussion on SI based Hierarchical Routing Protocols

Virtual clustering with mobile sink approach and particle swarm optimization leads to energy efficient behavior of EPMS. EPMS is not suitable for large networks due to its limited scalability. Protocol needs further enhancements to handle mobility of SNs and QoS awareness. EPMS fails to select an alternate path during path failures and doesn't exhibit fault tolerance.

Optimized CH selection is achieved using artificial fish swarm algorithm and a fitness function that selects best set of CHs which leads to reduced energy consumption per round in AFSA protocol. It exhibits a good level of scalability. However, it does not provide QoS. AFSA still needs validation of its behavior and results in NS2. AFSA protocol needs further enhancement for large network scenarios.

A PSO based multi agent model utilizes intelligent software agents to obtain a better QoS measure in QoS-PSO protocol. QoS-PSO is good choice for real time applications. High scalability of protocol makes it suitable for large scale network topologies. Due to its multipath nature it effectively handles path failures and exhibits fault tolerant behavior. However, protocol needs further enhancements to effectively handle high mobility and multi sink architecture.

Load balanced clustering, multi objective fitness function and PSO based encoding leads to reduced energy consumption and enhanced network lifetime of PSO protocol. PSO protocol needs further enhancements to handle mobility in dynamic network scenarios. PSO exhibits good scalability. Protocol lacks QoS awareness and does not provide fault tolerance.

PSO-ECHS attains better network performance and high energy efficiency by applying particle swarm optimization and fitness function. A weight function based clustering procedure provides load balancing. PSO-ECHS exhibits good scalability to handle large network scenarios in multi hop environments. However, future enhancements are required to embed the fault tolerant behavior for reliability-based applications.

HSA-PSO protocol attains high energy efficiency, better convergence and high search efficiency by utilizing hybrid harmony search and PSO. However, future enhancements are required to improve scalability of protocol for large scale network scenarios. Mobility and fault tolerant feature of HSA-PSO is still unexplored.

Fuzzy c-mean based balanced clustering, hybrid firefly and simulated annealing based optimization conserves energy in SIF protocol. SIF defines application specific fitness function and exhibits application specific behavior. It extends network lifetime as per nature of application. Protocol needs a significant improvement in terms of scalability to deal with large network scenarios in multi hop environment. Future enhancements are required to build up fault tolerance and effectively handle the mobility of SNs and sink in dynamic network scenarios. EPMS, AFSA and SIF protocols support location awareness.

Optimal clustering during setup phase and bee colony optimization during data transfer phase are the main focus in PECE to attain balanced energy consumption and highly energy efficient operation. PECE exhibits fault tolerance by providing alternate path selection during path failures in the network. Scalability of the protocol still needs an improvement. Future enhancements are required for QoS awareness and mobility aspect.

A new improved encoding of harmony memory, effective local search and a new dynamic adaptive parameter HMCR in IHSBEER results in high energy efficient operation and enhanced network lifetime. It shows better performance for small networks. However, moderate scalability is still a concern as it needs a significant improvement to handle large network scenarios. Protocol also lacks QoS awareness. Future enhancements are required for QoS awareness and fault tolerant behavior.

PDORP utilizes genetic algorithm and BFO optimization along with hybrid properties of PEGASIS, DSR to conserve energy and QoS awareness. PDORP handles real time applications effectively. However, PDORP fails in dynamic environments. It requires further enhancements to handle mobility. Protocol fails to maintain alternate path during path failures and does not exhibit fault tolerance. PDORP is suitable for large network scenarios as it exhibits very good scalability.

Honey bee mating based clustering and light weight trust method provides enhanced network lifetime in LWTC-BMA protocol. LWTC-BMA shows good scalability however it needs further enhancements to handle mobility for dynamic scenarios. QoS awareness and fault tolerance features are still unexplored in LWTC-BMA.

Designing low-power scalable network, energy efficiency, throughput, link quality and scalability are the main focus of ABC-SD. It attains energy efficiency by applying ABC Meta - heuristic and cost function. ABC-SD exhibits QoS awareness and therefore is a good choice for real time applications. It shows a good level of scalability. ABC-SD fails to select an alternate path during path failures. Future enhancements are required to effectively handle SNs and sink mobility for dynamic network scenarios.

Unequal clustering, Fuzzy logic and ACO are the key aspects of FAMACROW protocol which leads to energy efficient operation. FAMACROW exhibits a very good level of scalability for large networks. Future enhancements of protocol are required for mobility aspect, QoS awareness and fault tolerance.

BeeSwarm protocol achieve high energy efficiency using ABC meta-heuristic based optimal clustering. BeeSwarm protocol needs an improvement in terms of scalability. Further enhancements in the protocol are required for its application specific implementation. QoS awareness and fault tolerance are the areas which need to be worked upon.

Bee agent model and agent –agent communication conserves energy in BeeSensor. BeeSensor is a good choice for reliability-based applications due to its fault-tolerant behavior and multipath nature. QoS awareness and moderate scalability of BeeSensor is still a concern. The Scalability of Bee Sensor is required to be validated for large scale networks. Future enhancements of protocol are required to handle the mobility of SNs, sink.

AFSA, PSO, PSO-ECHS, HSA-PSO, SIF, PDORP, LWTC-BMA, ABC-SD, FAMACROW, Bee Swarm, Bee Sensor protocols exhibit data aggregation property. However, QoS-PSO, PECE, IHSBEER protocols do not perform data aggregation.

2.4 Gap Analysis

In the previous sections, a detailed study of various hierarchical routing protocols for WSNs have been performed. After the literature review the following research gaps have been identified:

- The limited network lifetime is one of the major research challenges due to limited battery capacities of WSNs (Yang *et al.*, 2010).
- The Energy conservation is also an important research issue posed by WSNs which requires optimal route construction and novel cluster head selection. In cluster based routing protocols cluster heads are overburdened with the task of data forwarding to BS which causes unbalanced energy consumption (Gajjar *et al.*, 2016). Thus, it is an important task to maintain a fair balance between inter and intra cluster communication load in order to reduce energy consumption.
- Ensuring good network performance dynamics is a major challenge faced by WSNs due to dynamically changing behavior of WSNs (Wang *et al.*, 2012; Bara'a and Khalil, 2012).
- Military surveillance monitoring, target tracking in battlefield and intrusion detection applications require mobility aspect to be explored to handle SNs mobility. The Mobility of SNs pose another challenge of topology management/maintenance, connectivity of nodes which needs to be researched further in an energy constrained environment (Shokouhifar and Jalali, 2015).

2.5 Problem Formulation

Energy consumption is one of the major constraints in WSNs environment due to the restricted battery capabilities of SNs. Hardware restrictions necessitate the requirement of energy efficient routing protocols. The Novel cluster head selection and optimal route construction is considered as an important activity in the design of cluster based routing protocol. Further, cluster based routing protocols, cluster heads are overburdened with the task of data forwarding to BS which causes unbalanced energy consumption (Gajjar *et al.*, 2016). Thus, it is an important task to maintain a fair balance between inter and intra cluster communication load in order to reduce energy consumption. Therefore, the proposed routing protocols should perform energy efficient operations which will in turn elongate the network lifetime.

WSN performance is greatly affected by the way routing is implemented. Due to data centric communication paradigm of WSN, it usually forms traffic patterns as multicast or converge cast trees. Energy consumption and route calculations in routing protocols are highly influenced by data reporting methods. Therefore, the proposed protocol should reduce the data transmission overhead to a minimum.

Dynamically changing behavior of WSNs poses one of the major challenges for maintaining good network performance dynamics. Hence, the proposed protocol should assure good network performance dynamics.

Ability of Routing protocols to handle mobility of SNs is still an area which lags. Handling mobility aspect of SNs pose another challenge of topology maintenance and connectivity of nodes which needs to be researched further in an energy constrained environment. Therefore, the routing protocol must be able to handle mobility of SNs and deal with link fault/failures by initiating link maintenance procedures for rerouting of packets through energy abundant paths.

Hence, the research work will focus on the formulation of new routing technique which should be energy efficient, maintains longevity of WSN's, adaptive to link failures and maintains good network performance as well. The research work will incorporate ideas from traditional routing based upon above mentioned vision.

2.6 Objectives

On analyzing the gaps in various WSN routing techniques and after formulating problem, the following objectives have been laid down.

1. To study and review existing routing techniques for WSNs.
2. To design and develop a novel routing technique for WSNs.
3. To verify and validate the proposed routing technique.

Chapter 3

An Energy Efficient Load Balanced Cluster based Routing using Ant Colony Optimization for WSN

Researchers have proposed various cluster based routing protocols for WSN's. After thorough comprehension of these protocols, this chapter presents an energy efficient load balanced cluster based routing using Ant Colony Optimization. The Low Energy Adaptive Hierarchy (LEACH) (Heinzelman *et al.*, 2000; Li *et al.*, 2011) is one of the premier clustering algorithms. It is adaptive in nature and performs the task of cluster formation iteratively after a predefined period. LEACH assigns equal probability to all the nodes to act as a cluster head. Selection of node as a cluster head is done on a random basis which leads to balanced energy consumption up to some extent. LEACH does not check remaining energy of sensor nodes, RSSI, coverage or connectivity metric, node density during cluster formation. Random selection of nodes in LEACH can't assure uniform distribution and connectivity of cluster head nodes (Zhang *et al.*, 2016). Enhancements over LEACH are provided Energy aware distance based LEACH (LEACH-ED) (Tong *et al.*, 2010), Threshold- LEACH (LEACH-T) (Xu *et al.*, 2012) and Energy Efficient LEACH (EE-LEACH) (Arumugam and Ponnuchamy, 2015) by considering residual energy, distance metric from source to cluster head. However, these protocols also lack uniform distribution of cluster head nodes and node density metric for load balanced operation of WSN.

Energy Efficient Unequal Clustering EEUC (Li *et al.*, 2005) proposes a multi-hop communication where inter and intra -cluster communication is considered. However, Protocol exhibits higher energy consumption when the network grows.

3.1 System Model

This section describes network model and energy consumption model used in the proposed protocol.

3.1.1 Network Model

Prior to the network setup the following assumptions have been made:

a) N is the set of all nodes in the network such that n_i is a member node of N. A node n_i contains list of its neighbors ($N_{H}\_L_{ST}$), location i (LOC_i) with respect to BS or nearest cluster head.
b) All network nodes N have the same energy and functional characteristics.
c) All nodes N are randomly distributed. They behave as stationery nodes and show no movement after deployment.
d) All network Nodes possess location awareness feature which means location of all nodes can be accessed.
e) Transmission range of nodes N is established and the distance of the nodes from the Base Station or nearest cluster head is calculated by RSSI.

3.1.2 Energy Consumption Model

The energy consumption model presented in proposed work is similar to the energy consumption model presented in the literature (Zhang *et al.*, 2015). Energy consumed during data transmission can be defined as mentioned in equation in equation 3.1.

$$E_t(k,d) = \begin{cases} E_{elec}.k + \mathcal{E}_{fs}.k.d^2, d < d_0 \\ E_{elec}.k + \mathcal{E}_{mp}.k.d^2, d \geq d_0 \end{cases} \quad (3.1)$$

d_0 is expressed as mentioned in equation 3.2.

$$d_0 = \sqrt{\frac{{\mathcal{E}_{fs}}^2}{\mathcal{E}_{mp}}} \quad (3.2)$$

$$E_r.(k) = E_{elec}.k \quad (3.3)$$

Energy consumed while reception of data is defined as mentioned in equation 3.4.

$$E_0.(k) = E_{elec}.k \quad (3.4)$$

While d < d_0 (threshold distance measure), free space propagation model is utilized for power amplification else it makes use of multipath fading model.

where E_{elec} (J/bit)- RF energy consumption factor, $\mathcal{E}_{fs}$ - Energy consumption factor in free space model, $\mathcal{E}_{mp}$ - Energy consumption factor in multipath fading model

Formula used for calculation of distance d by using RSSI measure is as described in equation 3.5.

$$d = 10^{\frac{[RSSI-A]}{10*n}} \quad (3.5)$$

where A - RSSI calculated from a distance of 1 meter away from transmitting point, RSSI - Received Signal Strength Indicator, n - Path fading factor (Value of this factor usually ranging from 2 to 5).

The total energy consumed by a node n_i is expressed as in equation 3.6.

$$E(n_i) = E_t(kn_i, d) + E_t(kn_i) + E_0(kn_i) \quad (3.6)$$

Energy consumed during communication process for transmission and reception of data is regarded as valid energy consumption whereas energy spent during idle operation accounts for depletion of batteries which is not a desired behavior.

3.2 Proposed Algorithm

Routing in wireless networks can be thought of as similar to the phenomenon of natural ants' behavior which are intelligent in nature and searches for the shortest connecting path from food site to nest site (Guo et al., 2010; Pankajavalli, and Arumugam, 2011; Wankhade and Ali, 2011; Singh *et al.*, 2014). This phenomenon has led to a performance enhancement method called as Ant Colony Optimization (ACO) (Di Caro and Dorigo, 1998). It works well since ACO algorithms are decentralized in nature and so are wireless sensor networks. Further, it is to be added that ACO shows flexibility to adjust with the inherently dynamic nature of WSN.

"An energy efficient load balanced cluster based routing using Ant Colony Optimization (LB-CR-ACO)" is an effort to enhance network life time. It performs optimal clustering based on cluster head selection weighing function. The cluster formation utilizes various parameters like remaining energy of the nodes, received signal strength indicator and node density. The priority weights are also assigned among these parameters. The presented protocol also performs a dynamic selection of optimal cluster head periodically which conserves energy, thereby utilizing network resources in an efficient and balanced manner. The optimal route construction is done using ACO in steady state phase for multi hop data transfer.

The proposed protocol basically aims at providing reduced energy consumption and enhanced network lifetime. The proposed protocol contains two stages: Cluster formation and steady state or multi-hop data forwarding. During cluster formation parameters like remaining energy of nodes, RSSI, node density, number of load balanced nodes affect the process of clustering and account for energy efficient operation of the WSN. In steady state phase, multi-hop routing is executed by applying ACO.

3.2.1 Cluster Head Selection and Cluster Formation

This section explains the process of cluster head selection by considering metrics like remaining energy of nodes (ReEn), RSSI of links taken as measure of proper connectivity/coverage, node connection density of elected cluster head node for load balanced operation.

The Base Station broadcasts a cluster setup request. Nodes will calculate ReEn (N_i), RSSI of links and will generate a response. Calculate cluster head node set which will provide full connectivity to all the neighboring nodes. Node set $NS_i = \{N_i, N_{i+1}, N_{i+2}, \ldots\ldots\ldots, N_n)$ having n number of nodes is calculated which provides full connectivity to all the neighbors. Further, there may exists n number of such node sets NS = $\{NS_1, NS_2, NS_3, \ldots\ldots\ldots NS_n\}$ where $NS_i=\{N_i, N_{i+1}, N_{i+2}, \ldots N_n\}$. Set the cluster head selection weighing factors for optimal cluster head node set selection which are minimum remaining energy of cluster head node set (Wf_1=Min{ReEn(NS_i)}), minimum no. of nodes for load balanced operation in cluster head node set (Wf_2=Min {No_ of_ LB_nodes (NSi)}), minimum RSSI of all links in cluster head node set (Wf_3=Min{RSSI_all_links(NS_i)}), load Balanced Node connection density at Node Set NS_i (Wf_4=Balanced {Node_density (NS_i)}). Apply Wf_1, Wf_2, Wf_3, Wf_4 weighing factors to cluster head node sets $\{NS_i, NS_{i+1}, NS_{i+2}, NS_{i+3}, \ldots\ldots\ldots NS_n\}$ and create weighing factor matrix as mentioned below:

$$\begin{vmatrix} Wf_1(NS_i) & Wf_1(NS_{i+1}) & Wf_1(NS_{i+2}) & Wf_1(NS_{i+3}) & \cdots & Wf_1(NS_n) \\ Wf_2(NS_i) & Wf_2(NS_{i+1}) & Wf_2(NS_{i+2}) & Wf_2(NS_{i+3}) & \cdots & Wf_2(NS_n) \\ Wf_3(NS_i) & Wf_3(NS_{i+1}) & Wf_3(NS_{i+2}) & Wf_3(NS_{i+3}) & \cdots & Wf_3(NS_n) \\ Wf_4(NS_i) & Wf_4(NS_{i+1}) & Wf_4(NS_{i+2}) & Wf_4(NS_{i+3}) & \cdots & Wf_4(NS_n) \end{vmatrix}$$

After applying weighing factors, select the values which are: maximum value of ReEn in node set NS_i ($Wf_1(NS_i) = V_{1,i}$), Best Load Balanced nodes in NS_i ($Wf_2(NS_i) = V_{2,i}$), maximum RSSI_all_links of NS_i ($Wf_3(NS_i) = V_{3,i}$) , Best load Balanced Node connection density at NS_i ($Wf_4(NS_i) = V_{4,i}$) . The value Matrix obtained after applying weighing factors for all optimal Node Sets NS_i, $NS_{i+1}, \ldots. NS_n$ is as follows:

$$\begin{vmatrix} V_{1,i} & V_{1,i+1} & V_{1,i+2} & V_{1,i+3} & \ldots & V_{1,n} \\ V_{2,i} & V_{2,i+1}, & V_{2,i+2} & V_{2,i+3} & \ldots & V_{2,n} \\ V_{3,i} & V_{3,i+1}, & V_{3,i+2} & V_{3,i+3} & \ldots & V_{3,n} \\ V_{4,i} & V_{4,i+1}, & V_{4,i+2} & V_{4,i+3} & \ldots & V_{4,n} \end{vmatrix}$$

Row 1 of value matrix is minimum value of ReEn in each Cluster head Node Set. Row 2 of value matrix is the minimum value of Load Balanced nodes in each probable cluster head node Set. Row 3 of value matrix is the minimum value of RSSI of all links in each probable cluster head node set. Row 4 of value matrix is node connection density of each probable cluster head node set taken as load balanced network operation perspective.

Create Optimal_Node_Set_Selection_Matrix by assigning weights to values of different parameters as per following heuristic rules:

Rule 1:

Max[$V_{1,i}$]->Min[$V_{1,n}$] = [Highest, 2^{nd} Highest, 3^{rd} Highest ,.....2^{nd} lowest, Lowest]

***Rule 2**:*

Best_Load_Balanced_nodes[$V_{1,i}$]->Min_Load_Balanced_nodes[$V_{1,n}$] = [Highest, 2^{nd} Highest, 3^{rd} Highest ,..., 2^{nd} lowest, Lowest].

Rule 3:

Max_RSSI_all_links[$V_{1,i}$]->Min_ RSSI_all_links [$V_{1,n}$] = [Highest, 2^{nd} Highest, 3^{rd} Highest ,..., 2^{nd} lowest, Lowest]

Rule 4:

Best_Balanced_node_density[$V_{1,i}$]->Min_Balanced_node_density [$V_{1,n}$] = [Highest, 2^{nd} Highest, 3^{rd} Highest ,..., 2^{nd} lowest, Lowest].

Now Optimal_Node_Set_Selection_Matrix is created as mentioned below:

$$\begin{vmatrix} Wt_{1,i} & Wt_{1,i+1} & Wt_{1,i+2} & \ldots & Wt_{1,n} \\ Wt_{2,i} & Wt_{2,i+1} & Wt_{2,i+2} & \ldots & Wt_{2,n} \end{vmatrix}$$

$Wt_{3,i}$	$Wt_{3,i+1}$	$Wt_{3,i+2}$	…	$Wt_{3,n}$
$Wt_{4,i}$	$Wt_{4,i+1}$	$Wt_{4,i+2}$	…	$Wt_{4,n}$

Assigning priority weights (P_{wt}) 40% to ReEn , 20% to LB_nodes, 20% to RSSI_of_links, 20% to node_density . Optimal_Node_Set_Selection_Matrix will be constituted again as mentioned below:

$P_{wt}* Wt_{1,i}$	$P_{wt} *Wt_{1,i+1}$	$P_{wt} *Wt_{1,i+2}$	…	$P_{wt} *Wt_{1,n}$
$P_{wt} * Wt_{2,i}$	$P_{wt} *Wt_{2,i+1}$	$P_{wt} *Wt_{2,i+2}$	…	$P_{wt} *Wt_{2,n}$
$P_{wt} *Wt_{3,i}$	$P_{wt} *Wt_{3,i+1}$	$P_{wt} *Wt_{3,i+2}$	…	$P_{wt} *Wt_{3,n}$
$P_{wt} *Wt_{4,i}$	$P_{wt} *Wt_{4,i+1}$	$P_{wt} *Wt_{4,i+2}$	…	$P_{wt} *Wt_{4,n}$

To find out optimal Cluster_Head_Node_Set, calculate sum of all columns of matrix separately as mentioned in equation 3.7.

$$\sum_{t=1}^{4} P_{wt} * W_{t,i} , \sum_{t=1}^{4} P_{wt} * W_{t,i+1} , \sum_{t=1}^{4} P_{wt} * W_{t,i+2} , \sum_{t=1}^{4} P_{wt} * W_{t,i+n} \ldots \quad (3.7)$$

Find highest selection probability of Cluster_Head_Node_Set NS_i as in equation 3.8

$$\max \sum_{t=1}^{4} P_{wt} * W_{t,i} \quad (3.8)$$

It results in the optimal Cluster_Head_Node_Set NS_i having highest selection probability. The cluster head selection procedure is applied periodically after time t_1 to implement dynamic clustering by choosing new optimal Cluster_Head_Node_Set NS_i depending upon current network statistics at t_1. It balances the network load and avoids the depletion of batteries for some specific nodes. The nodes other than cluster head will choose to be a member of particular cluster head depending upon the RSSI measure of cluster head. The procedure of cluster formation is illustrated in Figure 3.1

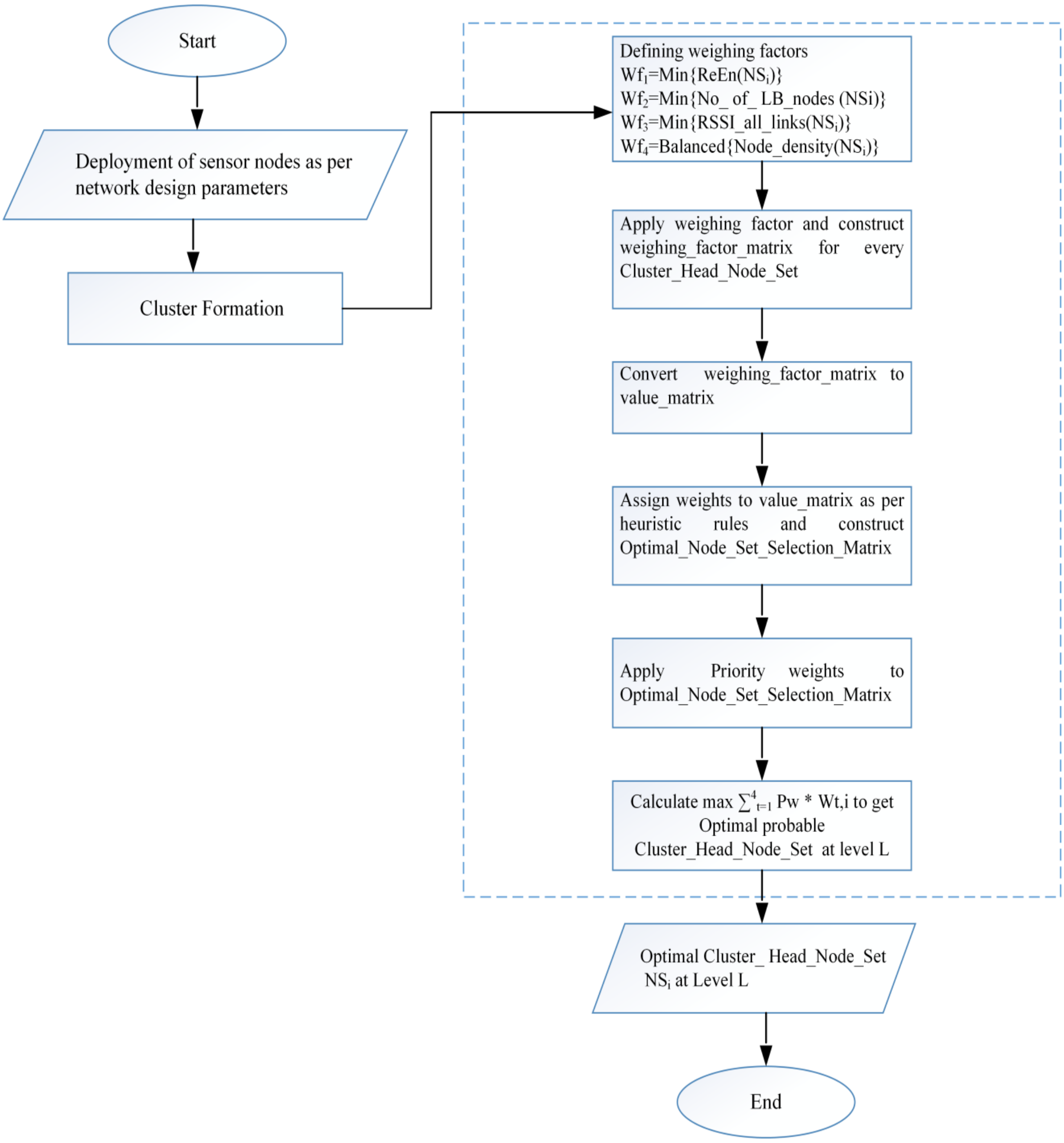

Figure 3. 1 Cluster Formation

3.2.2 Multi-hop Routing using Ant Colony Optimization

When cluster head selection and cluster formation procedure is over, next task is to start stable data transfer. Therefore, cluster head nodes compose a TDMA schedule for its participating nodes and inform them about their designated slot for data transmission. Sensor nodes send sensed data to their cluster head according to their turn in TDMA slot and switch to a sleep state for rest of the time so as to save energy and to avoid depletion of their batteries. Cluster heads perform data aggregation (Mishra and Mandal, 2006) and forward aggregated data on the route. Here ant colony optimization is applied for finding the best route to forward data from cluster head to BS. The ACO algorithm used for multi-hop routing is as follow:

The proposed protocol LB-CR-ACO makes use of Ant Colony optimization for multi-hop data communication because ACO exhibits better performance when applied for route optimization. Initially for every node r and every node s the path is named as $path_{rs}$ which is the minimum distance path between cluster head r and s. Let us assume that $\tau_{rs}(t)$ are the initial pheromone heuristic for $path_{rs}$ at time t.

The next hop selection probability P_{rs}^D where r is a cluster head whose next hop neighbor s is required to be selected when the destination is D is defined as in equation 3.9.

$$P_{rs}^D = [\tau_{rs}^D]^\alpha [\eta_{rs}]^\beta / \sum_{i\epsilon N(r)}[\tau_{ri}^D]^\alpha[\eta_{ri}]^\beta , \qquad \alpha, \beta \epsilon R^+ \qquad (3.9)$$

Where τ_{rs}^D is defined as pheromone variables, at cluster head r which gives a measure based on various heuristics for the selection of neighbor s as next hop in the path to destination node D. η_{rs} is defined as a measure of expected waiting time on link r to s based on the various heuristics. Heuristic measure η_{rs} is defined as in equation 3.10.

$$\eta_{rs} = ReEn(s) / \sum_{k\epsilon Ni(k)} ReEn(k) \qquad (3.10)$$

where ReEn(s)- residual energy of node s. $\sum_{k\epsilon Ni(k)} ReEn(k)$ - summary of residual energy of all the neighbor nodes of node r. Initially at t=0,

$\tau_{rs}(t) = 1$ for each probable cluster head.

The pheromone heuristic $\tau_{rs}(t)$ will be $\Delta\tau_{rs}$, and is calculated at each step. FAnt Fk completes its round trip in mCH steps where m is defined as number of cluster heads $\Delta\tau_{rs}^k$ is illustrated as in equation 3.11.

$$\Delta\tau_{rs}^k = fn(ERR_k^*, \Delta\tau^{k-1}) \qquad (3.11)$$

If the delay occurred during path discovery, is less than the threshold value D then pheromone updation is $\Delta\tau_{rs}^k = 0$.

$$ERR_k^* = ERR_k / CH\_Hops^k \quad (3.12)$$

The equation 3.12 ensures that proposed algorithm does not select for longer paths which have higher delays and subsequently these long delay paths will not get any pheromone reinforcement. In proposed implementation, a new cluster head node is chosen towards the sink as next level linear cluster head. Figure 3.2 depicts the optimal path selection using ACO.

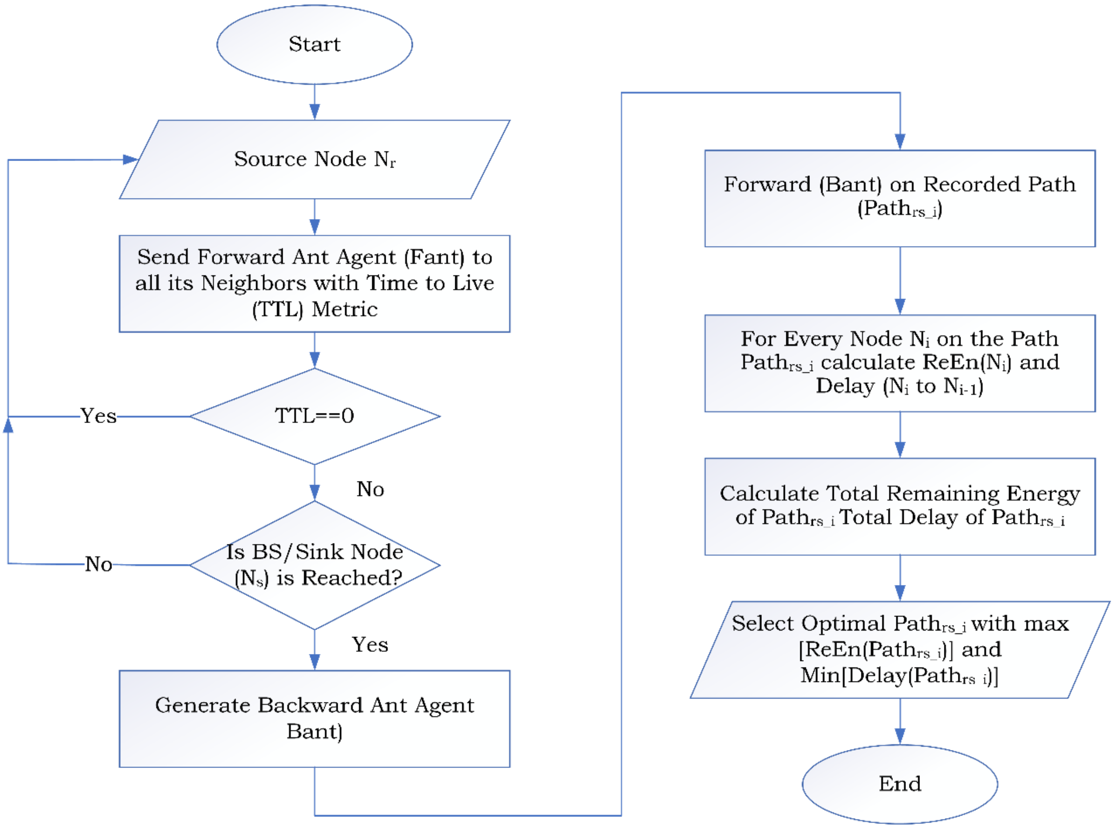

Figure 3. 2 Optimal Path Search using Ant Colony Optimization

Optimal Path Selection Algorithm using ACO

For every edge of a path do

Initialize pheromone heuristic value τ_{rs} *(t) =1*

End for

For every probable cluster head

Calculate next hop selection probability η_{rs} *using remaining energy and delay*

End for

Generate a Forward ant (FAnt)

For every FAnt

Select a cluster head from current NS_i

For r =1 to s do

Calculate next hop selection probability P_{rs}

Select next hop using P_{rs} *probability*

End for

Receive optimal path information from Backward Ant (BAnt) based on ReEn and path length of a route.

Update the optimal path in the path list $Path_{rs}$

Update pheromone heuristics $\tau_{rs}(t)$ *for every edge of a path*

Select an optimal path from path list $Path_{rs}$

End for

Select Cluster Head CH_i *form optimal node set* NS_i *which is nearest to BS as LEADING Cluster Head*

For Every Cluster Head selected

transmit data packet under the supervision of LEADING CH

End for

When route discovery and learning is over by ants the "ListRoute" lists the paths discovered by ants. Thereafter only minimum distance paths are recorded in $path_{rs.}$ After getting an optimal route from path list $path_{rs}$ we define an optimal value for a maximum number of iterations $mC_{max.}$ In order to get good results, it is theoretically suggested to set a higher value of mC_{max} but on the other hand, it will lead to increased complexity as well. Our algorithm sets mC_{max}= 7 since we have already optimized our route during the clustering process.

The Cluster Head node set with the highest weight is the optimal node set to be chosen as cluster head which provides full connectivity. Let us assume that at an instance t proposed algorithm sets the Cluster Head CH_i from the optimal cluster head node set list NS_i, the selected CH is nearest to a base station having maximum RSSI and is called as LEADING Cluster Head $CH_{i.}$ The data fusion strategy is used by CH_i to restrict the number of transmissions in order to conserve energy. Continuing this way, the CH_i transmits its data further to next hop neighbor towards BS. Finally sink node receives the data under the supervision of LEADING Cluster Head.

3.3 Simulation and Performance Evaluation

This section, presents simulation parameters, evaluations, and results along with comparison metrics. The proposed protocol is compared with LEACH, EEUC, and EE -LEACH.

For better evaluation of proposed protocol LB-CR-ACO, the simulation evaluation has been performed under two different scenarios in NS 2.3.4.

Scenario I

An Area of 200 m X 200 m is selected for network deployment. BS is placed at the center place in WSN (100m X 100m) range. The initial energy of sensor nodes is 3J. Maximum data packet length is 4000 bits.

Control message size is limited to 200 bits and data aggregation ratio and threshold are set to 15% and 65 respectively. $\mathcal{E}_{mp}$ is set to 100PJ/bits/m^2 and E_{elec} is set to 50mJ/bit. The performance of proposed protocol has been analyzed in three types of node deployments: sparse, medium and highly dense wireless sensor networks.

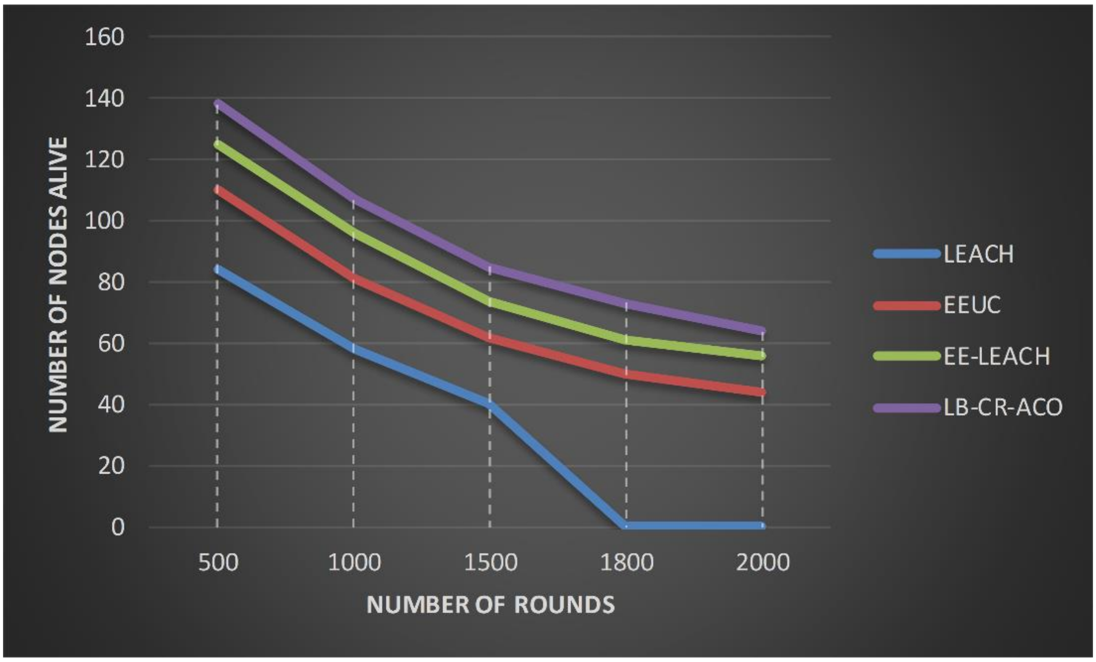

Figure 3. 3 No. of Alive Nodes at the End of 2000 Rounds, No. of Nodes 200; BS (100X100) m^2

Figure 3.3, 3.4, 3.5 illustrates the plotting of graph for a number of alive nodes vs. number of rounds for LEACH, EEUC, EE-LEACH and LB-CR-ACO. The graphs are plotted for varied number of node densities like 200,300,400 (Sparse, medium, dense) sensor nodes. The performance of LEACH is minimum among all since it does not take into consideration remaining energy, RSSI/distance metric while selecting cluster head nodes whereas it chooses nodes as cluster head on a random basis by assigning equal probability to all the nodes. EEUC protocol makes use of energy and distance measure to calculate competition radius. Therefore, it performs better than LEACH. Figure

3.3 depicts performance of LB-CR-ACO and other protocol for sparsely deployed networks. LB-CR-ACO protocol is 32% better than LEACH, 10% better than EEUC, 4% better than EE-LEACH for network lifetime measure. Figure 3.4 shows that proposed protocol is 8.26% better than EE- LEACH, 16.6% better than EEUC and 35.6% better than LEACH for medium dense wireless sensor networks.

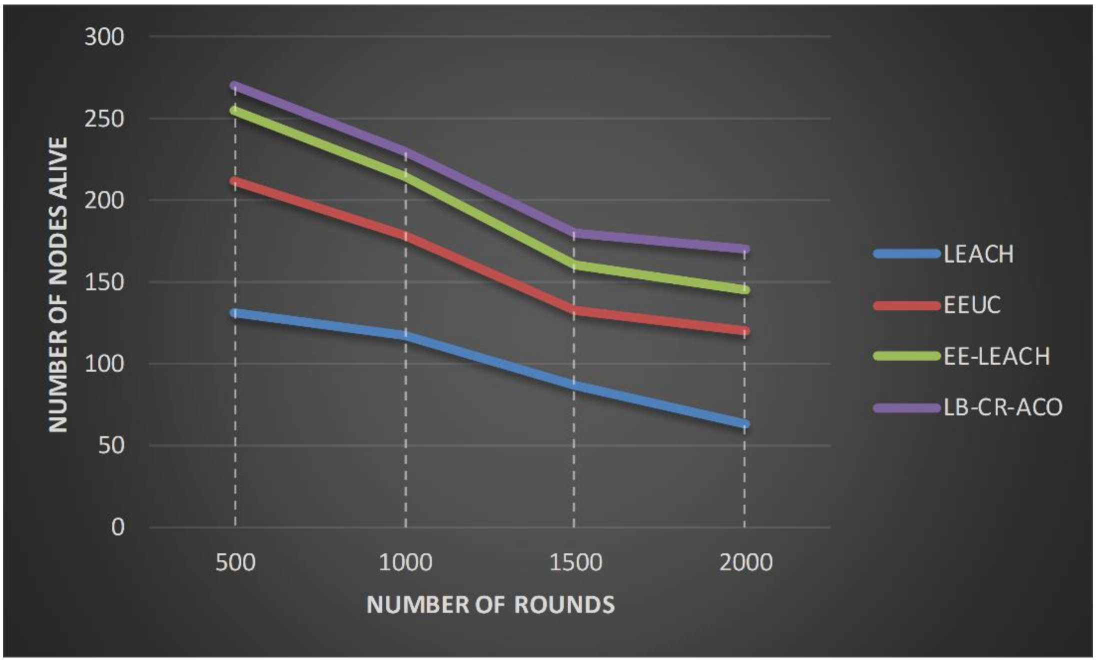

Figure 3.4 No. of Alive Nodes at the End of 2000 Rounds, No. of Nodes 300; BS (100X100) m²

Figure 3.5 illustrates that LB-CR-ACO is 7.5% better than EE- LEACH, 11.25% better than EEUC and 27.5% better than LEACH for highly dense WSNs. Figure 3.6, 3.7, 3.8 illustrates the energy consumption per round when BS is placed at the Centre of ROI for sparse, medium and dense deployments respectively.

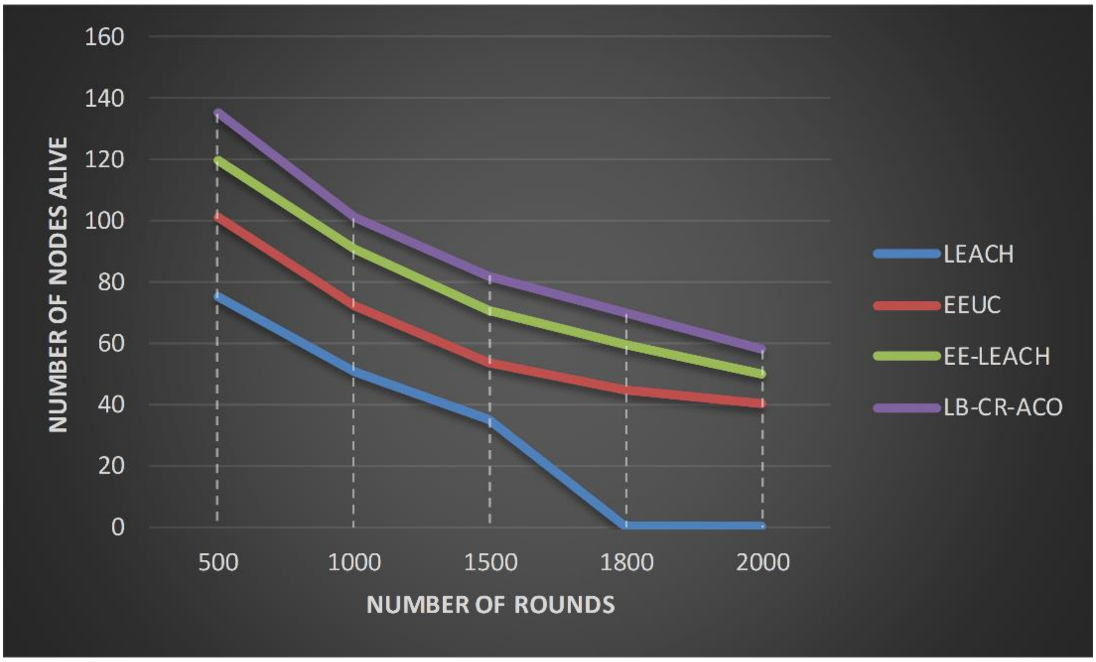

Figure 3. 5 No. of Alive Nodes at the End of 2000 Rounds; No. of Nodes 400; BS (100X100) m²

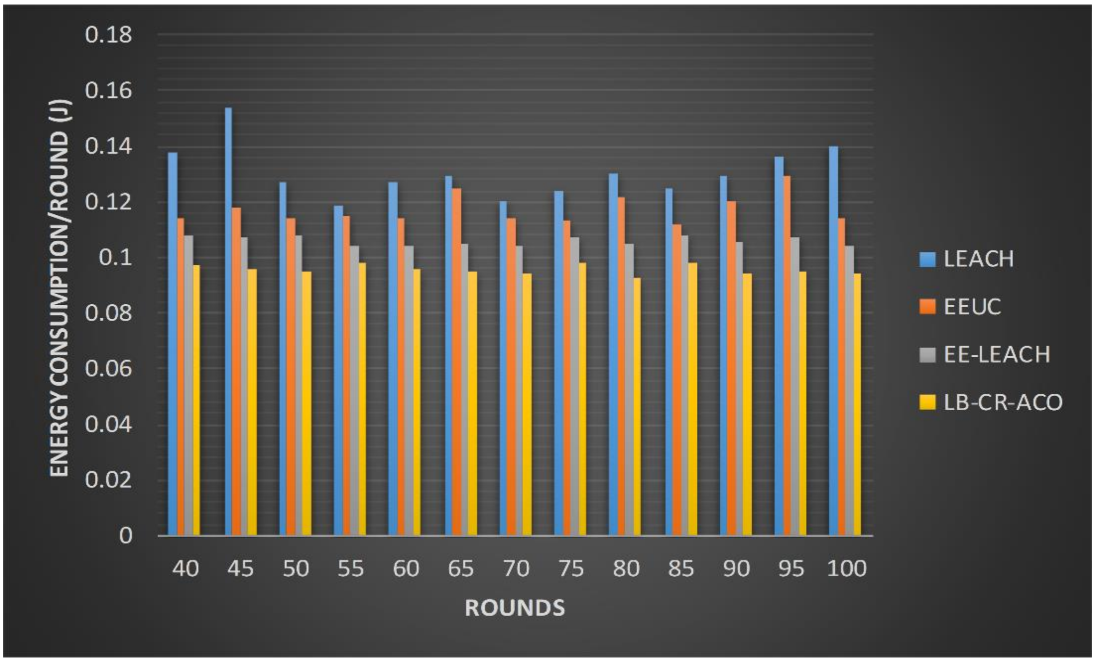

Figure 3.6 Energy Consumption/Round, No. of Nodes 200; BS (100X100) m²

It is worth mentioning that LB-CR-ACO performs network lifetime enhancement since it selects the novel cluster head calculating highest probability weighting factor for selection by taking into account the remaining energy of nodes, Received Signal Strength Indicator (RSSI), node density, number of load-balanced node connections at a probable cluster head node. Priority weights are also assigned among these metrics while calculating best cluster head selection probability.

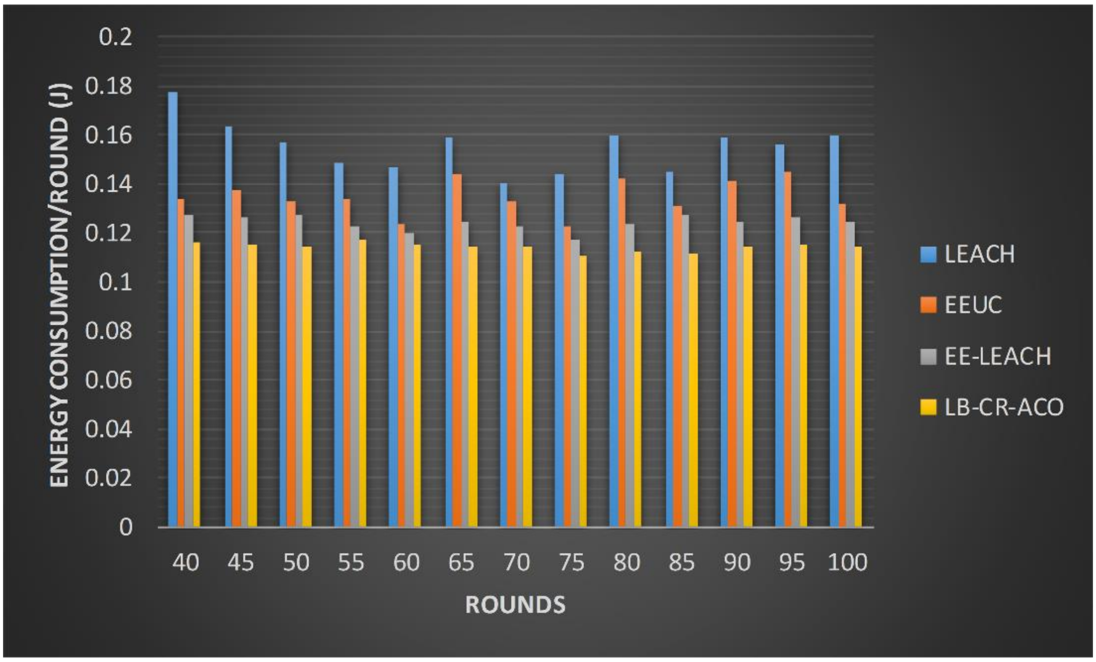

Figure 3.7 Energy Consumption/Round, No. of Nodes 300; BS (100X100) m^2

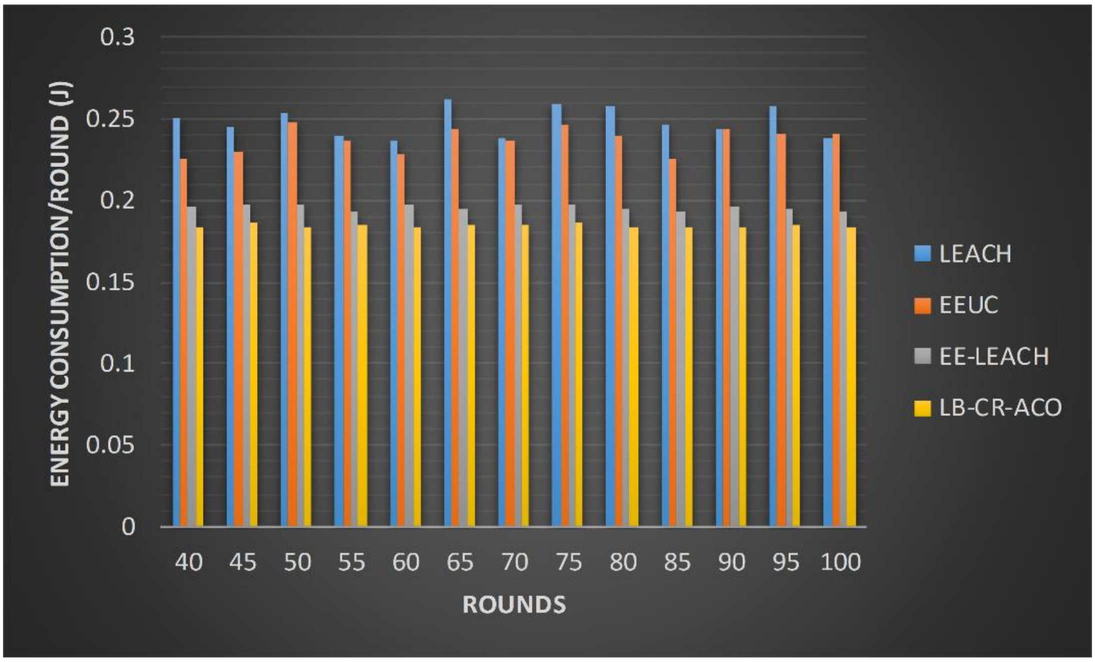

Figure 3.8 Energy Consumption/Round, No. of Nodes 400; BS (100X100) m^2

The ACO approach is used for multi-hop routing during steady state phase. It is observed that at the initial stage of network setup, all the sensor nodes depict the same amount of energy whereas it starts depleting as the number of rounds keep on increasing with the passage of time. We would also like to mention that communication model chosen is also one of the major factors determining energy depletion. An assumption made here is that if a node's energy reaches at its threshold value, it will be counted as a dead node. It has been observed that proposed protocol LB-CR-ACO provides a better result in comparison to other protocols for a number of alive node metrics. It is quite evident from Fig. 3.3, 3.4, 3.5 that proposed protocol's performance is better than LEACH, EEUC, EE- LEACH for no. of alive node metric and energy consumption per round as well.

Scenario II

Scenario II has been created to analyze the impact of BS position if it is changed from the Centre of WSN to far away from it. Maximum distance calculated from BS is 150.42 m approx. for (200X200) m^2 area when BS is positioned at (200,200) m. The initial energy of sensor nodes is 3J. Maximum data packet length is 4000 bits. Control message size is limited to 200 bits, data aggregation ratio and the threshold is set to 15% and 65 respectively. We have analyzed the performance of proposed protocol along with other protocols in three types of node deployments: sparse, medium and highly dense wireless sensor networks.

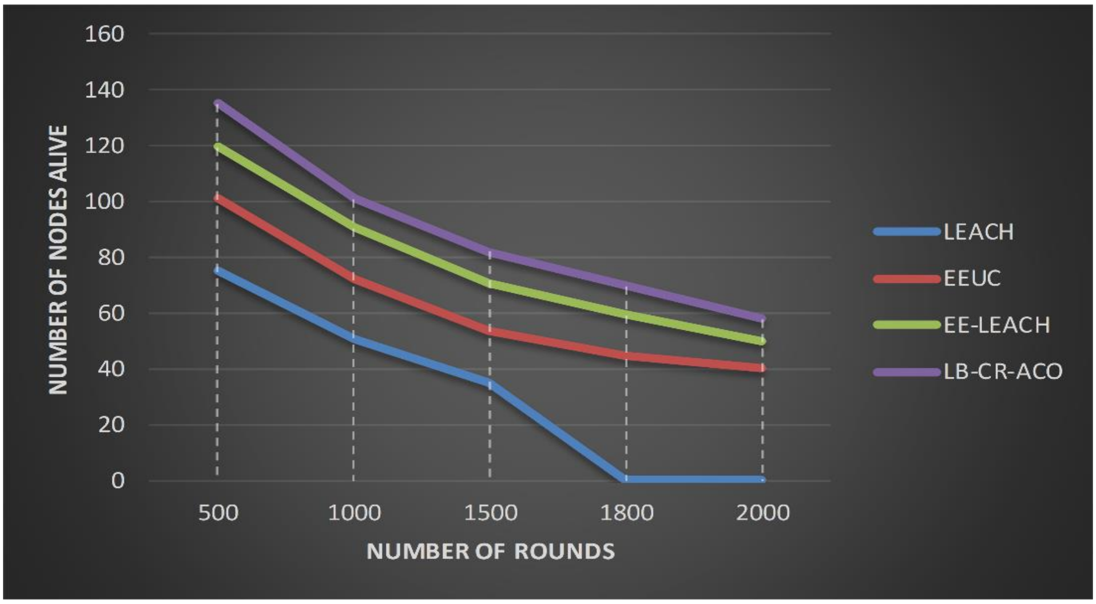

Figure 3. 9 No. of Alive Nodes at the End of 2000 rounds; No. of Nodes 200; BS (200X200) m^2

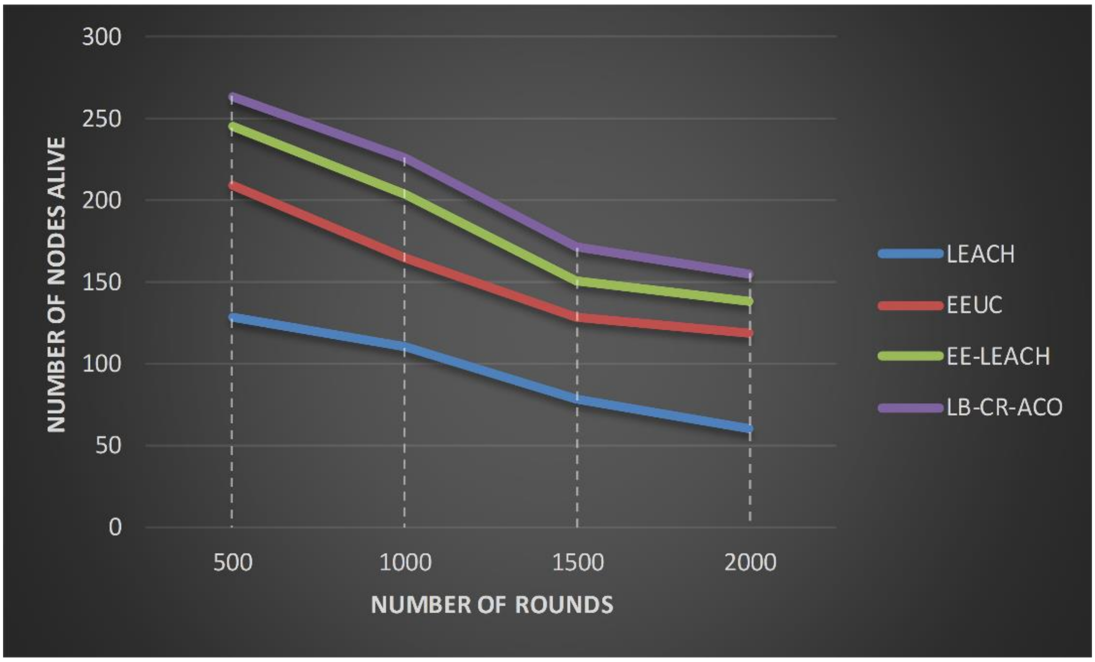

Figure 3.10 No. of Alive Nodes at the End of 2000 Rounds; No. of Nodes 300; BS (200X200) m²

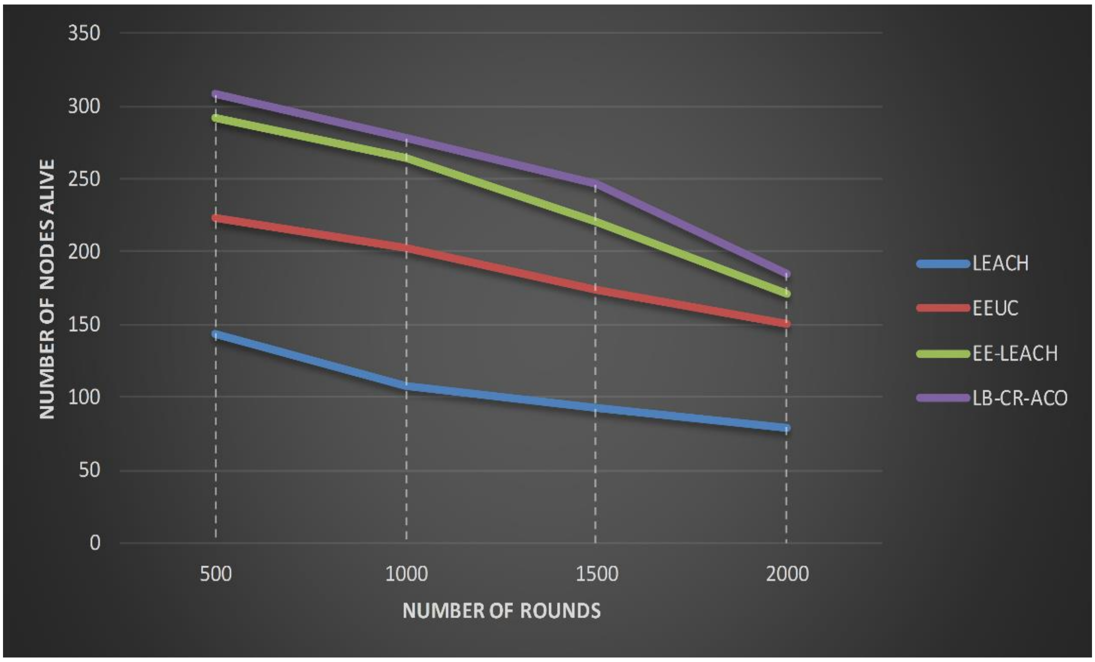

Figure 3.11 No. of Alive Nodes at the End of 2000 Rounds; No. of Nodes 400; BS (200X200) m²

Figure 3.9, 3.10, 3.11 graphically depicts that LB-CR-ACO performs better than other protocols after the completion of 2000 rounds for a number of alive sensor nodes. It is found that LEACH shows minimum performance among all. Figure 3.9 depicts performance of LB-CR-ACO and other protocol for sparsely deployed networks, LB-CR-ACO is 29% better than LEACH, 9 % better than EEUC, 4% better than EE- LEACH for network lifetime measure. Figure 3.10 shows that LB-CR-ACO protocol is 5.66 % better than EE- LEACH, 11.9% better than EEUC and 31.66% better than LEACH for medium dense networks. Figure 3.11 illustrates that LB-CR-ACO protocol is 3.5% better than EE- LEACH, 8.5% better than EEUC and 26.5% better than LEACH for highly dense WSNs. Figure 3.12, 3.13, 3.14 illustrates the energy consumption per round when BS is placed far from the Centre of ROI (200X200) m^2 for sparse , medium and dense deployments respectively.

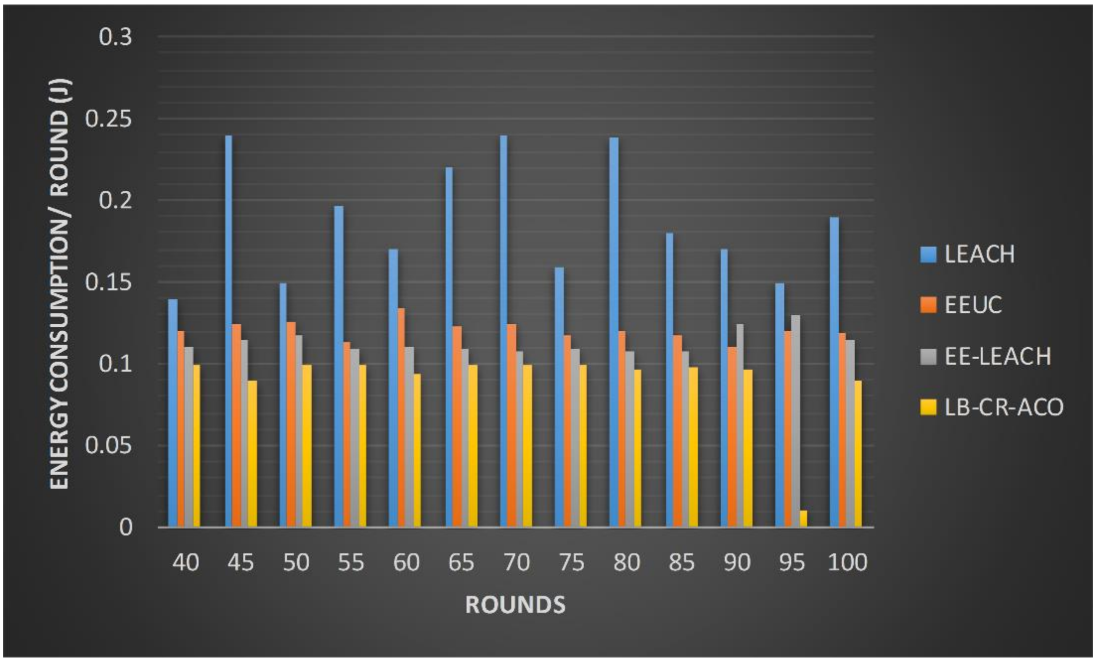

Figure 3.12 Energy Consumption/Round, No. of Nodes 200; BS (200X200) m^2

It has been analyzed from Figure 3.6, 3.7, 3.8 and Figure 3.12, 3.13, 3.15 that there is less energy consumption per round when the BS is placed at Centre of ROI in comparison to BS is placed at far from ROI. It is because when BS is moved far from ROI distance between CH and its nodes becomes relatively large and more energy is consumed per round.

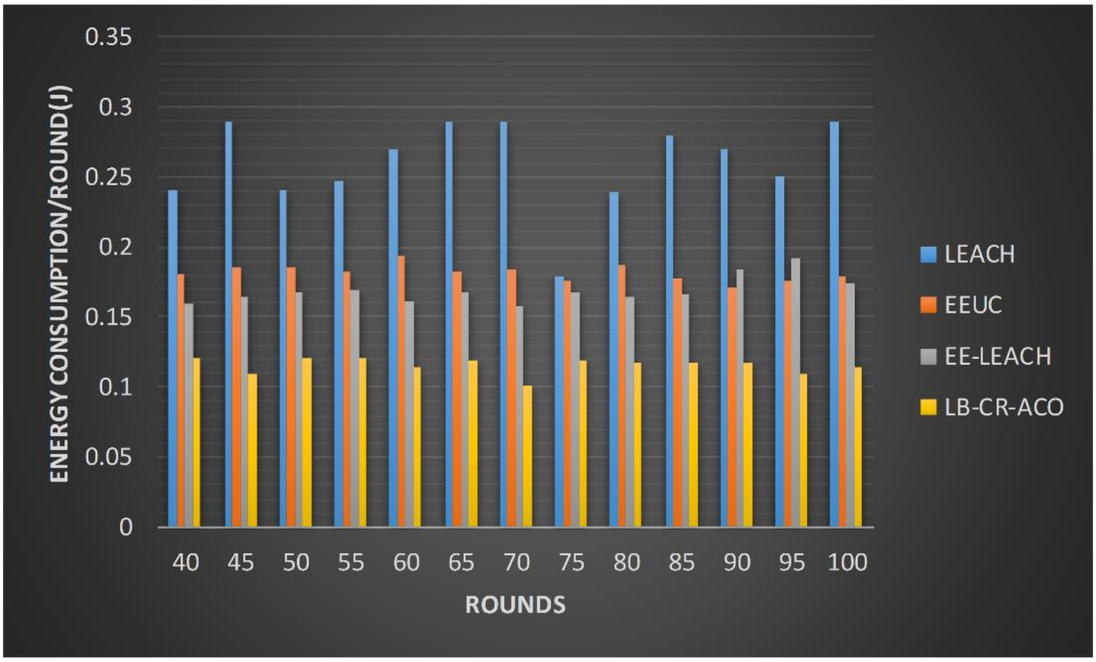

Figure 3.13 Energy Consumption/Round, No. of Nodes 300; BS (200X200) m²

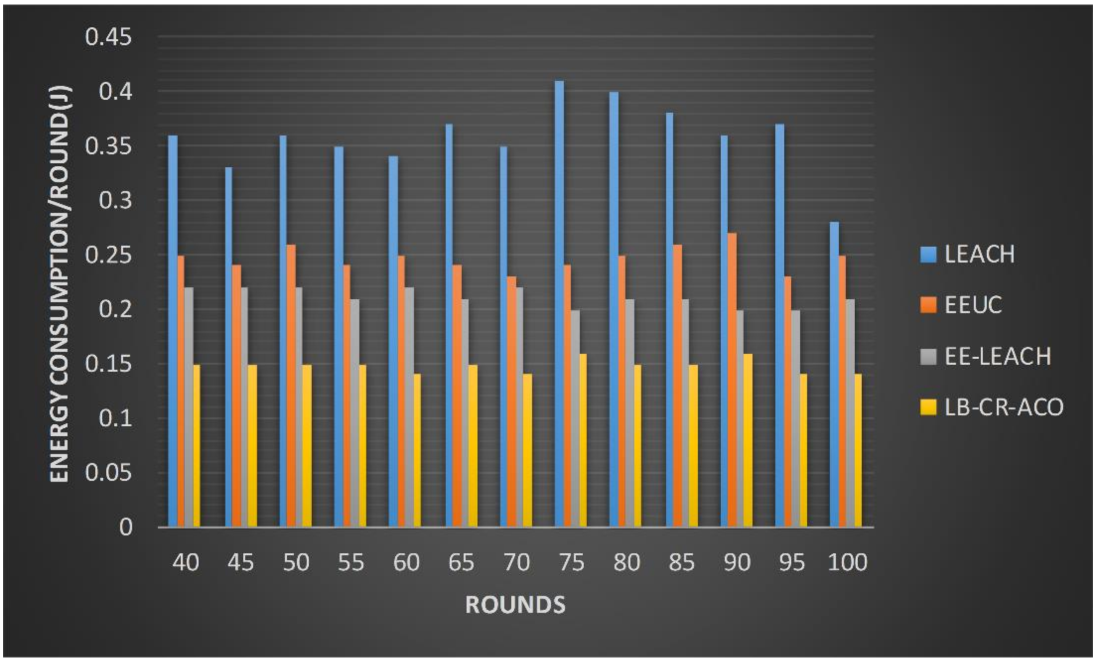

Figure 3. 14 Energy Consumption/Round, No. of Nodes 400; BS (200X200) m²

It has also been observed that LB-CR-ACO exhibits better performance for network lifetime measure when the base station is placed at the center of Region of interest (ROI) rather than at the corner of ROI. Node density has a little effect on the number of alive node metric when BS is at centre of ROI however it has some effect on Alive nodes metric as the BS is moved far from ROI. Alive nodes are more when BS is at centre of ROI as compare to BS is far from ROI and less energy is consumed per round when the BS is placed at the centre of ROI rather than far from ROI.

The performance of LEACH is minimum among all since it does not take into consideration remaining energy, RSSI/distance metric while selecting cluster head nodes. However, it chooses nodes as cluster head on a random basis by assigning equal probability to all the nodes. EEUC protocol makes use of energy and distance measure to calculate competition radius. Therefore, it performs better than LEACH. It is worth mentioning that proposed protocol performs network lifetime enhancement since it selects best optimal cluster heads by calculating highest probability weighing factor for selection by taking into account remaining energy of the nodes, Received Signal Strength Indicator, node density, load-balanced node connections at a probable cluster head node. Priority weights are assigned among these metrics. The protocol also does a dynamic selection of best optimal cluster head node set periodically to enhance network lifetime, conserve energy and thereby utilizing network resources in an efficient manner. The ACO approach is used for multi-hop routing during steady state phase.

3.4 Summary

Energy saving is one the most stringent requirement of WSNs. The proposed protocol LB-CR-ACO is an effort towards this direction which introduces an energy efficient load balanced cluster - based routing protocol using ACO. The protocol contains two stages: Cluster formation and steady state or multi-hop data forwarding. During cluster formation, parameters like remaining energy of nodes, RSSI, node density and number of load balanced nodes affect the process of clustering and account for energy efficient operation of the WSN. In steady state phase, multi hop routing is executed by applying ACO. The proposed protocol enhances the network lifetime since it selects best optimal cluster heads node sets by calculating highest probability weighing factor for cluster head node set selection. Further, the priority weights are assigned among these selection metrics. The protocol also performs a dynamic selection of optimal cluster head periodically which conserve energy and thereby utilizing network resources in an efficient manner. The ACO approach is used for multi-hop routing during steady state phase. Simulations prove that proposed protocol LB-CR-ACO performs load balancing and thereby balance the energy consumed among sensor nodes which leads to an enhanced network lifetime.

LB-CR-ACO performs a dynamic selection of optimal cluster head periodically and it utilizes network resources in an efficient and balanced manner. However, the cluster heads are overburdened with the task of data forwarding to BS. Thus, it is an important task to maintain a fair balance between inter and intra cluster communication load and energy consumption as well. To overcome this limitation another protocol has been presented in the next chapter.

Chapter 4

Meta-Heuristic Ant Colony Optimization based Unequal Clustering

As discussed, in cluster based routing protocols, cluster heads are overburdened with the task of data forwarding to BS which causes unbalanced energy consumption. Thus, it is an important task to maintain a fair balance between inter and intra cluster communication load in order to reduce energy consumption.

Baranidharan and santhi, 2016 had proposed Distributed Unequal Clustering using Fuzzy logic (DUCF) which performs unequal clustering to achieve balanced energy consumption among CHs. The algorithm considers node degree, residual energy and distance to BS as basic input variables for CH selection process. Authors compared the performance of DUCF algorithm with Energy Aware Fuzzy Unequal Clustering (EAUCF) algorithm (Bagci, and Yazici, 2010) and Cluster Head Election using Fuzzy (CHEF) algorithm (Kim *et al.*, 2008). Simulation results prove that DUCF exhibits enhanced network lifetime in comparison to EAUCF and CHEF.

Gajjar et al., 2014 presented a Cluster Head selection protocol using Fuzzy Logic (CHUFL). Residual energy, node reachability from neighboring nodes and communication link quality are considered as basic parameters for cluster formation. Further, Gajjar et al., 2016 proposed a cross layer based protocol which utilizes the concept of fuzzy logic along with ACO and called it as Fuzzy and Ant Colony Optimization Based Combined MAC, Routing, and Unequal Clustering Cross-Layer Protocol for WSN (FAMACROW). The construction of unequal clustering structures solved the energy-hole problem by forming smaller size clusters nearer to BS. The formation of unequal clustering structures with the objective of energy-hole problem avoidance, scalability enhancement are the key attributes of this protocol. The FAMACROW protocol is compared with the Improved Fuzzy Unequal Clustering (IFUC) algorithm and exhibits higher energy efficiency as well as network lifetime.

Even though the integration of ACO with the fuzzy rules inspired by the foraging behavior of ants provides an optimal path, the search process and population initialization consume more time. The suitable CH selection and reduction in the dimensionality of message transmission are the major requirements for reduced network energy consumption. Hence this chapter proposes Meta-Heuristic Ant Colony Optimization based unequal clustering (MHACO-UC), novel CH selection, inter and intra cluster load balancing and relay node concept based data forwarding to alleviate these issues in the existing models.

4.1 Network Model

Prior to the network set-up, the basic assumptions considered for proposed work are listed as follows.

- Sensor nodes available in the network must have the same energy.
- Once the nodes are deployed, they remain in static form.
- On the basis of the Received Signal Strength Indicator, the distance is estimated.
- The significant percentage of node death is due to the energy depletion only
- The network environment is considered as homogeneous.

The BS is situated in the network and has sufficient knowledge about it.

4.2 Meta-Heuristic Ant Colony Optimization based Unequal Clustering

This section discusses the proposed meta-heuristic ACO based Unequal Clustering (MHACO-UC). The proposed work consists of several phases such as network set-up phase, neighbor finding phase, CH selection and Meta- Heuristic based Ant Colony Optimization (ACO) (Singh et al, 2012; Guleria and Verma 2018 b) to determine optimal path selection for the energy-efficient packet delivery among the nodes. Initially, the set of nodes is placed in various locations to form the network. Based on BS location, simulation setup is comprised of three scenarios such as central placement, corner placement and top level placement. But, the placement of BS at the center of network will reduce the number of hops for data transmission and hence the energy consumption is minimum.

Figure 4.1 shows the workflow of proposed system. The Haversine distance (Afrin *et al.,* 2015) measure identifies the relationship between the nodes by formulating the objective function in the neighbor finding phase. Based on this relationship measure, the population initialization is performed for ACO. This initial population is further improved with crossover and mutation to predict the optimal path with low energy consumption. This is implemented by minimizing the number of message transmissions.

4.2.1 Network Set-up phase

The BS in the network initiates the network setup message with the attributes of location, timing information, transmitting power and the signal strength. The node present in the network computes its distance from the BS based on the Haversine distance formulation as follows:

The location of each node is predicted by the analysis of signals transmitted and received. The Global Positioning System (GPS) finds the location of a node by collecting the latitude and longitude information. The GPS data is not in the readable form and hence the reverse geocoding is applied to get the readable form. The latitude data from the GPS is available in degrees, minutes and seconds which is expressed as mentioned in equation 4.1.

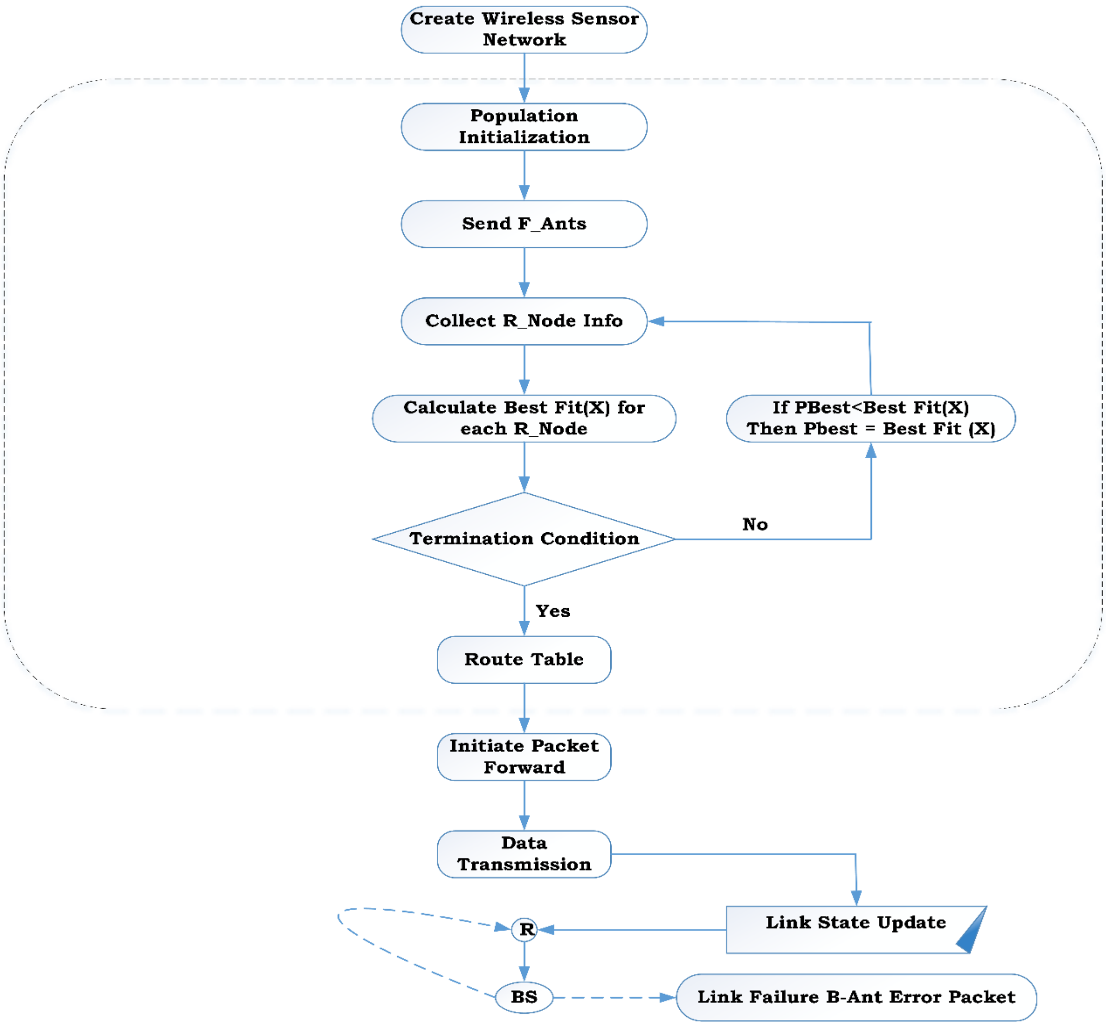

Figure 4. 1 Workflow of Proposed Work

$$Latitude(in\ decimal\ degs) = degrees + \left(\frac{minutes}{60}\right) + \left(\frac{seconds}{3600}\right) \qquad (4.1)$$

With the declaration of minimum/maximum longitude bound values (-5.004101, -4.952431) and the wide value of map (500 px), the coefficients (a, b) are computed to state the longitude in decimal value as per equation 4.2.

$$-5.004101a + b = 0\,; \qquad -4.952431a + b = 500 \qquad (4.2)$$

The solutions of equation 4.2 describe the coefficient values as $a = 9676.9$ and $b = 48423.66$ which are helpful to predict the longitude of the particular point by using the following equation 4.3.

$$x = 9676.9 * longitude + 48423.6 \quad (4.3)$$

The major assumption for the Haversine implementation is that the earth is in spherical shape rather than ellipsoidal. The mathematical formula for Haversine distance estimation is expressed as per equation 4.4.

$$\partial = \sin^2 {d_{lt}}/_2 + \cos \alpha_{u_i} * \cos \alpha_{req} * \sin^2 {d_{lg}}/_2 \quad (4.4)$$

where, ∂ – distance, d_{lt}, d_{lg} – Deviation values of latitude and longitude from requested value, α_{n_i} – Node's latitude information, and α_{req} – Requested latitude information. The distance estimation from the coordinate value obtained from 4.4 is mathematically expressed as in equation 4.5.

$$Nd_i = 2 * R * \text{atan}^2(\sqrt{\partial}) \quad (4.5)$$

where, R denotes the Radius of the earth (3961 miles or 6371 km).

Based on the placement of BS, the scenarios are represented with the grid formation in figure 4.2 a, b, and c. Figure 4.2 illustrates various scenarios of BS placement. As shown in figure 4.2a the centralized BS placement reduces the number of hops through the circular-based coverage which reduces the number of message transmissions among the nodes and hence the energy consumption is less. The proposed work considers this as the network model to evaluate the application of Ant Colony Optimization Meta-Heuristic.

The scenarios illustrated in figures 4.2b and 4.2c, exhibit the corner and top-level placement of BS respectively. These scenarios increase the load distribution around the base station. The energy consumption of the hops nearer to the base station increases to the maximum level. So the number of message transmissions among the nodes increase and overall performance of the WSN degrades.

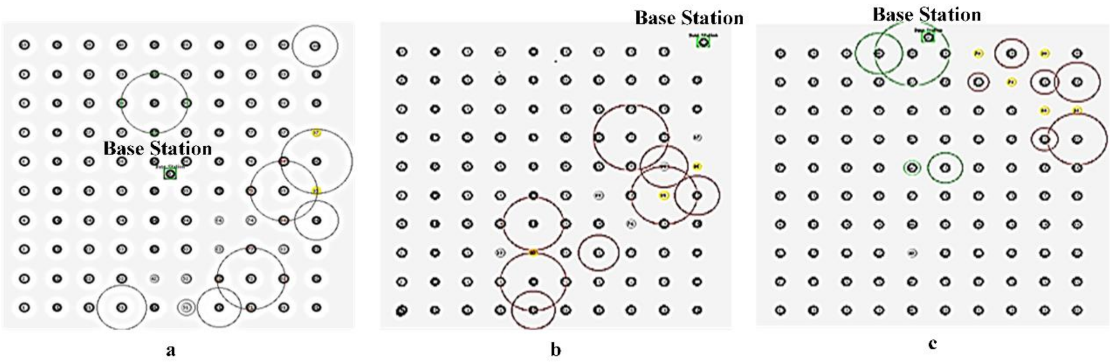

Figure 4. 2 a Centre Placement of BS; b. Corner Placement of BS; c. Top-level Placement of BS

4.2.2 Neighbor finding phase

The node utilizes the Medium Access Control (MAC) protocol to find the neighboring nodes. The node initially broadcasts its details to the network through the node details message. The attributes in the message field are listed as follows:

(i) Node ID

(ii) Layer ID

(iii) Distance from BS

(iv) RSSI

When each node receives this information, it is stored in the table called neighbor information table. The distance among the nodes and the distance from the node to BS are estimated by using Haversine distance formulation. Based on the calculation of absolute value of difference obtained between the distance of a node from the BS and the distance of the neighbor node from BS, the direction ('towards' or 'away' from BS) of the neighbor node is predicted. Comparative analysis of the results is based on below two cases:

- Case I: The neighbour node is away from the BS if it is at a greater distance from the BS
- Case II: The neighbour node is towards the BS if it is at a lesser distance from the BS

Due to non-functioning of nodes and link failures the neighbor node automatically changes based on network topology. To make the proposed MHACO-UC as adaptive to node failures, this phase is repeated on the certain number of simulation rounds. The node death due to the energy depletion causes the neighbor finding phase to occur frequently and hence the message transmissions are more at this stage. To alleviate such issues, the fuzzy-based clustering and CH selection are used by considering the parameter called as node proximity.

4.2.3 Unequal Clustering of Nodes

The basic intricacy involved in managing a heterogeneous network prior to dissemination of information gets intensified for energy management among CHs. As stated earlier, a packet usually incurs a huge amount of energy and expends a lot of energy in accomplishing sufficient intermediate hops so as to reach an associated base station. This sort of situation certainly occurs often when there exists a concept of equal clustering, in which every distinct cluster head encompasses a stipulated number of member nodes attached to it. At this juncture, when a member node tends to send an information to a base station, it has to traverse as much number of fixed set of member nodes which is typically coordinated via associated cluster heads. Subsequently this prompt for a superfluous energy drain in particular with CHs. Hence, an unstable network is inferred owing to this convolution of energy drain and ensuing node expiry. A vast amount of energy drain is observed with those cluster heads that are positioned far isolated from a base station because, it usually tends to traverse for an outmost distance which is comparatively greater than that of a proximally positioned member node. Hence, an unequal clustering methodology scores an ample space for getting realized in a homogeneous network as a means of managing the energy over both cluster as well as member nodes involved with it.

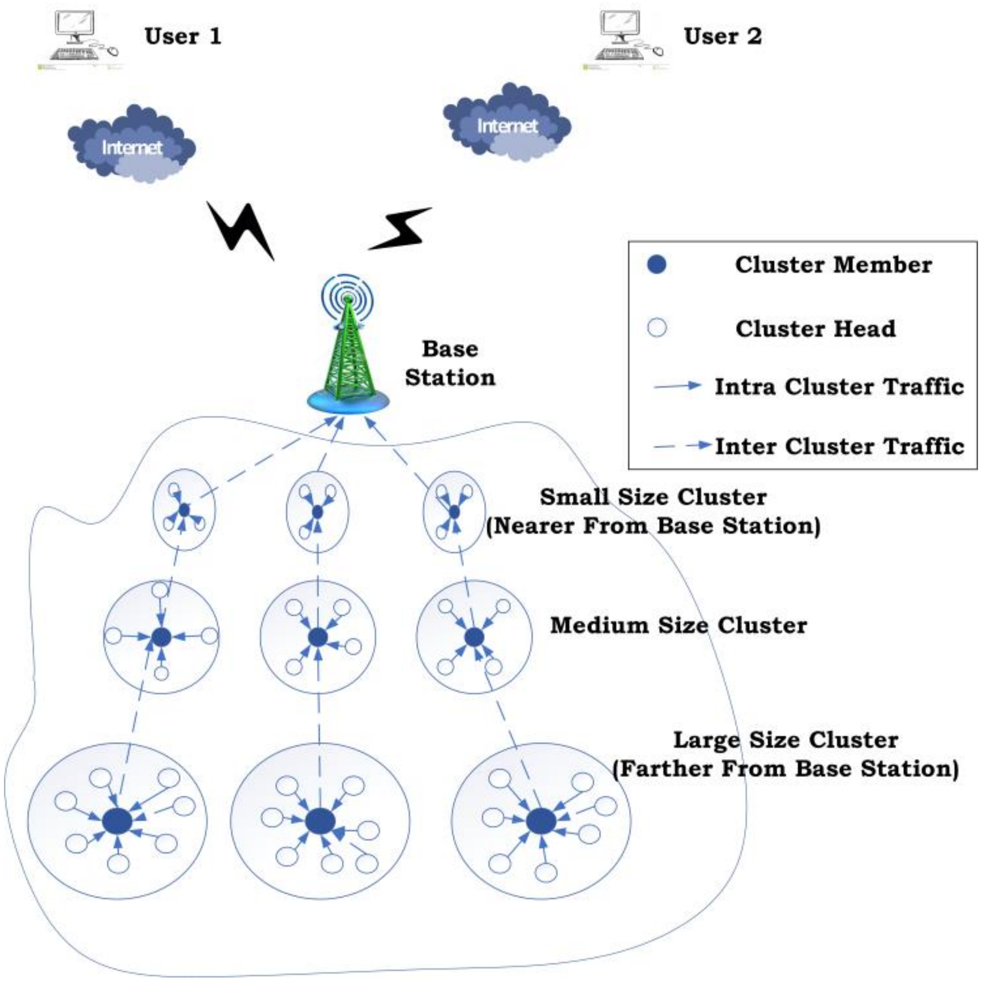

Figure 4. 3 Architecture of Unequal Clustering

Figure 4.3 shows the architecture of unequal clustering. In an unequal clustering mechanism, no postulated number of predefined nodes get bonded with a cluster head intuitively. As mentioned earlier, unequal number of member nodes get connected with a cluster head. All sorts of cluster heads prevailing within a clustered network tend to opt for its cluster members which are positioned in a single hop distance. Hence, a vast depreciation of energy consumption is inferred in accordance with a mitigation plan in intra-cluster communication. Subsequently, this induces the proficient energy utilization for inter-cluster communication. An energy balance is thus accomplished among nodes primarily as means of alleviating multi-hop communication to reach the cluster head. Clusters which are formed through this process are proficient enough to navigate the information through the network. A node sends the collected information to its associated CH via the devised data fusion model. Thus, all the information possessed by distinct member nodes is collected by CH and is finally sent to BS. Hence, a significant reduction in energy consumption is achieved.

The selected cluster head holds the responsibility of transferring the packets towards BS through relay node which possesses the capability of transmitting the perceived information directly from CH to BS. Relay node (Rnode) is a specific node which is chosen by a CH on the basis of its proximity towards itself and the BS. Every CH is likely to opt for a Rnode suitable for its own criterion involved. Thus, the energy consumption involved in transferring an information from a CH to BS is highly reduced. A moderate balance of energy is deployed among CHs, Rnode and its member nodes. The procedure used for electing a CH employs necessary constraints as prescribed in subsequent section.

4.2.4 Cluster Head Selection

The selection of CH among the nodes in particular cluster depends on diverse set of parameters such as proximity, residual energy and Link Quality Factor (LQF). In general, the energy consumed by the node depends on data collection, transmission and reception. The node participating in the network activities must have the sufficient energy and such energy is referred as residual energy. Another condition for a node to be selected as CH is that it should have more residual energy than other nodes. A fuzzy based approach is employed on these three metrics to choose those proximal set of nodes for bonding member nodes with appropriate CH. The proximity of the neighbor node is defined as in equation 4.6.

$$N_P = \frac{1}{N_{tot}} \sum_{i=1}^{N_{tot}-1} dist(n, i) \tag{4.6}$$

where N_{tot} - the total number of neighboring nodes in network and $dist(n, i)$ is the distance between node and neighboring nodes.

The distance assessed for opting a node as a neighboring node or as a cluster member node is considered as the basis of proximity between those nodes. This subsequently accounts for a distance assessment relying upon signal strength prevailing within distinct nodes. The queue size is the basic measure to estimate the LQF and it is defined as the ratio of the difference between the total available and occupied queue to the frame length and it is expressed as per equation 4.7.

$$Qs_i = \frac{Total\ Queue\ Size - Occupied\ Queue\ size}{Frame\ length} \tag{4.7}$$

The response time is estimated as per equation 4.8.

$$Rt_i = (T_{DERX} - T_{DDTX}) + (T_{ACKETX} - T_{ACKDRX}) \tag{4.8}$$

where T_{DERX} -Time of Data Packet Enqueued in Rx_Port , T_{DDTX}- Time of Data Packet Dequeued in Tx_Port, T_{ACKETX} - Time of acknowledgment Packet Enqueued in Tx_Port, T_{ACKDRX} - Time of acknowledgment Packet Dequeued in Rx_Port.

The RSSI measure depends on the distance between the source and destination nodes in the traditional studies (Abdellatif *et al.*, 2014). But, the RSSI estimation is modified with the inclusion of minimum energy consumption mode. Mobility function describes the movement of mobile nodes with the speed of a node along its direction. The distance between the nodes is calculated using a constant value 'k' and power required for transmission/reception $(\mathrm{Pt}, \mathrm{Pr})$ (Garg and Kaur, 2014) is expressed by equation 4.9.

$$d = \sqrt[4]{\mathrm{k.\,Pt/Pr}} \tag{4.9}$$

Relative velocity is calculated by equation 4.10.

$$\bar{v} = \Delta \mathrm{d}/\Delta \mathrm{t} \tag{4.10}$$

The position of neighbor node with respect to current node is expressed through the velocity according to the directional information. If the velocity is greater than zero, then node moves towards the BS and it moves away from BS otherwise. The LQF depends on goodness of RSSI and the remaining parameters (bandwidth, response time and the connection) are temporal in nature. The LQF between the source and destination is described by equation 4.11.

$$LQF(S,D) = \sum_{i=0}^{n}(Qs_i + Rt_i + BW_i - IR_i) \quad (4.11)$$

where, IR_i – interference ratio. Based on the signal and noise level, the state of RSSI and QF values are described as in Table 4.1.

Table 4. 1 RSSI and QF States

SIGNAL STRENGTH	NOISE	RSSI	LQF
Weak	Present	Low	Low
Weak	Absent	Low	High
Strong	Absent	High	High
Strong	Present	High	Low

The number of paths available between the nodes are stored in a list form which is used to select the best path for an efficient transmission. The layered architecture is evolved in WSN to reduce the data traffic among the clusters. The nodes present in the first layer transmit the data to BS by broadcasting the CH advertisement to all the nodes in a cluster. The advertisement radius for relay node or CH computation in other layers is defined by equation 4.12.

$$R_{node\_adv} = [\left(1 - w\frac{Nd_{max} - dist(CHi,BS)}{Nd_{max} - Nd_{min}}\right) \times \left(\frac{E_{current}(CHi)}{E_{initial}(CHi)}\right)]R_{adv\_max} \quad (4.12)$$

where, Nd_{max} - Maximum distance between node and BS. Nd_{min} – Minimum distance between node and BS. $E_{current}(CH_i)$- Current

Energy of CH_i. $E_{initial}(CH_i)$- Initial Energy of CH_i. R_{adv_max} is maximum value of advertisement radius R_{adv}.

The value of R_{adv} is kept small for clusters near the BS and large for farther clusters. SNs opt for CH which has highest RSSI of CH_Adv (CH advertisement) because higher RSSI of CH_Adv means that it is the nearest cluster. SNs sends cluster membership request (C_Mem_Req). C_Mem_Req has SN's ID, CH_ID. CH's selects their chosen members and form a TDMA schedule for inter cluster communication. In order to maintain a fair balance of energy among cluster members and CH's the role of CH is distributed among cluster members. Therefore, after certain time period neighbor discovery, CH selection and clustering is performed again.

The total number of message transmissions needed to form the CH is more and the complexity is defined by $O(N^2)$. But, the complexity needs to be minimized in order to reduce the energy consumption. Hence, the optimal path is selected to reduce the message transmissions. The proposed work utilizes Meta heuristic ACO optimization technique to find the optimal path for during inter cluster communication.

4.2.5 Meta-heuristic ACO based optimal path selection

In this stage, the meta-heuristic ACO optimization technique is implemented to select the optimal path with the help of fruit fly optimization. Moreover, it incorporates the stochastic elucidations obtained from these artificial ants as a means of fabricating an optimal solution. The components involved in fabricating a feasible solution is acquired through ants with an added flexibility. In general, movement of an ant is characterized to traverse the set of available candidate solutions as means of excavating an optimal solution. Hence, the problem is initially defined through the following:

$$C, o, \lambda \tag{4.13}$$

where, C- indicates the complete set that represents candidate solutions, o-states the objective function defined, and λ-specifies the constraints for accomplishing an optimal solution.

Ants tend to navigate through the defined problem space and observe for an optimal set of solution. This solution optimal solution completely satisfies the constraints in varied set of states encompassing various components given as:

$$S = \{s_1, s_2, s_3 \dots, s_{N_s}\} \tag{4.14}$$

These components are confined around the position of nodes in order to form a cluster. The procedure of proposed meta- heuristic ACO based optimal path selection model is represented as below:

Metaheuristic ACO based optimal Path Selection

Input: **Deployed set of clusters**

Output: **Optimal path for reaching destination**

Initialize pheromone values Ph

repeat

for ant k∈ $1, \ldots, m$ do

construct a solution

for all Ph values do

decrease the value by a certain percentage evaporation

(TTL)

end for

$S = 1, \ldots, n$

choose node i with probability p_{0i}

repeat

choose node $j \in S$ with probability p_{ij}

$S = Sj$

$i = j$

until $S = 0$;

end for

Find shortest path using vision function employed based on the following steps:

Initialize the random position of the nodes in cluster as $x, y = 0$

Estimate the direction based on the Haversine distance formulation

Once the location information of CH and neighbor nodes are known, then estimate the distance between them Form

the smell or fitness function as follows:

$$S = 1/N_d \quad (4.15)$$

Extract the distance corresponding to the minimum node count and maximum smell concentration as follows:

$$n = node\ (\min D\ .\max\_S) \qquad (4.16)$$

Aggregate the data from the node to BS based on smell value

Repeat the iterative processes in FFO for all the nodes in network.

until stopping criterion is met

for $\forall Ph$ values corresponding to good solutions do Increase the value intensification

end for

until stopping criterion is met

Based on above mentioned steps, the best optimal path is selected which reduces the message transmission and hence the complexity is reduced into $O(N)$. The integrated framework of optimization approaches with the Haversine distance formulation increases the packets aggregated to BS with minimum energy consumption effectively. In this technique, the initial set of solution is plotted with a feasible set of candidate solutions acquired formerly and the feasibility constraint obtained for probing a CH is assessed. Haversine distance is employed for computing the feasibility of proximal nodes. Energy consumption due to noise interference influences the process of finding the best fit value for the route establishment using the Haversine distance. The low energy level nodes will not be considered during path selection, because the low energy level nodes will provide poor result in calculating the best fit value. For those confined set of nodes being deliberated within a network, a set of pheromones traverse all through the network to fetch for framing a solution. Every distinct set of solutions i.e., a feasible CH for a selected set of clustered nodes is realized through pheromone that is alive for a stipulated amount of time. When the Time to Live (TTL) expires the pheromone gets evaporated. So, the feasibility of finding optimal path for a member node itself ceases. Hence, the complexity involved in finding a feasible shortest path gets minimized. If an optimal solution is not found within TTL, then the process of path identification is stopped and traversing is performed to find out a different set of solution. This intensification is induced to opt for a probability to choose a CH for all available nodes. The shortest path to reach destination BS via relay node is obtained by means of utilizing the maximized smell intensity accompanied with a minimum Haversine distance inferred. Here, the reason of integrating fruit fly optimization with meta-heuristic ACO technique is applied to select the CH based on the nodes that are in the minimum distance in later stages. The Haversine distance formulation in proposed work predicts the distance radially and then it is compared with each distance to select the minimum distance. After inferring such a path, the data fusion model is incorporated to patch up all the information into a single plot and it is further passed on through the same path to reach BS. Thus, those optimal solutions are reckoned and added up until all information is transferred to an ultimate destination.

4.3 Simulation and Performance Evaluation

In this section, the performance of the proposed MHACO-UC is investigated with respect to existing methods of EAUCF (Bagci, and Yazici, 2010), CHEF (Kim *et al.*, 2008; Baranidharan and Santhi, 2016), FAMACROW (Gajjar et al., 2016) and IFUC (Mao *et al.*, 2013) on the basis the parameters of like Packet Delivery Ratio (PDR), energy consumption, residual energy, percentage of nodes dead and number of packets received at BS with respect to the simulation period and number of rounds with the help of NS-2.3.4 simulator. The validation of the endorsed MHACO-UC approach is realized through simulation performed in NS 2.3.4 and simulation parameters are tabulated in Table 4.2.

Table 4. 2 Simulation Parameters

Simulation Parameter	
NS2 Version	ns-allinone-2.3.4
Coverage Area	$200m^2, 400m^2, 600m^2$
MAC	IEEE 802.15.4
Simulation Time	100 Secs
Antenna Type	Omni Antenna
Energy Model	Energy Model(true)
Initial energy	1000 mjoules
Number of Nodes	100,150,200...800
Queue Length	50

Data Rate	Variable (150, 250, …… 512)
Interface Type	Wireless Physical Interface
Radio Range for Node	25m, 35m

4.3.1 Packet Delivery Ratio

The ratio of the number of packets successfully delivered to the destination and the total number of packets transmitted is referred as Packet Delivery Ratio (PDR) which linearly increases with the simulation period. In this section, the numerical variations of PDR with the linear increase of simulation periods are discussed as shown in Fig. 4.4.

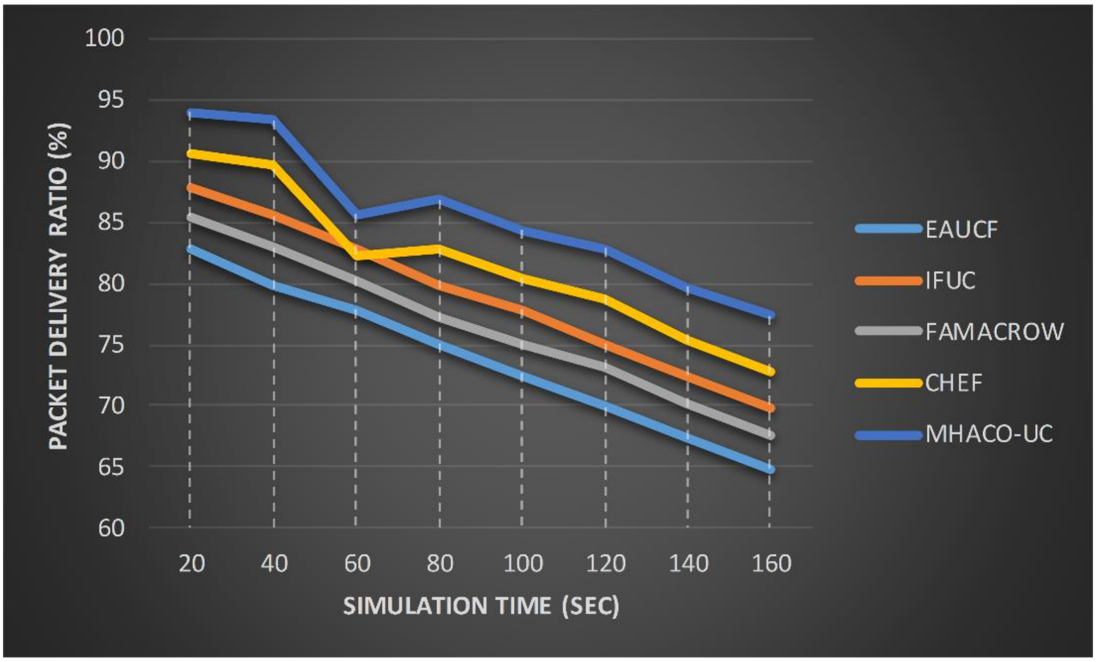

Figure 4. 4 Packet Delivery Ratio Analysis

Figure 4.4 shows the variations of PDR for existing and proposed MHACO-UC with respect to the simulation period variations from 20s to 160s. In existing methods, the CHEF offers better results compared to other methods. But, the incorporation of meta-heuristic ACO with FF optimization in proposed work reduces the complexity and the centralized BS placement updates the neighbor list immediately which increases the PDR values. For a minimum period (20s), the PDR values of CHEF and proposed MHACO-UC are 90.65% and 93.93% respectively. Similarly, they offer 72.81% and 77.37 % for a maximum period (160s). The comparative analysis shows that the proposed MHACO-UC improves the PDR values by 3.49% and 5.89 % compared to CHEF for minimum and maximum simulation periods respectively.

4.3.2 Energy Consumption

The total energy consumed during the transmission (E_{tx}) and reception (E_{rx}) process depends on the electronic energy (E_{elec}), number of bits transmitted (l), energy dissipated in multi-path propagation (ϵ_{mp}) and distance (d). It is expressed as per equation 4.17 and 4.18.

$$E_{tx} = l * E_{elec} + \epsilon_{mp} * d \quad (4.17)$$

$$E_{rx} = l * E_{elec} \quad (4.18)$$

In this section, the numerical variations of energy consumption with the linear increase of simulation rounds are discussed as shown in figure 4.5.

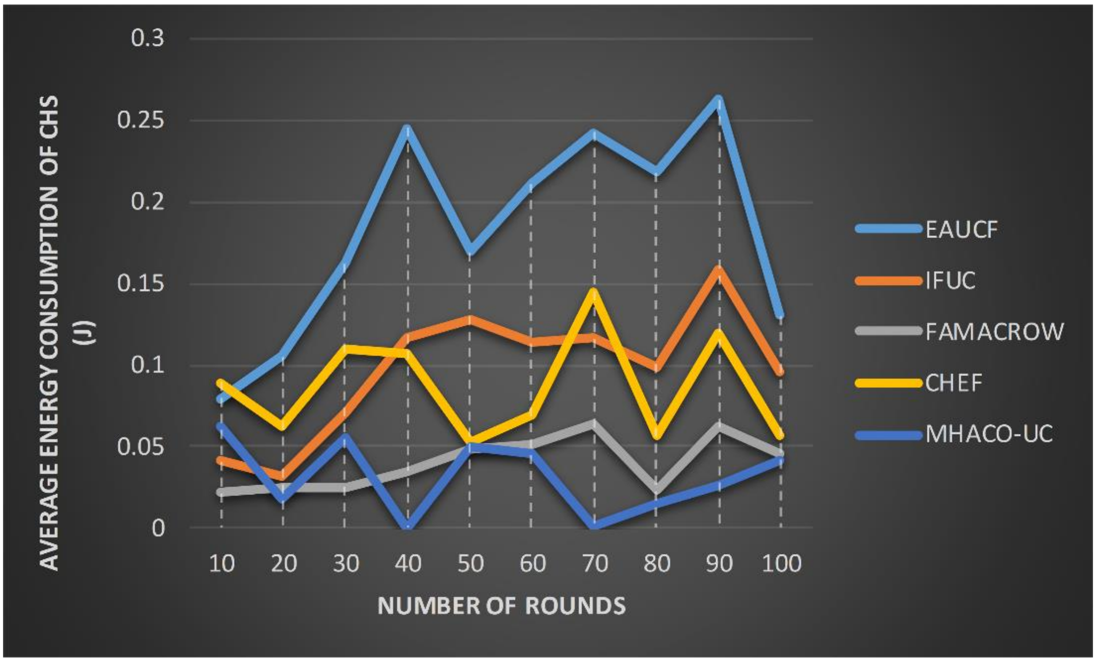

Figure 4. 5 Average Energy Consumption Analysis

Figure 4.5 shows the variations of energy consumption for existing and proposed technique with respect to the various simulation rounds. In existing methods, the IFUC offers better results compared to other methods. But, the integrated framework of FFO with the Haversine distance update reduces the message complexity which will directly reduce the energy consumption. For minimum rounds (10), the energy consumed by the IFUC and MHACO-UC are 0.042J and 0.062J respectively. Similarly, the FAMACROW offers 0.057J and MHACO-UC offers 0.041J for maximum rounds (100). The comparative analysis shows that the proposed MHACO-UC reduces the energy consumption by 28.07% than FAMACROW for maximum simulation period.

4.3.2 Total Residual Energy

In this section, the total amount of remaining energy for all nodes after data transmission is discussed across the simulation rounds as shown in figure 4.6.

This section shows the variations of residual energy for existing and proposed MHACO-UC with respect to the simulation round variations from 10 to 100. In existing methods, the CHEF offers maximum residual energy compared to other methods. But, the incorporation of optimization approaches with the relaying capability in proposed work increases the amount of energy remaining. For minimum rounds (10), the residual energy values of CHEF and MHACO-UC are 608J and 610J respectively. The FAMACROW and MHACO-UC offers 198J and 223J respectively for maximum simulation rounds (100). The comparative analysis shows that the proposed MHACO-UC offers 0.327% and 11.21% improvement in residual energy compared to the existing CHEF and FAMACROW methods respectively.

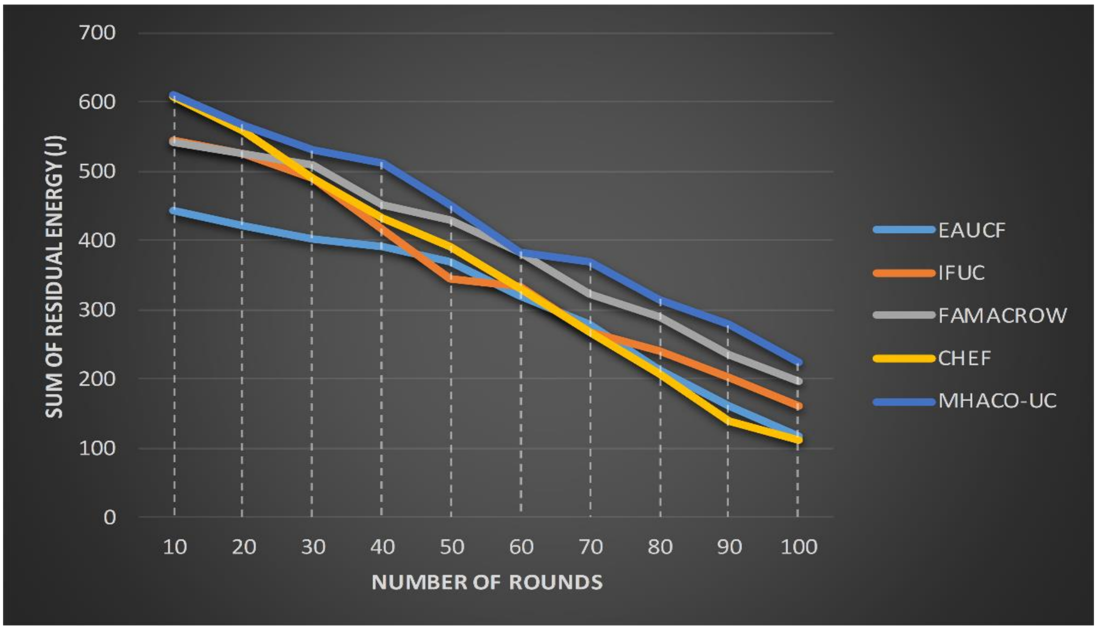

Figure 4. 6 Residual Energy Analysis

4.3.3 Percentage of Nodes Dead

The ratio of a number of nodes lost to the total number of nodes available is referred as the percentage of nodes dead, which linearly increases with the increase in simulation rounds. In this section, the numerical variations of percentage of dead nodes with the linear increase in number of simulation rounds have been discussed as shown in figure 4.7.

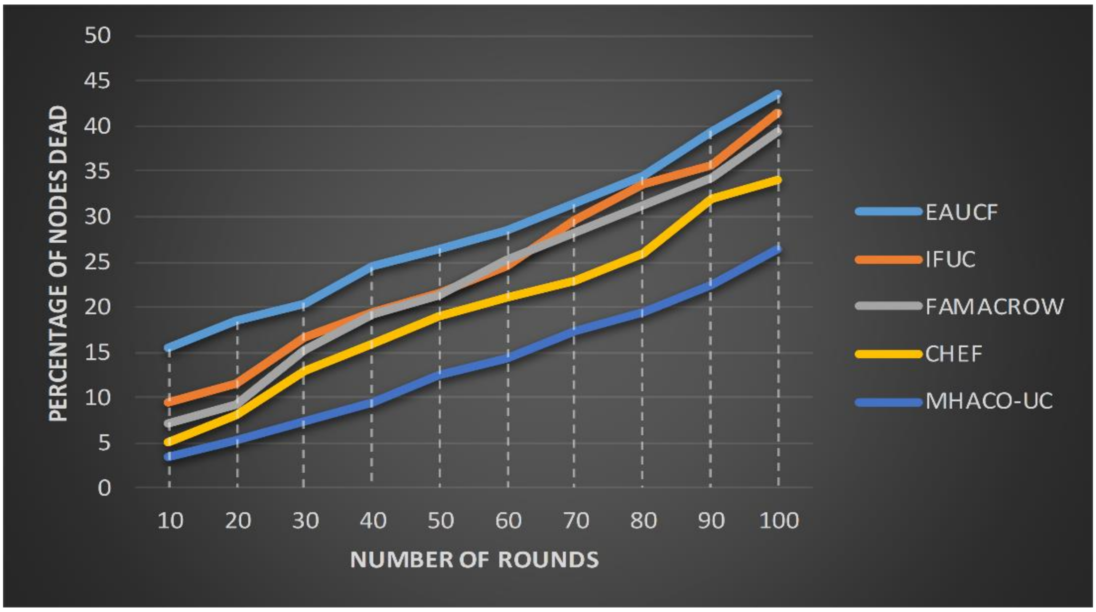

Figure 4. 7 Analysis of Percentage of Nodes Dead

Figure 4.7 shows a variation in percentage of nodes with respect to the simulation rounds from 10 to 100. In existing methods, CHEF offers minimum percentage compared to the previous methods. But, the incorporation of unequal clustering and the optimization based CH selection further reduces the node loss ratio. For minimum simulation round(10), the percentage of node loss for CHEF and MHACO-UC are 5.04% and 3.42 % respectively. Similarly, they offer 34.04% and 26.42 % for maximum rounds (100) respectively. The comparative analysis shows that the proposed MHACO-UC reduces the loss ratio values by 32.14 % and 22.39 % compared to CHEF for minimum and maximum rounds respectively.

4.3.4 Packet Aggregation Analysis

Number of packets aggregated into the BS against the simulation rounds are referred as packet aggregation. In this section, the numerical variations in packets received at BS with the linear increase of simulation rounds are discussed as shown in figure 4.8.

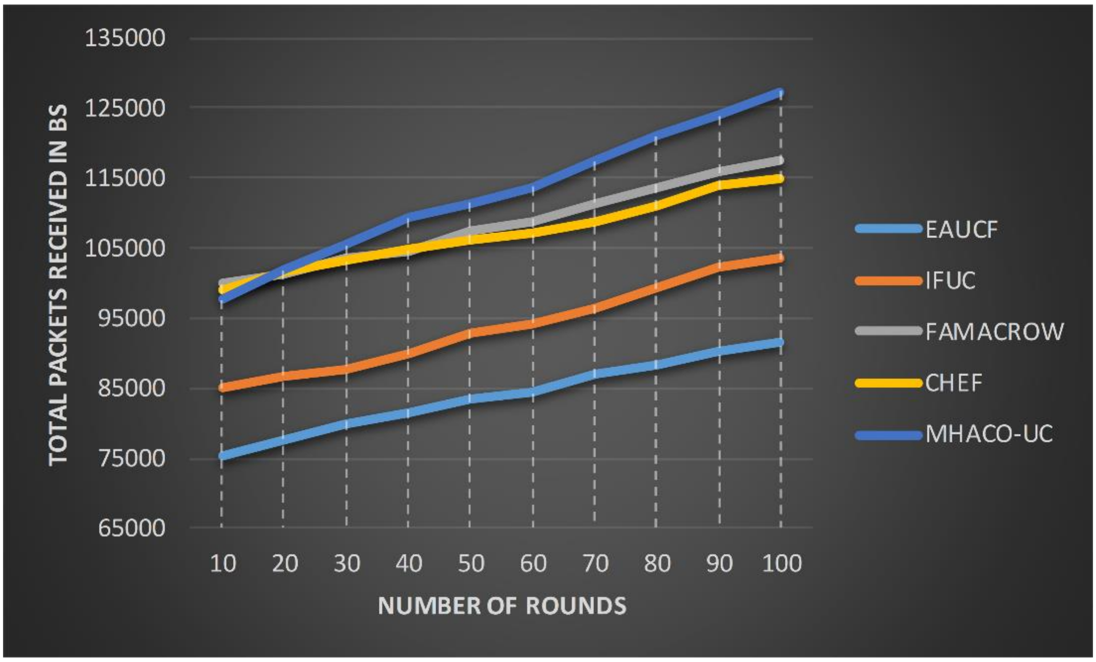

Figure 4. 8 Packet Aggregation Analysis

Figure 4.8 shows the variation of packets aggregated into BS for existing and proposed methods with respect to the simulation rounds from 10 to 100. In existing methods, the FAMACROW offers better results compared to other methods for minimum and maximum rounds. But, the incorporation of unequal clustering framework with the Haversine distance formulation increases the number of packets aggregated at BS. For a maximum number of rounds (10), the total number of packets aggregated at BS are 117481 and 127275 for FAMACROW and MHACO-UC respectively. The comparative analysis between the proposed MHACO-UC and FAMACROW shows the 7.7% improvement in packet aggregation for maximum rounds.

4.3.5 End to end delay analysis

End to End delay is the amount of time taken by the packets to reach the destination from a particular source. The variations of end to end delay with respect to the simulation period are graphically presented in figure 4.9.

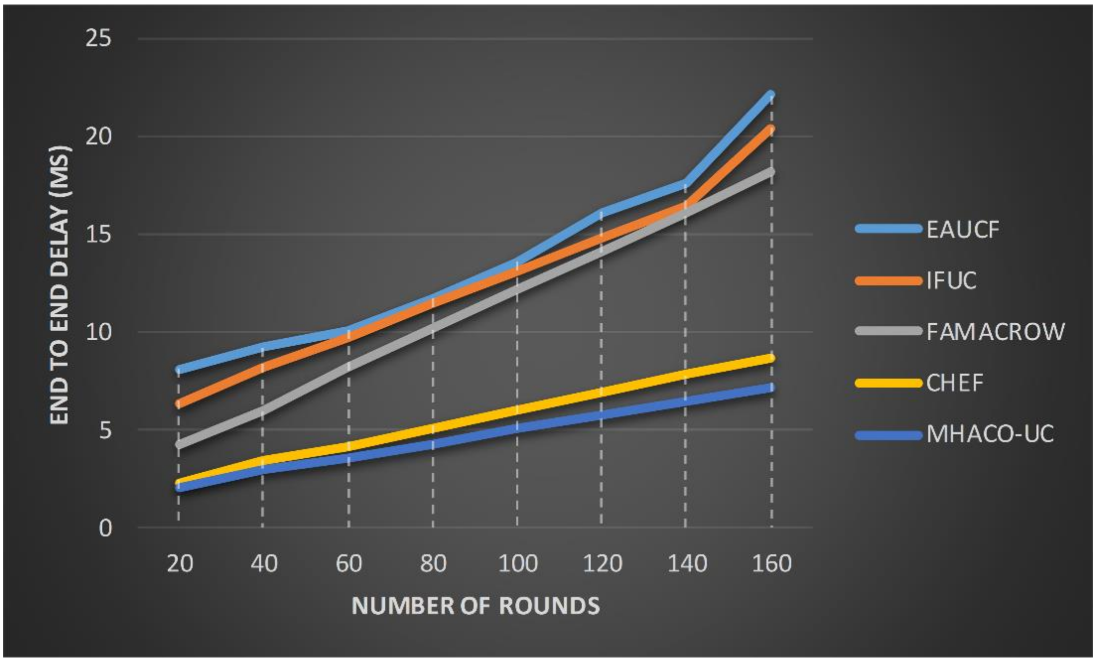

Figure 4. 9 End to End Delay Analysis

It shows the various results of end-to-end delay for the existing and proposed methods with respect to the simulation time period ranging from 20ms to 160ms. The CHEF offers minimum delay compared to others in existing methods. But the incorporation of unequal clustering framework with the distance formulation reduces the delay further. For a maximum number of rounds (20), the end-to-end delay values for CHEF and MHACO-UC are 2.36ms and 2.13ms respectively. Similarly, they offer8.71ms and 7.19ms for CHEF and MHACO-UC respectively for maximum simulation period. The comparative analysis between the proposed MHACO-UC with the CHEF shows that the proposed work reduces the delay value by 2.11% and 17.45 % for minimum and maximum simulation period respectively.

4.4 Summary

Hardware restrictions in WSNs necessitates the design and development of energy efficient load balanced routing protocols. The proposed work is an effort towards this direction. This paper proposes a novel Meta-Heuristic Ant Colony Optimization based Unequal Clustering (MHACO-UC) for the novel CH and optimal path selection. Unequal clustering in the proposed algorithm increases the lifetime of CH node by introducing the concept of Relay node. The incorporation of data fusion provides reduced number of transmissions from the CH or Relay node to other nodes in the network which further reduces the energy consumption level. The specific area monitoring based on minimum energy level, node proximity and performance enhancement through meta-heuristic optimization provides an optimal solution. The proposed MHACO-UC ensures energy-efficient packet delivery and increases the number of packets delivered to the destination. The population initialization based on Haversine distance estimation reduces the dimensionality of message transmissions among the nodes and hence brings down the energy consumption to minimum. The prediction of optimal path , novel CH selection , reduced path selection complexity are the key characteristics of proposed MHACO-UC which in turn reduces the energy consumption and enhances the network performance effectively as well. The comparative analysis of proposed

MHACO-UC with the existing unequal clustering approaches shows the effectiveness of proposed work in WSN applications.

In the proposed MHACO-UC the network was deployed with static SNs whereas WSNs applications like military surveillance monitoring, target tracking in battlefield and intrusion detection require mobility aspect to be explored to handle SNs mobility. Mobility of SNs pose another challenge of topology management/maintenance, connectivity of nodes which needs to be researched further in an energy constrained environment. Therefore, next chapter proposes a routing protocol which handles SNs mobility in an energy constrained environment.

Chapter 5

An Enhanced Energy Proficient Clustering Algorithm for Relay Selection in Heterogeneous WSNs

In this chapter, an enhanced energy proficient clustering (EEPC) algorithm is presented. EEPC handles the mobility of SNs in an energy constrained environment.

Vimalarani et al., 2016 have utilized PSO technique and clustering for energy optimization in wireless sensor networks. This technique examined the population of performing optimization process with fitness function. The algorithm was implemented in centralized manner along with the base station but the cluster heads were elected by PSO in a distributed manner. The sensed tracking data was aggregated in CH and transmitted to base station directly. The main demerit of this system is reduced life time of CHs which are nearest to the BS due to their continuous involvement in data transmission. Su and Zhao, 2017 have developed an effective clustering algorithm based on fuzzy C-means for WSNs. Unequal distribution of sensor nodes (SNs) and unpredictable behavior of radio channel are the main reasons which lead to the fuzzy based partitioning during cluster construction. Node density is considered as the main parameter for optimal CHs calculation. Objective function is based on the weight of membership value and distance measure of SNs to CH. Fuzzy C mean algorithm ensures better distribution of CHs and balances energy consumption. However, further enhancements are required for real time WSN applications.

Gupta and Jana, 2015 have presented an energy efficient clustering method which utilizes genetic approach. Basic parameters considered for clustering are remaining energy of gateways and distance of SNs to their designated gateways. Trade-off among frequency of data forwards and remaining energy of gateways forms the basis of optimal path selection. The protocol exhibits better performance for energy consumption. However, clustering in dynamic environment which is subjected to link failure problems is still an area to be explored.

To alleviate the issues related to network lifetime, traffic overhead, CH's energy consumption, tracking accuracy, a novel relay node discovery algorithm is proposed. The optimal selection of relay nodes reduces the energy depletion of CH node. Paper also proposes a decentralized data fusion method and link maintenance procedure. Decentralized data fusion reduces complexity of data transmission and contributes for enhanced network lifetime as well.

5.1 Network Model

Prior to the network set-up, the basic assumptions considered for proposed work are:

- There are N numbers of SNs that are located in a square field. The static nodes are the nodes whose location is fixed and will be selected as relay nodes. However, there are some mobile nodes which can move within the deployed network and may act as cluster member only.
- Sensor nodes are heterogeneous in nature and they are having unchangeable battery.
- All the SNs have power control feature to adjust or control the transmission power.
- Base Station is positioned at the center of area to be inspected and it doesn't have any energy constraint.
- Partial nodes which are static participate for CH election procedure.
- All SNs are location-aware and every SN has a unique identity.

It is assumed that every SN can communicate with other SNs within its transmission range. Each sensor node gives a binary output value as per the sensed information. Sensor node covers the area as a circle having radius R_s. It is assumed that the ideal sensor node value will be 1 if the mobile node comes within the radius R_s, otherwise it indicates 0. The probability of identifying target nodes depends upon the distance of mobile node to the static sensor node. This can be defined as in equation 5.1.

$$p(d) = \begin{cases} 1, & d \leq R_s \\ 0, & d > R_s \end{cases} \tag{5.1}$$

where d - distance of the target to the sensor node; R_s- sensing radius of the sensor node. The statically positioned sensor nodes are conscious of their whereabouts using GPS based location estimation. Neighboring nodes location information is calculated and accumulated at each sensor node at the beginning of the tracking time to boost the routing performance.

5.2 Proposed Algorithm

In this section, the thorough explanation about the proposed methodology has been presented. The main objective of this paper is to decrease the energy consumption by selecting static nodes as relay nodes to route the data to reach the BS. The network is constructed with both static and mobile nodes. The Static nodes are placed in grid structures and mobile nodes are deployed randomly**.** Initially, static nodes broadcast information and mobile nodes select the cluster head from static nodes. The mobile nodes select their cluster head (CH) on the basis of their associated placement and energy level. The mobile nodes transmit the data to the CH. Generally, CH transmits the sensed information to the base station. The cluster heads near the base station suffers from energy depletion issues due to heavy load traffic intensity. This is a major drawback of the existing WSN environment. The proposed approach introduces the concept of finding relay nodes, which are static nodes. The EEPC algorithm selects the relay nodes based on its velocity and location by calculating particle fitness value. The selected intermediate relay nodes transmit the collected information to the Base Station (BS) using sensor data fusion technique. The link fault of static nodes could be predicted based on the deviation value. The proposed method finds an alternate path based on selected static nodes, which are called as relay nodes. In the absence of relay nodes, the mobile sensor nodes which have high energy level, may act as relay nodes. The proposed work operates in three stages which are unequal clustering process, relay node discovery and data fusion.

In Figure 5.1 first stage illustrates the process of cluster head selection and unequal clustering. An attribute based CH selection method, based on the parameters proximity, residual energy and link quality factor (LQF) has been used. The CH selection and unequal clustering in the proposed EEPC is performed in a similar way as it is done in MHACO-UC protocol (Guleria and Verma, 2019) presented in chapter 4. The second stage determines the optimal relay nodes. There will be many static nodes near the CH. Enhanced Energy Proficient Clustering (EEPC) algorithm is used to find the optimal relay nodes. In the next stage the sensing information is transmitted through relay nodes based on sensor data fusion technique. Static and mobile nodes always transmit bulk amount of time dependent sensing information to the cluster head.

Cluster head collects the data and transmits it to the base station. Frequent data transmission degrades the performance of network due to higher energy consumption. The proposed work utilizes data fusion technique which collects the data in fixed time interval and transmits it to BS. Therefore, the energy ingestion of CH and static nodes is minimized.

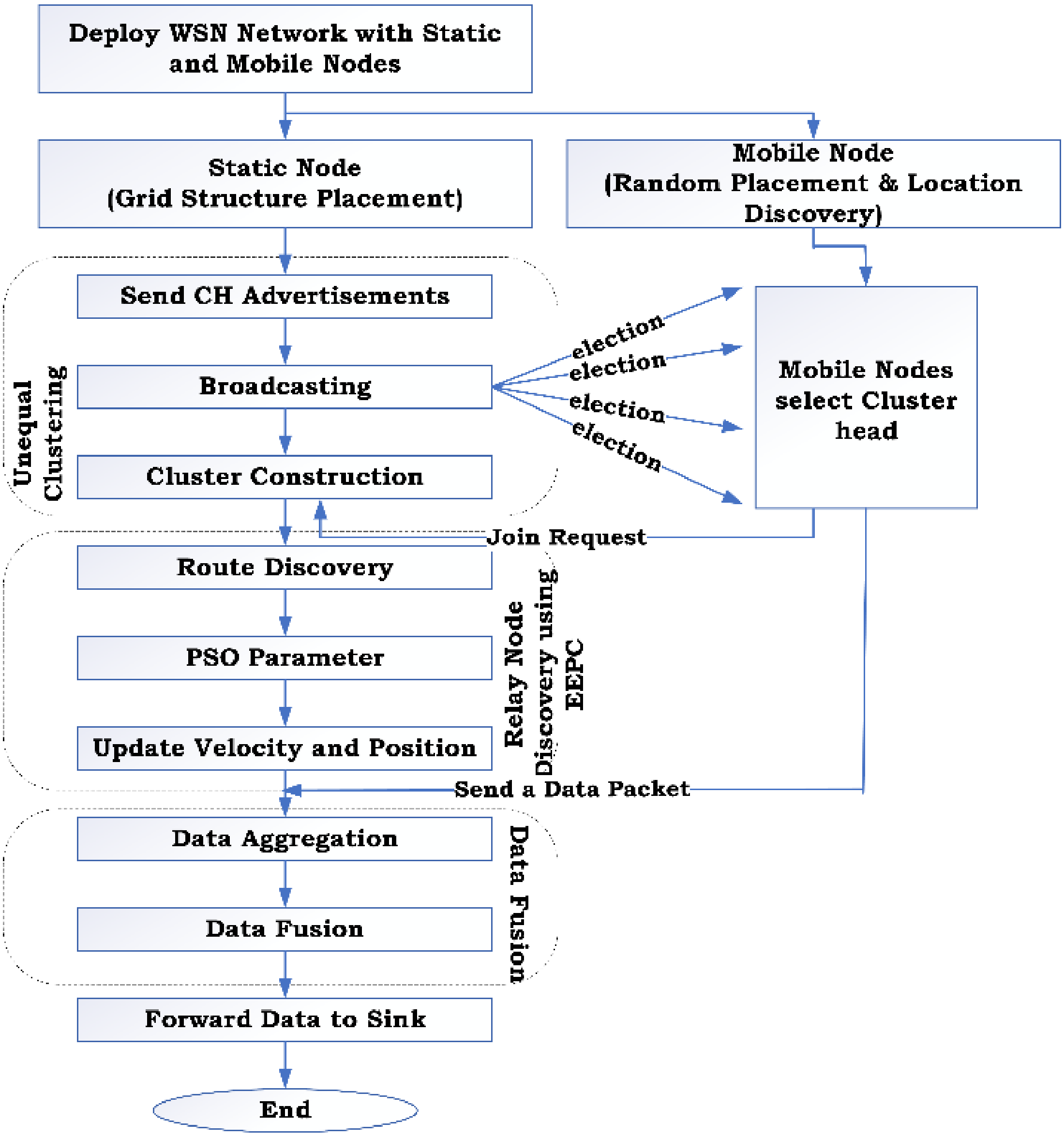

Figure 5.1 Proposed Work Flow

5.2.1 Optimal Route Discovery and Relay selection

Optimal route construction for inter cluster communication is an important task. Determination of relay nodes is a major part of our proposed work. Figure 5.1 illustrates the relay selection process in the proposed workflow. Figure 5.2 gives a runtime view of relay node selection. The mobile nodes and static nodes present in the WSN select the cluster head depending upon energy standard of the node, LQF and node proximity. In the proposed method, the link stability of a node can be pre-determined based on the movement deviation among the clusters. EEPC assumes that WSN sensor nodes exhibit a self-organized behavior. It examines the movement of sensor nodes in a similar way as of swarm bases. The determined optimal solution particles cover the problem space to find best optimal solution. Initialization of these particles can be done in an unspecified or random manner. The fitness function quantifies fitness value of each particle, which is then used for the optimization in each generation. Every particle has its individual best p_{best} and the overall best value of all agents g_{best}. The swarm (particle) has both velocity and placement position which listens to the flying of particles. For every single reiteration, new generation will be created associated with its new velocity and position value. The velocity and related position of agent update equations are specified below as equation 5.1 and 5.2 respectively.

$$V_{id} = V_{id} + \eta_1 r_1 (P_{id} - X_{id}) + \eta_2 r_2 (P_{id}^{n} - X_{id}) \quad (5.1)$$

$$X_{id} = X_{id} + V_{id} \quad (5.2)$$

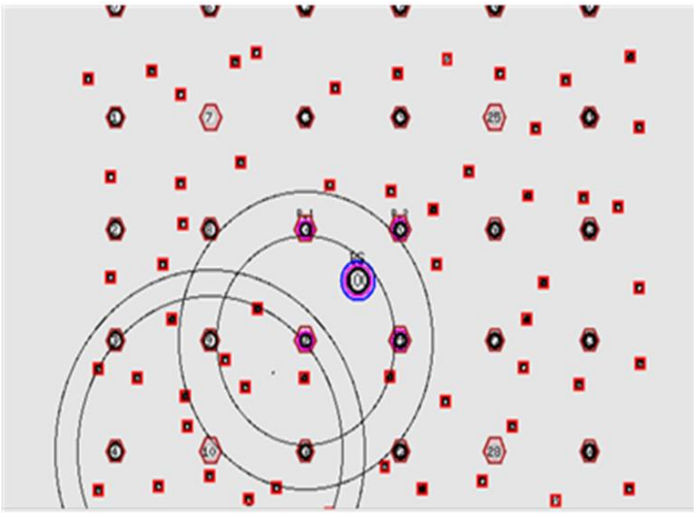

Figure 5. 2 Relay Node Selection

The parameters used in Equations 5.1 and 5.2 are described in Table 5.1.

Algorithm: Enhance Energy Proficient Clustering

Input: *N number of nodes* ; **Output**: *Optimized path*

fitness value of the global best particle

\\ \\P_{id}^{n} = *Position of particle with different fitness value in the nodes*

initailazing all particles in the node

For each particle 'i'

do

Initialize the position (X_{id}) *randomly*

Initialize the velocity (V_{id}) *randomly*

$X_{id} = V_{id}$

Evaluate the particle's fitness value $F(i)$;

If $(f_{best} < F(i))$

$\{ f_{best} = F(i);$

$P_{id}^{n} = X_{id}; \}$

End of for loop;

Iteration _count $= 0$;

While (*iteration_count* < *max_iteration*)

\\\\ *max_iteration* = *maximum number of iteration*

for each particle 'i'

do *Calculate the velocity* V_{id}

$$V_{id} = V_{id} + \eta_1 r_1 (P_{id} - X_{id}) + \eta_2 r_2 (P_{id}^{n} - X_{id})$$

Where, $i = 1, 2 \ldots \ldots N$. *and* $d = 1, 2 \ldots D$

Update the position X_{id}

$X_{id} = X_{id} + V_{id}$

If the static node is overhead or dead then

the mobile node acts as relay node to forward the packets

Evaluate the particle fitness value $F(i)$

Update position P_{id}

if $(f_{best} = F(i))$

$\{ f_{best} = F(i)$

$P_{id}^{n} = X_{id} \}$

end of if

Iteration _count ++

end of while ; *return* P_{id}^{n}

It can be utilized to estimate the distance between CH and the mobile nodes using equation 5.3.

$$RSSI = P + G - PL(d) \quad (5.3)$$

where, P - transmit power, G - antenna gain, d - distance between current node and the source node.

5.2.2 Sensor Data Fusion

Sensor data fusion is a method of collecting and merging the data derived from various sensor nodes, which is more efficient and potentially more accurate than if it is achieved by means of a single source. The sensed information is in the form of videos and images which consumes more memory space and takes longer time to reach the BS. In order to tackle the issue of low battery power of nodes, the sensed data is integrated and transferred to the BS through relay nodes. In WSN every node has a potential to transmit and receive sensing data. The data fusion utilizes the decentralized data fusion mechanism. Self-monitored information and the adjacent node's conveyed information have to be collected by every individual node for sensor data fusion. This method is deployed in a distributed manner. There is no need of centralized node for fusion or universal decision to be applied. The sensor data fusion is performed only in relay nodes which transmits the sensing information to the BS. Proposed work implements track-by-track fusion method in order to track the sensing nodes. Centralized sensor data fusion algorithms focus its importance based on states and probabilities. But proposed decentralized algorithm concerns only with sensing data communication. So, the additional burden and complexity of data fusion is reduced. In order to achieve dynamic node tracking, the relevant events should not be missed in the temporal coverage. Sampling rate, duty cycle, and communication delay of nodes decide the various levels of event missing rate. Cooperative, redundant and complementary are the various types of sensor fusion techniques.

Complementary sensor data fusion deals with the sensors that are not directly dependent on each other, but can be combined to provide an accurate image of the sensed information.

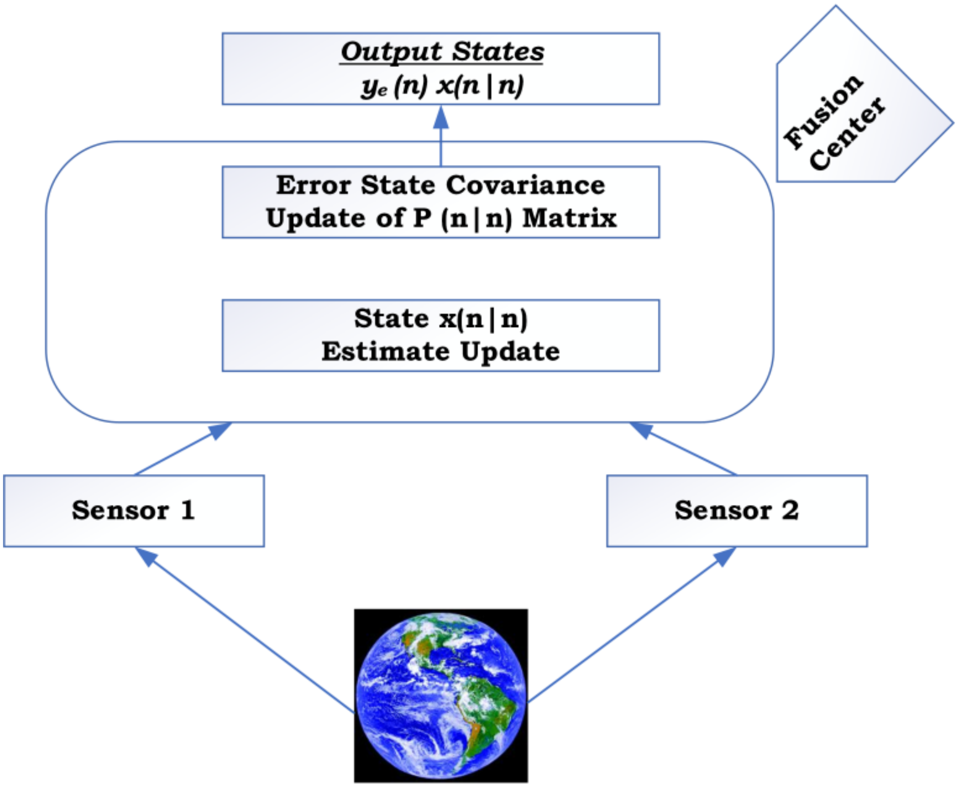

Figure 5. 3 Complementary Data Fusion

From the Figure 5.3, it could be observed that both S1 and S2 are independent sensors. The event detection achieved by both the sensors is data (a) and data (b) respectively. These two sets of data could be integrated to get perfect matched complete set of data $(a + b)$. The resultant data is the combination of two sensors S1 and S2. Thus, the incompleteness of data can be resolved. Two distinct sensor nodes can observe the same mobile node. Complementary data fusion appends the vision of two independent sensors. If two or more independent sources deliver the same data, then this data is fused to increase the associated confidence.

The proposed work uses Kalman filter (Gui et al., 2015; Wang et al., 2016) for the implementation of complementary data fusion.

The fused data is applied in the subsequent information which is subjected to inaccuracies and imperfection of entire contributing sources. The angle of vision and the distance of mobile node may change for two sensor nodes. However, both sensors are involved to capture the same mobile node. Each node selects the nearest cluster head for forwarding packets to Base station. The optimal path is selected to transmit the message from relay node to CH and CH to BS as well. The amount of message transmissions is reduced through optimal path selection using proposed EEPC and sensor data fusion.

5.2.3 Link Fault

Figure 5.4 demonstrates the cluster reformation in link fault condition. The mobile node-tracking scenario suffers from high level of frequent link failures. The link fault is observed when the mobile nodes move out of radio range and the mobile nodes cannot be located. Topological issues and tag orientation can cause this failure. The 75% of connection reliability is acceptable. The mobile sensor nodes continuously transmit the data to the CH and CH continuously transmits data to relay static nodes. The alternate routing path is identified in the case of link failure. New CH is selected when the existing CH node fails or link connection failure occurs. In link fault analysis nodes velocity and location are taken into consideration. Let (X_x, Y_y) represents the actual location of node j, it is obtained by localization technique. Node j, computes the deviation PL(d) as mentioned in equation 5.4.

$$\text{PL(d)} = \sqrt{(X_x^j - X_q^j)^2 + (Y_y^j - Y_q^j)^2} \tag{5.4}$$

The deviation of a sensor node can be calculated using equation 5.4 at time interval T_i and Table 5.2 describes variable description of the same. The link failure is predicted based on node's location and the velocity with which it moves out of radio range. If the calculated deviation of a mobile node becomes more than threshold limit, then it means that the link is going to fail. In this case the mobile node goes out of range and there is no coverage of other sensor node that means the node cannot be located and the link is identified as fault. Generally wireless radio communication range will be 250 m. If the calculated deviation range reaches near 200m, then the node automatically starts to find its cluster head to reform its link as shown in the Figure 5.4. The proposed approach reduces the energy consumption in every phase such as CH selection, optimal path selection, relay node selection and data fusion. Thus, the network life time is prolonged and it increases the number of alive nodes. Therefore, this process of dealing with link fault/failures reduces the target missing rate in an effective manner.

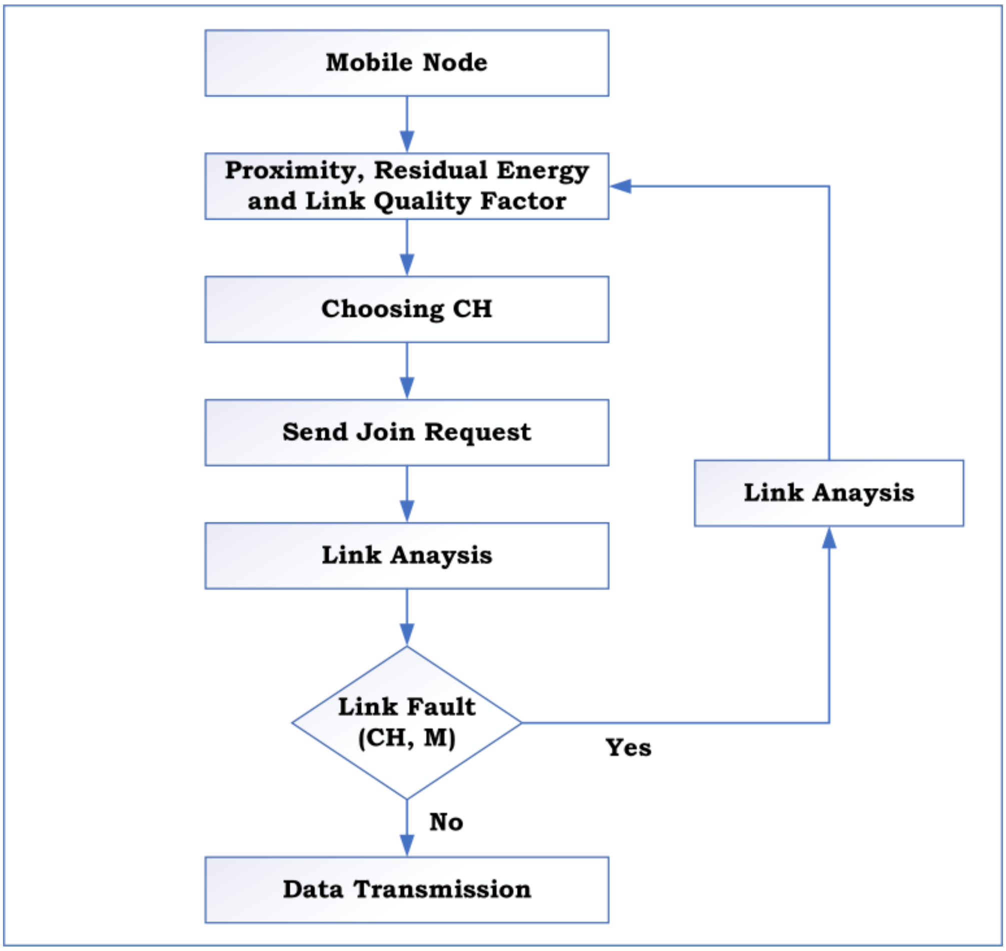

Figure 5. 4 Cluster Reformation in Link Fault Condition

Table 5. 2 Variable description

VARIABLES	DEFINITION
X_x^j, Y_y^j	The coordinate of SN j at time T_i
V_x^j, V_y^j	The velocity of SN j towards the x and y axis at time T_i
T_i	Time of final beacon broadcast
T_q	The present time
X_q^j, Y_q^j	The projected position of SN j at present time

5.3 Simulation and Performance Evaluation

The performance of proposed EEPC protocol has been evaluated through extensive simulations using ns-2 fixed with Mannasim framework (Pereira *et al.*, 2015) The Performance of EEPC is evaluated by considering mobile sensing tracking as an event and is compared with PSO based Enhanced Clustering and Cluster head selection (PECC)(Vimalarani *et al.*, 2015), Energy-aware Cluster head Selection using Particle Swarm Optimization (ECS-PSO)(Singh and Lobiyal, (2012; Su and Zhao, 2017), Optimal Clustering Mechanism based on Fuzzy-C Means(OCM-FCM)(Su and Zhao, 2017) having two dimensional coverage area 1000m x 1000m. The performance of proposed EEPC is evaluated with reference to various performance metrics which are total packets received at BS, end to end delay, packet dropping ratio, packet delivery ratio, routing packet overhead, throughput, average residual energy, alive nodes.

The simulation network setup is constructed with hundred nodes, which comprises of both static and mobile nodes. It is comprised of 36 static nodes and 64 mobile nodes. The static nodes are located in non-moving constructions and dynamic sensors are placed in the mobile entities called as mobile nodes. In order to form the link IEEE 802.11P MAC protocol is used. The mobile nodes collect information about the tracked event and environment. This collected information is further forwarded to static nodes. Table 5.3 shows simulation parameters.

Table 5. 3 Simulation Parameters

Simulation Parameter	
NS2 Version	ns-allinone-2.3.5
Coverage Area	$1000m \times 1000m$
MAC	IEEE 802.11P
Simulation Time	100 Secs
Antenna Type	Omni Antenna
Energy Model	Energy Model(true)
Initial energy	10J
Number of Nodes	100 (36 Static,64 Mobile)
Queue Length	50
Data Rate	256-512
Interface Type	Wireless Physical Interface
Max Sensing Radius	20m
Transmission Range	250m(<200m)

5.3.1 Number of Packets Received at BS

Figure 5.5 shows the number of packets received at BS by the proposed EEPC and existing PECC, ECS-PSO and OCM-FCM. X Axis stands for the simulation rounds and Y axis points to the quantity of received packet. The resultant graph indicates that the proposed algorithm yields higher number of aggregated packets in comparison to other existing techniques. The proposed EEPC achieves 1684 packets at the end of 200 simulation rounds. However, OCM-FCM receives 1554 packets at the end of 200 rounds. Proposed EEPC achieves 7.71% more number of packets than OCM-FCM because of data fusion. The ECS-PSO and PECC receives 1521 and 1252 packets respectively at the end of 200 simulation rounds. The proposed EEPC achieves 9.67% and 25.65% more packets at BS with respect to ECS-PSO and PECC respectively.

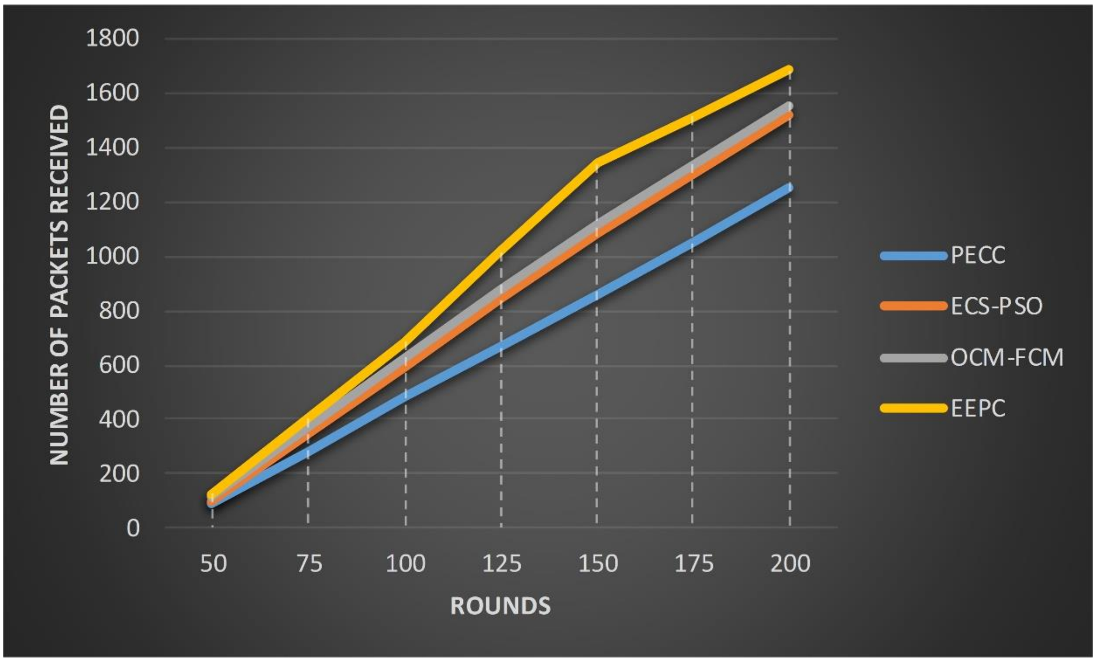

Figure 5. 5 Number of Packets Received

5.3.2 End- to-End delay

End to End delay is the amount of time taken by the packets to reach the destination from a particular source. In the target tracking event, the sensed information reaches the cluster head and thereafter it is aggregated by sensor data fusion processor. This fused data is sent to the relay nodes which further transmit this data to the BS.

The source is mobile sensor nodes and the destination is base station. Figure 5.6 shows the end to end delay between both existing and proposed technique. The performance of EEPC is evaluated through extensive simulations which range up to 200 rounds. The packets in proposed EEPC exhibit very less end to end delay while reaching the destination through data fusion technique. It has also been observed that in proposed EEPC end to end delay remains steady with increasing number of rounds. At the end of 200 rounds, proposed EEPC shows 0.015ms of end to end delay. However, OCM-FCM and ECS-PSO shows 0.02ms of end to end delay. Proposed EEPC shows a 25% reduction in end-to-end delay time as compared to existing OCM-FCM and ECS-PSO.

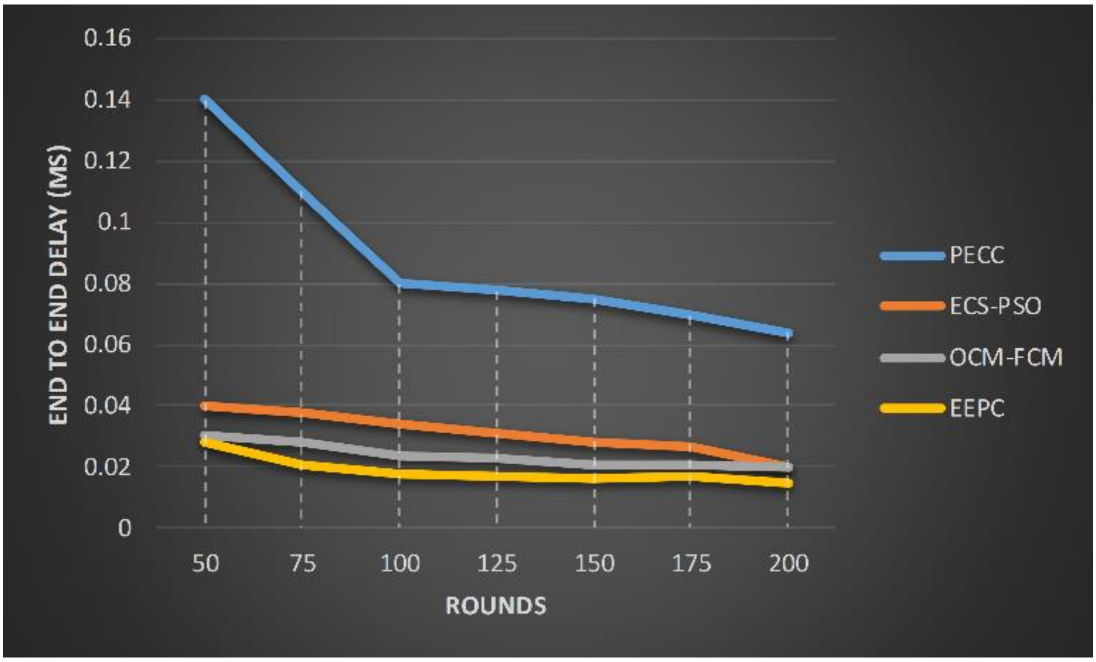

Figure 5. 6 End-to-End delay

5.3.4 Packet Dropping Ratio

Packet dropping ratio is defined as the percentage of packets lost with respect to packets sent. It occurs due to the compromised bad node behavior as it drops all or some of the packets that need to be forwarded. Packet loss and packet dropping is a common problem in WSN which minimizes the packet delivery ratio. It could be caused by signal deterioration in the medium due to multi-path dropping.

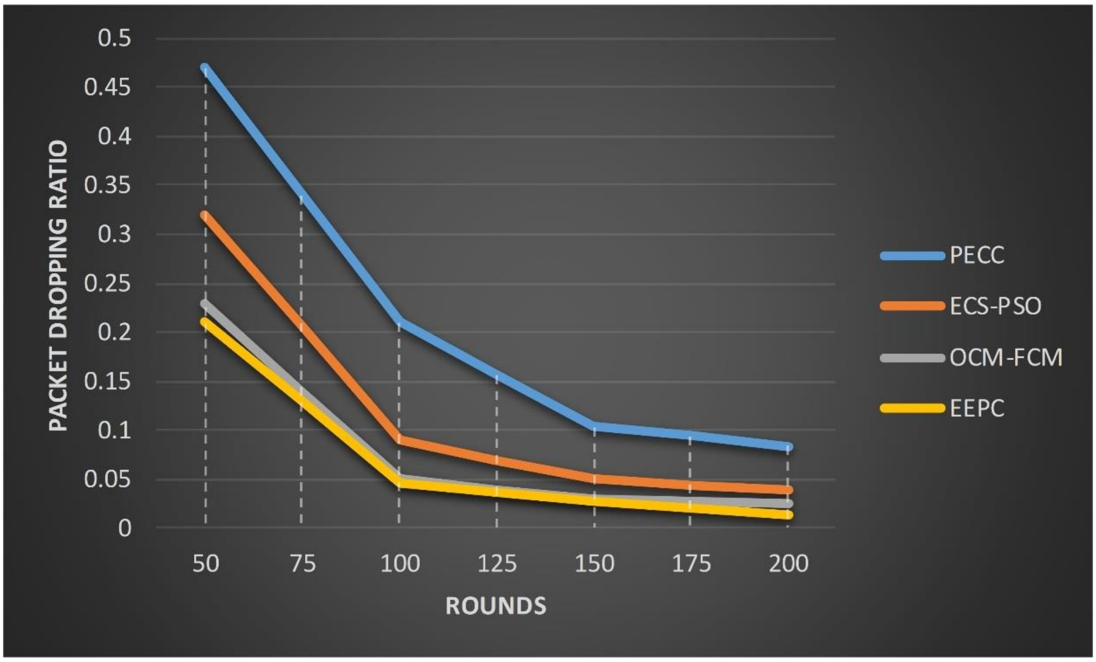

Figure 5. 7 Packet Dropping Ratio

Figure 5.7 shows the packet dropping ratio of proposed and existing techniques. In proposed EEPC the packet dropping ratio is calculated as 0.0142 at the end of 200 rounds. However, other existing algorithms OCM-FCM, ECS-PSO and PECC exhibit 0.025, 0.04, 0.084 packet dropping ratios respectively. Proposed EEPC performs well from the first round to end of 200^{th} simulation round. This is because of balanced load distribution by unequal clustering and involvement of relay nodes.

5.3.5 Packet Delivery Ratio

The ratio of sums of packets effectively received to the entire amount of packets transmitted is called as packet delivery ratio. It is represented in terms of percentage as shown in equation 5.5.

$$PDR = \frac{Number\ of\ Packets\ Received}{Number\ of\ Pckets\ Transmitted} * 100 \tag{5.5}$$

Tracking event deals with temporal data. The packet delivery should be fast enough in the event of target tracking. If packet delivery ratio is too low then it means that we cannot achieve accurate and complete data. The sensor data fusion technique overcomes the incompleteness of data. In order to achieve high performance the tracking mechanism should have high packet delivery ratio as well. Figure 5.8 shows the packet delivery ratio (PDR) of proposed EEPC and existing techniques. The experimental results show that the packet delivery ratio of proposed EEPC is increased in comparison to other existing techniques. Proposed EEPC exhibits 98.86% PDR at the end of 200 simulation rounds. However, OCM-FCM, ECS-PSO, PECC exhibit 97.81%, 96.02%, 89.584% PDR respectively for 200 simulation rounds.

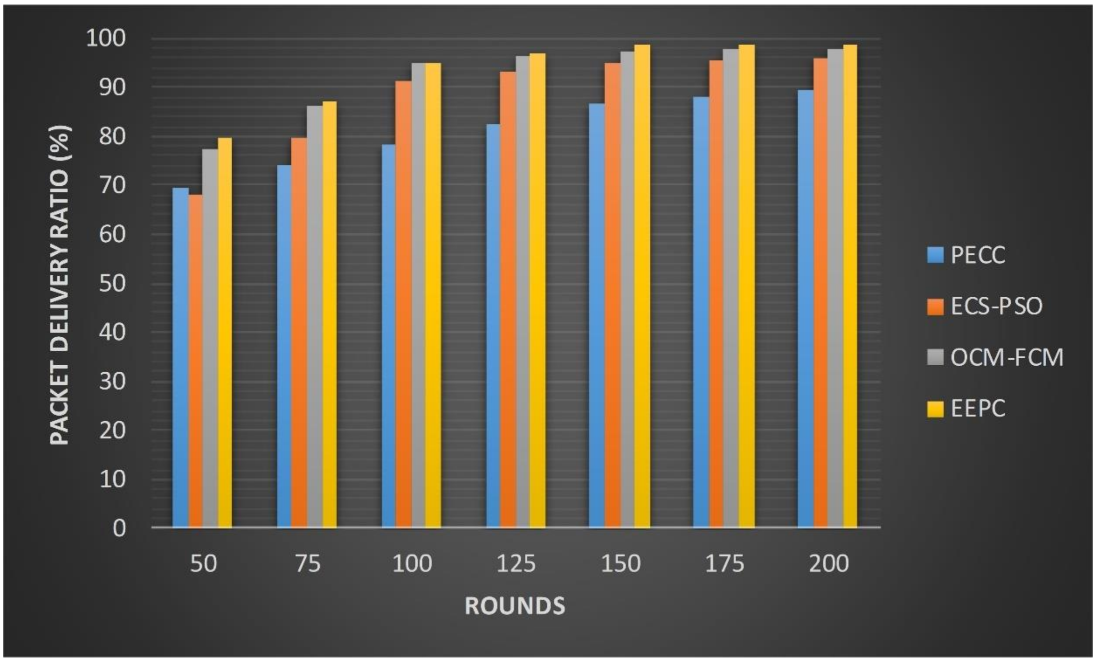

Figure 5. 8 Packet Delivery Ratio

5.3.6 Routing Packet Overhead

It is defined as the measure of ratio between control and data packets. In proposed simulation setup the routing takes place between the CH and static relay nodes. There is no problem with relay nodes which transmit data to the BS.

However, sometimes the group of mobile nodes may increase in a particular radio range due to which the data transmission increases within a particular range. The CH and static nodes overwhelmed with huge amount of data. The network should sustain such situation in the dynamic sensing environment.

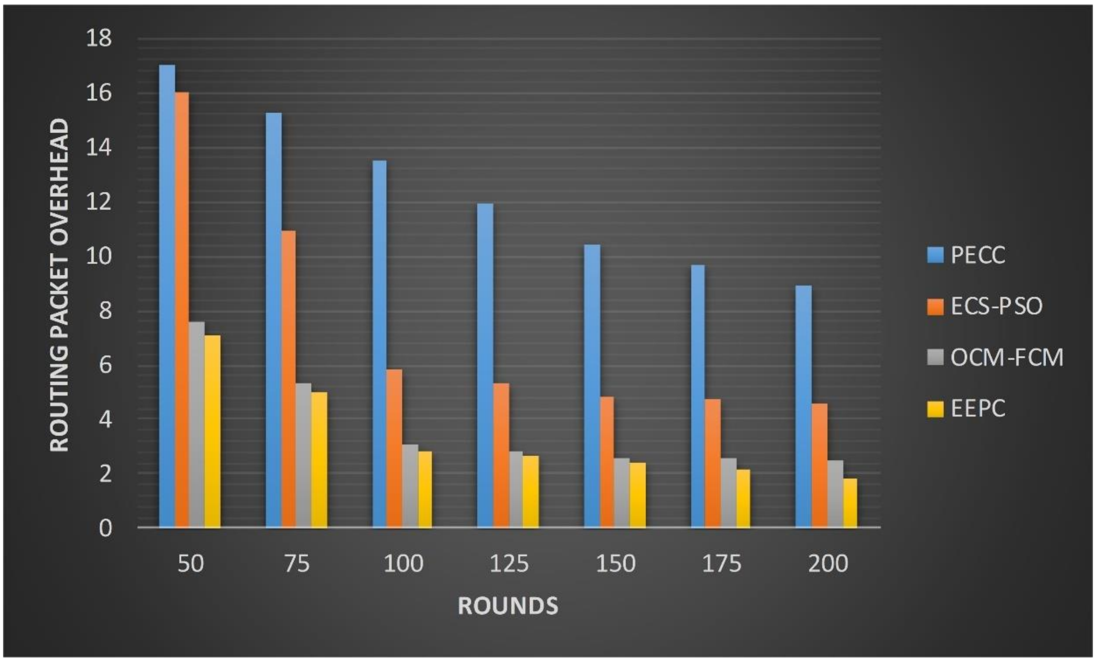

Figure 5. 9 Routing Packet Overhead

The proposed system performs well from the beginning to the end. Figure 5.9 shows the path determination overhead of proposed and existing techniques. The proposed EEPC suffered with only 1.84 routing packet overhead in the 200 round of simulations. PECC and ECS-PSO suffered by 8.94 and 4.56 routing packet overhead respectively by the end of 200 simulation round. OCM-FCM performed equally well as EEPC. However, it suffered with 2.48 routing packet overhead when it reached last round of simulation. The routing packet overhead in proposed EEPC is decreased by 25.8% in comparison to existing OCM-FCM. The inclusion of data fusion in proposed EEPC reduces the routing packet overhead.

5.3.7 Throughput

Throughput is measured as the volume of data packets effectively directed towards the endpoint terminus within the total simulation period. The precise formulation for throughput is conveyed by equation 5.6.

$$\text{Throughput} = \frac{Number\ of\ data\ packets\ sent\ (bits)}{Time\ period\ (seconds)} \tag{5.6}$$

The mobile sensors might move out of the radio range and bond with other range. The partial data needs to be sent by a CH and another partial data needs to be sent by another CH.

Therefore, the throughput metric plays a significant role. Figure 5.10 represents the throughput of proposed and existing techniques. The graph indicates number of rounds on X axis and throughput on Y axis in bits per seconds. The existing PECC technique provides the minimum throughput of 32500 bits per second as compared to the other techniques by the end of 200 simulation round. ECS-PSO, OCM-FCM and proposed EEPC exhibits 39438, 40200, 45850 bits per seconds respectively in the last simulation round. The proposed EEPC offers 12% higher throughput value as compared to OCM-FCM. Dynamic selection of CH and relay nodes reduces the energy depletion constraint and increases the overall throughput of proposed EEPC.

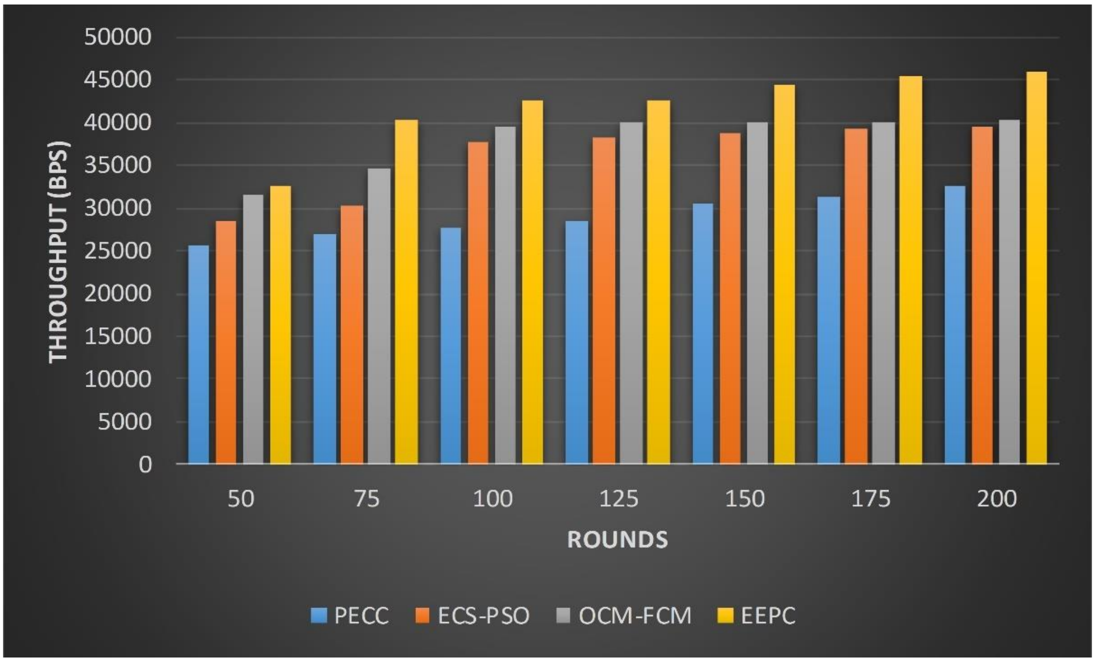

Figure 5. 10 Throughput

5.3.8 Average Residual Energy

Energy level varies in every mobile and static sensor node at different locations within the tracking field. The sensors lifetime is subject to energy level in the deployed environment. If the static nodes are overwhelmed with the heavy network load then it means that energy level will be decreased and there may be a need of using mobile nodes as relay nodes. During simulation, the initial energy has been predefined to 10 Joules. Figure 5.11 shows the average remaining energy of proposed EEPC and existing algorithms. It is observed that at the end of 500 rounds PECC lost its residual energy. However, ECS-PSO, OCM-FCM, EEPC survived with 2.89 Joules, 3.14 Joules and 4.28 Joules respectively. All the nodes in ECS-PSO and OCM-FCM are dead at the end of 600 and 650 simulation rounds respectively. However, proposed EEPC survived with 2.33 Joules at the end of 650 rounds. Proposed EEPC lengthens the lifetime of nodes up to 650 simulation rounds.

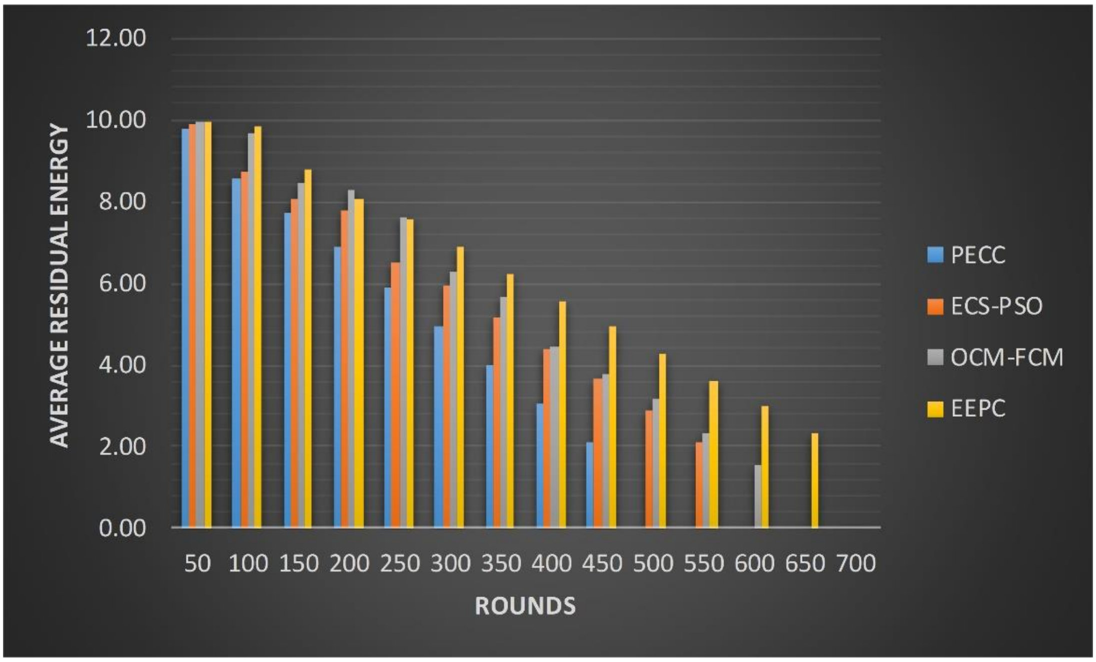

Figure 5. 11 Average Residual Energy

5.3.9 Alive nodes

Retransmission of data vitiates the performance of WSN in dynamic tracking. Transmission issues deplete the energy of nodes and increases the dead nodes. The alive nodes should be maximized in an efficient event tracking algorithm. Figure 5.12 shows the alive nodes count between existing and proposed technique. All algorithms maintained the same number of alive nodes up to 300 rounds. After that the existing PECC technique affords a very less number of alive nodes as compared to all other techniques. It loses all nodes by the end of 500 rounds. The number of alive nodes becomes zero for ECS-PSO in the 600 rounds and OCM-FCM in 650 rounds. The proposed EEPC technique survives with 13% alive nodes in 650 simulation rounds. Proposed EEPC has achieved 13% more number of alive nodes as compared to OCM-FCM. The amount of alive node decreases owing to energy weakening along the simulation rounds. The number of alive nodes is directly proportional to the residual energy level. Proposed EEPC algorithm conserves the energy in every stage of processing.

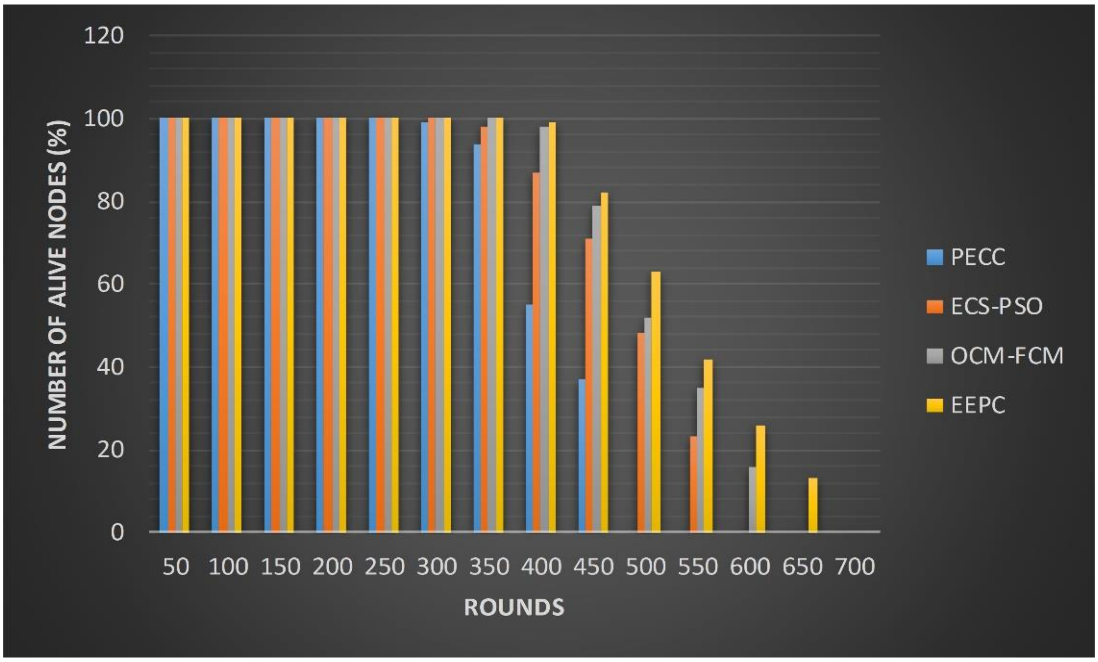

Figure 5. 12 Number of Alive Nodes

5.4 Summary

In this work, an Enhanced Energy Proficient Clustering (EEPC) protocol has been proposed to optimize the network path during data transmission. The core intention of this work is to enhance the sensor network lifetime and improve the tracking and monitoring activity in WSN environment. This work, proposes an energy efficient clustering algorithm for WSNs in order to decrease the consumed energy for sensing and hence prolong the network lifetime. The novelty of proposed work lies in the concept of finding relay nodes to transmit the sensing information to the base station and develop sensor data fusion technique to avoid energy exhaustion of CH and determine intermediate relay static nodes. It is observed, through simulation results that the proposed EEPC algorithm consumes less energy in comparison to other existing routing algorithms. The proposed EEPC algorithm improves the lifetime of sensor nodes by proposing an enhanced swarm optimization technique. It also overcomes the common drawback where the CH itself transmits track by track event driven data to the base station. Extensive simulations conclude that EEPC improves both energy efficiency and accuracy of mobile node tracking. The overall lifetime of sensor nodes is maximized through sensor data fusion technique. The proposed EEPC is evaluated for various performance parameters, which are total packets received at BS, packet dropping ratio, packet delivery ratio, end to end delay, average remaining energy, total energy consumption, alive nodes, total residual energy. The results prove that the proposed EEPC performs better than existing techniques PECC, ECS-PSO and OCM-FCM.

Chapter 6

Conclusion and Future Scope

This chapter concludes the thesis and highlights the future research directions.

6.1 Conclusion

In recent past, the WSNs are becoming more popular due to its increased application in remote sensing, health care, earthquake or volcano prediction, environmental monitoring, structural health monitoring, intrusion detection, target tracking, military and surveillance. Energy consumption is a significant problem for these systems due to restricted battery capabilities of SNs.

The second chapter presents a comprehensive review of various routing protocols. These protocols are classified based on network structure and properties. The Structure based routing protocols are classified as data-centric, hierarchical and location based. Further, the hierarchical protocols have been categorized as classical and swarm intelligence based. Additionally, the detailed analysis of routing protocols with their objective, methods, key metrics have been presented. This chapter summarizes routing protocols on the basis of energy efficiency, data aggregation, QoS, Scalability, load balancing, fault tolerance and location awareness.

The hardware restrictions necessitate the requirement of energy efficient design and development of hierarchical routing protocols. This thesis is an effort towards this direction. In this thesis three protocols have been proposed which are: "An energy efficient load balanced cluster based routing using ACO (LB-CR-ACO)", "An Unequal clustering using meta-heuristic Ant Colony Optimization (MHACO-UC)" and "An Enhanced Energy Proficient Clustering (EEPC) Algorithm for relay selection in heterogeneous WSNs".

In third chapter "An energy efficient load balanced cluster based routing using Ant Colony Optimization (LB-CR-ACO" is proposed. It performs optimal clustering based on cluster head selection weighing function. The cluster formation utilizes various parameters like remaining energy of the nodes, received signal strength indicator and node density. The priority weights are assigned among these parameters. The presented protocol also performs a dynamic selection of optimal cluster head periodically which conserves energy, thereby utilizing network resources in an efficient and balanced manner. Further, the optimal route construction is done using ACO in steady state phase for multi hop data transfer. It has been observed through simulations that the proposed protocol exhibits better performance for number of alive nodes, energy consumption per round than its peer protocols which shows higher network lifetime.

The fourth chapter presents "Meta-heuristic ant colony optimization based unequal clustering (MHACO-UC) for wireless sensor networks". The protocol's main focus is to deal with the issues related to unbalanced energy consumption and network performance dynamics. Apart from the optimal cluster head selection, this protocol emphasizes on unequal clustering to maintain a fair balance between intra and inter cluster communication load. The initialization of nodes nearer to Base Station (BS) as relay nodes increases the performance. Meta-Heuristic Ant Colony Optimization approach selects the optimal path among the nodes which increases the number of packets delivered to destination. The unequal clustering, novel CH selection, prediction of optimal path using meta- heuristic ant colony optimization reduces the energy consumption effectively. The simulation and comparative analysis of proposed MHACO-UC with the existing unequal clustering approaches on the basis of various performance parameters show the effectiveness of proposed work in WSN applications.

"An Enhanced Energy Proficient Clustering (EEPC) algorithm for relay selection in heterogeneous WSNs" is presented in chapter five.

EEPC reduces the energy consumption in the field of sensor tracking events. The main focus of the presented work is to handle mobility of SNs and to deal with link failures. In this work, network is constructed with both static and mobile nodes, which are placed in grid structures, and deployed randomly. The nodes select their cluster head (CH) on the basis of their associated placement and energy level. The mobile nodes transmit the data to the CH. Generally, CH transmits the sensing information to the base station. However, the proposed approach introduces the concept of finding relay nodes, which are static nodes. The EEPC algorithm selects the relay nodes based on its velocity and location by calculating particle fitness value. The selected intermediate relay static nodes transmit the collected sensing information to the Base Station (BS) using sensor data fusion technique. The link fault could be predicted based on the deviation value. The simulation results show that the proposed approach minimizes the energy depletion and enhances the network lifetime.

6.2 Future Research Scope

We have explored and researched evolutionary routing algorithms for WSNs. However, it would be interesting to observe the performance of these protocols (LB-CR-ACO, MHACO-UC, and EEPC) by implementing machine learning approaches.

The data packets sent must satisfy the security requirements for various WSNs applications where security is the prime concern like battlefield monitoring in military surveillance, target tracking etc. Since, if any data packets in the network get compromised, it can affect the whole network. Thus, a better security technique for the routing protocols is also required. These security algorithms may also affect the performance of the protocols, which can also be evaluated in the future.

The presented results are based on simulations. However, it would be interesting to observe the behavior of these three protocols (LB-CR-ACO, MHACO-UC, and EEPC) on a real test beds.

List of Publications

1. Kalpna Guleria, Anil Kumar Verma, (2018) “Comprehensive review for energy efficient hierarchical routing protocols on wireless sensor networks”, Wireless Networks, pp. 1-25, https://doi.org/10.1007/s11276-018-1696-1.
   (Published: SCI Indexed, Impact factor 1.981)

2. Kalpna Guleria, Anil Kumar Verma, (2019) “Meta-heuristic ant colony optimization based unequal clustering (MHACO-UC) for wireless sensor networks”, Wireless Personal Communications, DOI: 10.1007/s11277-019-06127-1.
   (Published: SCI Indexed, IF 1. 20)

3. Kalpna Guleria, Anil Kumar Verma, (2018) "An Energy Efficient Load Balanced Cluster based Routing using Ant Colony Optimization for WSN", International Journal of Pervasive Computing and Communications, https://doi.org/10.1108/IJPCC-D-18-00013.
   (Published: ESCI, Scopus Indexed Impact Factor: 0.68)

4. Kalpna Guleria, Anil Kumar Verma, “An Enhanced Energy Proficient Clustering (EEPC) algorithm for relay selection in heterogeneous WSNs” communicated in Wireless Networks.
   (Under Review: SCI Indexed, Impact Factor 1.981)

International Conferences

1. Kalpna Guleria, Anil Kumar Verma (2018), “Unequal Clustering - An Enhancement to network longevity in WSNs”, In Proceedings of 4th IEEE INTERNATIONAL CONFERENCE on Computing Communication and Automation, Galgotia University, Greater Noida, NCR - New Delhi India.
   (Accepted for Publication)

2. Kalpna Guleria, Anil Kumar Verma (2018), “Ant Colony Optimization Techniques - An Enhancement to Energy Efficiency in WSNs”, In *Proceedings of* International Conference on Computer Networks, Big Data and IoT (ICCBI 2018), VAIGAI college of Engineering, Madurai, In Springer Lecture Notes on Data Engineering and Communications Technologies.

   (Accepted for publication)

References

1. Abdellatif, M. M., Oliveira, J. M., & Ricardo, M. (2014, June). Neighbors and relative location identification using RSSI in a dense wireless sensor network. In Ad Hoc Networking Workshop (MED-HOC-NET), 2014 13th Annual Mediterranean (pp. 140-145). IEEE.
2. Afrin, M., Mahmud, M. R., & Razzaque, M. A. (2015, December). Real time detection of speed breakers and warning system for on-road drivers. In 2015 IEEE International WIE Conference on Electrical and Computer Engineering (WIECON-ECE) (pp. 495-498). IEEE.
3. Akyildiz, I. F., Lee, W. Y., & Chowdhury, K. R. (2009). CRAHNs: Cognitive radio ad hoc networks. AD hoc networks, 7(5), 810-836.
4. Akyildiz, I. F., Su, W., Sankarasubramaniam, Y., & Cayirci, E. (2002). Wireless sensor networks: a survey. Computer networks, 38(4), 393-422.
5. Ali, M. S., Dey, T., & Biswas, R. (2008, December). ALEACH: Advanced LEACH routing protocol for wireless microsensor networks. In 2008 International Conference on Electrical and Computer Engineering (pp. 909-914). IEEE
6. Ali, T., Jung, L. T., & Faye, I. (2014). End-to-end delay and energy efficient routing protocol for underwater wireless sensor networks. Wireless Personal Communications, 79(1), 339-361.
7. Anchora, L., Capone, A., Mighali, V., Patrono, L., Simone, F. (2014). A novel MAC scheduler to minimize the energy consumption in a Wireless Sensor Network. Ad Hoc Networks, 16, 88-104.
8. Ari, A.A.A., Yenke, B.O., Labraoui, N., Damakoa, I., Gueroui, A.(2016). A power efficient cluster-based routing algorithm for wireless sensor networks: Honeybees swarm intelligence based approach. Journal of Network and Computer Applications, 69, 77-97.
9. Arioua, M., El Assari, Y., Ez-Zazi, I., & El Oualkadi, A. (2016). Multi-hop cluster based routing approach for wireless sensor networks. Procedia Computer Science, 83, 584-591.
10. Arora, V.K., Sharma, V., Sachdeva, M. (2016). A survey on LEACH and other's routing protocols in wireless sensor network. Optik-International Journal for Light and Electron Optics, 127(16), 6590-6600.
11. Arumugam, G. S., and Ponnuchamy, T., 2015. EE-LEACH: development of energy-efficient LEACH Protocol for data gathering in WSN. EURASIP Journal on Wireless Communications and Networking, 2015(1), 1-9.
12. Badescu, A. M., & Cotofana, L. (2015). A wireless sensor network to monitor and protect tigers in the wild. Ecological indicators, 57, 447-451.

13. Bagci, H., & Yazici, A. (2010, July). An energy aware fuzzy unequal clustering algorithm for wireless sensor networks. In Fuzzy systems (FUZZ), 2010 IEEE international conference on (pp. 1-8). IEEE.
14. Bagci, H., & Yazici, A. (2013). An energy aware fuzzy approach to unequal clustering in wireless sensor networks. Applied Soft Computing, 13(4), 1741-1749.
15. Bai, S., Zhang, W., Xue, G., Tang, J., Wang, C. (2012). DEAR: Delay-bounded energy-constrained adaptive routing in wireless sensor networks. In INFOCOM, Proceedings IEEE (1593-1601). IEEE.
16. Bara'a, A. A., & Khalil, E. A. (2012). A new evolutionary based routing protocol for clustered heterogeneous wireless sensor networks. Applied Soft Computing, 12(7), 1950-1957.
17. Baradaran, A. A., & Navi, K. (2017). CAST-WSN: The presentation of new clustering algorithm based on Steiner tree and C-means algorithm improvement in wireless sensor networks. Wireless Personal Communications, 97(1), 1323-1344.
18. Baranidharan, B., & Santhi, B. (2016). DUCF: Distributed load balancing Unequal Clustering in wireless sensor networks using Fuzzy approach. Applied Soft Computing, 40, 495-506.
19. Barcelo, M., Correa, A., Vicario, J.L., Morell, A. (2016). Cooperative interaction among multiple RPL instances in wireless sensor networks. Computer Communications, 81, 61-71.
20. Brar, G.S., Rani, S., Chopra, V., Malhotra, R., Song, H., Ahmed, S.H. (2016). Energy Efficient Direction-Based PDORP Routing Protocol for WSN. IEEE Access, 4, 3182-3194.
21. Callaway, E., Gorday, P., Hester, L., Gutierrez, J. A., Naeve, M., Heile, B., & Bahl, V. (2002). Home networking with IEEE 802.15. 4: a developing standard for low-rate wireless personal area networks. IEEE Communications magazine, 40(8), 70-77.
22. Camilo, T., Carreto, C., Silva, J. S., & Boavida, F. (2006, September). An energy-efficient ant-based routing algorithm for wireless sensor networks. In International Workshop on Ant Colony Optimization and Swarm Intelligence (pp. 49-59). Springer, Berlin, Heidelberg.
23. Chamam, A., & Pierre, S. (2010). A distributed energy-efficient clustering protocol for wireless sensor networks. Computers & electrical engineering, 36(2), 303-312.
24. Chen, B., Liang, W., & Yu, J. X. (2012). Energy-efficient skyline query optimization in wireless sensor networks. Wireless Networks, 18(8), 985-1004.

25. Chen, C.W., Weng, C.C. (2012). A power efficiency routing and maintenance protocol in wireless multi-hop networks. Journal of Systems and Software, 85(1), 62-76.
26. Chen, G., Li, C., Ye, M., & Wu, J. (2009). An unequal cluster-based routing protocol in wireless sensor networks. Wireless Networks, 15(2), 193-207.
27. Chiang, S. S., Huang, C. H., & Chang, K. C. (2007). A minimum hop routing protocol for home security systems using wireless sensor networks. IEEE Transactions on Consumer Electronics, 53(4), 1483-1489.
28. Crow, B. P., Widjaja, I., Kim, J. G., & Sakai, P. T. (1997). IEEE 802.11 wireless local area networks. IEEE Communications magazine, 35(9), 116-126.
29. Darabkh, K. A., Albtoush, W. Y., & Jafar, I. F. (2017). Improved clustering algorithms for target tracking in wireless sensor networks. The Journal of Supercomputing, 73(5), 1952-1977.
30. Di Caro, G.A., and Dorigo, M.,1998. AntNet: distributed stigmergetic control for communication networks. Journal of Artificial Intelligence Research (JAIR), 9, 317–365.
31. Dravida, S., Walton, J. R., Nanda, S., & Surineni, S. K. (2012). U.S. Patent No. 8,311,543. Washington, DC: U.S. Patent and Trademark Office.
32. Elgala, H., Mesleh, R., & Haas, H. (2011). Indoor optical wireless communication: potential and state-of-the-art. IEEE Communications Magazine, 49(9).
33. Ever, E., Luchmun, R., Mostarda, L., Navarra, A., & Shah, P. (2012). UHEED-an unequal clustering algorithm for wireless sensor networks.
34. Fei, Z., Li, B., Yang, S., Xing, C., Chen, H., Hanzo, L. (2016). A survey of multi-objective optimization in wireless sensor networks: Metrics, algorithms and open problems. IEEE Communications Surveys & Tutorials.
35. Feng, D., Zhu, Y., 2009. An improved AODV routing protocol based on remaining power and fame. In: Proceedings of 2009 International Conference on Electronic Computer Technology, February 2009, pp. 117–121.
36. Gajjar, S., Sarkar, M., & Dasgupta, K. (2014). Cluster head selection protocol using fuzzy logic for wireless sensor networks. International Journal of Computer Applications, 97(7).
37. Gajjar, S., Sarkar, M., Dasgupta, K.(2016). FAMACROW: Fuzzy and ant colony optimization based combined mac, routing, and unequal clustering cross-layer protocol for wireless sensor networks. Applied Soft Computing, 43, 235-247.
38. Garg R. & Kaur G. (2014). Modified Neighbour Coverage Based Probabilistic Rebroadcast in MANET. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, 3(5), 9389-9394.

39. Garg, M. K., Vir, D., & Agarwal, S. K. (2013). Simulation analysis of AODV, DSR and ZRP routing protocols in manet using qualnet 5.0 simulator. International Journal of Scientific and Research Publications, 3(3), 1-6.

40. Garg, S., Peddoju, S. K., & Sarje, A. K. (2016). Scalable P2P bot detection system based on network data stream. Peer-to-Peer Networking and Applications, 9(6), 1209-1225

41. Geem, Z. W., Kim, J. H., & Loganathan, G. V. (2001). A new heuristic optimization algorithm: harmony search. simulation, 76(2), 60-68.

42. Govindan, K., & Mohapatra, P. (2012). Trust computations and trust dynamics in mobile adhoc networks: A survey. IEEE Communications Surveys & Tutorials, 14(2), 279-298.

43. Gui, P., Tang, L., & Mukhopadhyay, S. (2015, June). MEMS based IMU for tilting measurement: Comparison of complementary and kalman filter based data fusion. In Industrial Electronics and Applications (ICIEA), 2015 IEEE 10th Conference on (pp. 2004-2009). IEEE.

44. Guleria, K., & Verma, A. K. (2018 a). Comprehensive review for energy efficient hierarchical routing protocols on wireless sensor networks. Wireless Networks, 1-25.

45. Guleria, K., & Verma, A. K. (2018 b). An energy efficient load balanced cluster-based routing using ant colony optimization for WSN. International Journal of Pervasive Computing and Communications, 14(3/4), 233-246.

46. Guleria, K., & Verma, A. K. (2019). Metaheuristic Ant Colony Optimization based Unequal Clustering for wireless sensor network. Wireless Personnal Communications, DOI: 10.1007/s11277-019-06127-1.

47. Guo, L., Zhang, C., Sun, J., & Fang, Y. (2014). A privacy-preserving attribute-based authentication system for mobile health networks. IEEE Transactions on Mobile Computing, 13(9), 1927-1941.

48. Guo, W., Zhang, W., and Lu, G., 2010. PEGASIS protocol in wireless sensor network based on improved ant colony algorithm. In 2010 Second international workshop on education technology and computer science (pp. 64–67). Wuhan: IEEE Computer Society.

49. Gupta, S. K., & Jana, P. K. (2015). Energy efficient clustering and routing algorithms for wireless sensor networks: GA based approach. Wireless Personal Communications, 83(3), 2403-2423.

50. Gupta, S. K., Kuila, P., & Jana, P. K. (2013, February). GAR: an energy efficient GA-based routing for wireless sensor networks. In International conference on distributed computing and internet technology (pp. 267-277). Springer, Berlin, Heidelberg

51. H. Luo, F. Ye, J. Cheng, S. Lu, L. Zhang, TTDD: Two-Tier Data Dissemination in Large-Scale Wireless Sensor Networks, Wireless Networks, 11(1-2) (2005) 161-175.
52. Hayajneh, T., Doomun, R., Al-Mashaqbeh, G., & Mohd, B. J. (2014). An energy-efficient and security aware route selection protocol for wireless sensor networks. Security and Communication Networks, 7(11), 2015-2038
53. Hayashi, I., Kobayashi, T., Arai, Y., Maeda, T., & Inoue, A. (2009). Optimal Location of Wireless LAN Access Points Using Fuzzy ID3. JACIII, 13, 128-134.
54. Hayes, T., Ali, F.H. (2015). Proactive Highly Ambulatory Sensor Routing (PHASeR) protocol for mobile wireless sensor networks. Pervasive and Mobile Computing, 21, 47-61
55. Heinzelman, W. B., et al. (2002). An application specific protocol architecture for wireless microsensor networks. IEEE Transactions on Wireless Communications, 1(4), 660–670.
56. Heinzelman, W. R., Chandrakasan, A., & Balakrishnan, H. (2000, January). Energy-efficient communication protocol for wireless microsensor networks. In Proceedings of the 33rd annual Hawaii international conference on system sciences (pp. 10-pp). IEEE.
57. Helmy, A.O., Ahmed, S., Hassenian, A.E. (2015). Artificial fish swarm algorithm for energy-efficient routing technique. In Intelligent Systems' 2014, Springer International Publishing, 509-519.
58. Hsiung, P. A., Lu, P. H., & Liu, C. W. (2007, September). Energy efficient co-scheduling in dynamically reconfigurable systems. In 2007 5th IEEE/ACM/IFIP International Conference on Hardware/Software Codesign and System Synthesis (CODES+ ISSS) (pp. 87-92). IEEE.
59. Huang, C. F., & Tseng, Y. C. (2005). The coverage problem in a wireless sensor network. Mobile networks and Applications, 10(4), 519-528.
60. Huang, F., JIN, X. Y., ZHANG, Y., & TANG, J. (2009). Energy consumption balanced WSN routing protocol based on GASA. Chinese Journal of Sensors and Actuators, 22(4), 586-592.
61. Jan, M.A., Nanda, P., He, X., Liu, R.P.(2015). A Sybil Attack Detection Scheme for a Centralized Clustering-based Hierarchical Network. In Trustcom/BigDataSE/ISPA, 318-325, IEEE.
62. Jia, J. G., He, Z. W., Kuang, J. M., & Mu, Y. H. (2010, September). An energy consumption balanced clustering algorithm for wireless sensor network. In 2010 6th international conference on wireless communications networking and mobile computing (WiCOM) (pp. 1-4). IEEE.

63. Jin, R.C., Gao, T., Song, J.Y., Zou, J.Y., Wang, L.D.(2013). Passive cluster-based multipath routing protocol for wireless sensor networks. Wireless networks, 19(8), 1851-1866.

64. Jindal, V., Verma, A.K., Bawa, S. (2015). Quantitative Reduction in Communication Load for Energy Efficiency in WSN. Wireless Personal Communications, 85(4), 2795-2810.

65. Johnson, D.B., Maltz, D.A., 1996. Dynamic source routing in ad-hoc wireless networks In: Imielinski, T., Korth, H. (Eds.), Mobile Computing. Kluwer Academic Publishers, pp. 153–181 (Chapter 5).

66. Kang, S. H., & Nguyen, T. (2012). Distance based thresholds for cluster head selection in wireless sensor networks. IEEE Communications Letters, 16(9), 1396-1399.

67. Karaboga, D., Okdem, S., & Ozturk, C. (2012). Cluster based wireless sensor network routing using artificial bee colony algorithm. Wireless Networks, 18(7), 847-860.

68. Kennedy, J. (2010). Particle swarm optimization. Encyclopedia of machine learning, 760-766.

69. Khabiri, M., & Ghaffari, A. (2018). Energy-Aware Clustering-Based Routing in Wireless Sensor Networks Using Cuckoo Optimization Algorithm. Wireless Personal Communications, 98(3), 2473-2495.

70. Kim, J. M., Park, S. H., Han, Y. J., & Chung, T. M. (2008, February). CHEF: cluster head election mechanism using fuzzy logic in wireless sensor networks. In Advanced communication technology, 2008. ICACT 2008. 10th international conference on (Vol. 1, pp. 654-659). IEEE.

71. Kuila, P., & Jana, P. K. (2014). Energy efficient clustering and routing algorithms for wireless sensor networks: Particle swarm optimization approach. Engineering Applications of Artificial Intelligence, 33, 127-140.

72. Kumar, H., Arora, H., Singla, R.K. (2013). Energy-Aware Fisheye Routing (EA-FSR) algorithm for wireless mobile sensor networks. Egyptian Informatics Journal, 14(3), 235-238.

73. Kumar, S., & Verma, A. K. (2015). Position based routing protocols in VANET: A survey. Wireless Personal Communications, 83(4), 2747-2772.

74. Kumar, V., Kumar, R., & Pandey, S. K. Polynomial based non-interactive session key computation protocol for secure communication in dynamic groups. International Journal of Information Technology, 1-6.

75. Li, C., Ye, M., Chen, G., and Wu, J., 2005. An energy-efficient unequal clustering mechanism for wireless sensor networks. In IEEE international conference on mobile adhoc and sensor systems conference (MAHSS) (pp. 597–604).

76. Li, H., Liu, Y., Chen, W., Jia, W., Li, B., & Xiong, J. (2013). COCA: Constructing optimal clustering architecture to maximize sensor network lifetime. Computer Communications, 36(3), 256-268
77. Li, Y., Yu, N., Zhang, W., Zhao, W., You, X., & Daneshmand, M. (2011, April). Enhancing the performance of LEACH protocol in wireless sensor networks. In Computer Communications Workshops (INFOCOM WKSHPS), 2011 IEEE Conference on (pp. 223-228). IEEE.
78. Liao, Y., Qi, H., & Li, W. (2013). Load-balanced clustering algorithm with distributed self-organization for wireless sensor networks. IEEE sensors journal, 13(5), 1498-1506.
79. Lindsey, S., and Raghavendra, C. S., 2002. PEGASIS: Power-efficient gathering in sensor information systems. In Aerospace conference proceedings, 2002. IEEE (Vol. 3, pp. 3-3). IEEE
80. Liu, M., Xu, S., Sun, S. (2012). An agent-assisted QoS-based routing algorithm for wireless sensor networks. Journal of Network and Computer Applications, 35(1), 29-36.
81. Liu, Y., Gao, J., Jia, Y., & Zhu, L. (2008, June). A cluster maintenance algorithm based on LEACH-DCHS protoclol. In 2008 International Conference on Networking, Architecture, and Storage (pp. 165-166). IEEE.
82. Lu, H., Li, J. and Guizani, M.(2014). Secure and efficient data transmission for cluster-based wireless sensor networks. IEEE transactions on parallel and distributed systems, 25(3), 750-761.
83. Mann, P.S., Singh, S. (2017). Energy-Efficient Hierarchical Routing for Wireless Sensor Networks: A Swarm Intelligence Approach. Wireless Personal Communications, 92(2), 785-805.
84. Manzoor, B., Javaid, N., Rehman, O., Akbar, M., Nadeem, Q., Iqbal, A., Ishfaq, M. (2013). Q-LEACH: A new routing protocol for WSNs. Procedia Computer Science, 19, 926-931.
85. Mao, S., Zhao, C., Zhou, Z., & Ye, Y. (2013). An improved fuzzy unequal clustering algorithm for wireless sensor network. Mobile Networks and Applications, 18(2), 206-214.
86. Naeem, M. K., Patwary, M., & Abdel-Maguid, M. (2017). Universal and dynamic clustering scheme for energy constrained cooperative wireless sensor networks. IEEE Access, 5, 12318-12337.
87. Nayak, P., Devulapalli, A.(2016). A fuzzy logic-based clustering algorithm for wsn to extend the network lifetime. IEEE sensors journal, 16(1), 137-144.
88. Okdem, S., & Karaboga, D. (2009). Routing in wireless sensor networks using an ant colony optimization (ACO) router chip. Sensors, 9(2), 909-921.

89. Oracevic, A., Akbas, S., & Ozdemir, S. (2017). Secure and reliable object tracking in wireless sensor networks. Computers & Security, 70, 307-318.
90. Pankajavalli, P.B. and Arumugam, N., 2011. BADSR: an enhanced dynamic source routing algorithm for MANETs based on ant and bee colony optimization. European Journal of Scientific Research, 53(4), pp.576-581.
91. Pantazis, N.A., Nikolidakis, S.A., Vergados, D.D. (2013). Energy-efficient routing protocols in wireless sensor networks: A survey. IEEE Communications surveys & tutorials, 15(2), 551-591.
92. Pei, G., Gerla, M., & Chen, T. W. (2000). Fisheye state routing: A routing scheme for ad hoc wireless networks. In 2000 IEEE International Conference on Communications. ICC 2000. Global Convergence Through Communications. Conference Record (Vol. 1, pp. 70-74). IEEE.
93. Pereira, R. M., Ruiz, L. B., & Ghizoni, M. L. A. (2015). MannaSim: A NS-2 extension to simulate Wireless Sensor Network. ICN 2015, 107.
94. Perkins, C., Belding-Royer, E., & Das, S. (2003). Ad hoc on-demand distance vector (AODV) routing (No. RFC 3561).
95. Prasanna, S., & Rao, S. (2012). An overview of wireless sensor networks applications and security. International Journal of Soft Computing and Engineering (IJSCE), ISSN, 2231-2307.
96. Provost, F., & Fawcett, T. (2013). Data science and its relationship to big data and data-driven decision making. Big data, 1(1), 51-59.
97. Qing, L., Zhu, Q., & Wang, M. (2006). Design of a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks. Computer communications, 29(12), 2230-2237.
98. Quynh, T. N., Phung, K. H., & Quoc, H. V. (2012, October). Improvement of energy consumption and load balance for LEACH in Wireless Sensors Networks. In ICT Convergence (ICTC), 2012 International Conference on (pp. 583-588). IEEE.
99. R. M. Pereira, L. B. Ruiz, and M. L. A. Ghizoni, "MannaSim: A NS-2 extension to simulate Wireless Sensor Network," ICN 2015, p. 107, 2015.
100. Rai, M., Verma, S., & Tapaswi, S. (2009, March). A heuristic for minimum connected dominating set with local repair for wireless sensor networks. In 2009 Eighth International Conference on Networks (pp. 106-111). IEEE.
101. Ran, G., Zhang, H., & Gong, S. (2010). Improving on LEACH protocol of wireless sensor networks using fuzzy logic. Journal of Information &Computational Science, 7(3), 767-775.
102. Rao, P.S., Jana, P.K., Banka, H. (2016). A particle swarm optimization based energy efficient cluster head selection algorithm for wireless sensor networks. Wireless Networks, 1-16.

103. Rault, T., Bouabdallah, A., & Challal, Y. (2014). Energy efficiency in wireless sensor networks: A top-down survey. Computer Networks, 67, 104-122.
104. Sabet, M., & Naji, H. (2016). An energy efficient multi-level route-aware clustering algorithm for wireless sensor networks: A self-organized approach. Computers & Electrical Engineering, 56, 399-417.
105. Sahoo, R.R., Singh, M., Sahoo, B.M., Majumder, K., Ray, S., Sarkar, S.K.(2013). A light weight trust based secure and energy efficient clustering in wireless sensor network: honey bee mating intelligence approach. Procedia Technology, 10, 515-523.
106. Saleem, M., Ullah, I., Farooq, M.(2012). Bee Sensor: An energy-efficient and scalable routing protocol for wireless sensor networks. Information Sciences, 200, 38-56.
107. Saleh, S., Ahmed, M., Ali, B.M., Rasid, M.F.A. and Ismail, A. (2014). A survey on energy awareness mechanisms in routing protocols for wireless sensor networks using optimization methods. Transactions on Emerging Telecommunications Technologies, 25(12), 1184-1207.
108. Sambariya, D. K., Gupta, R., & Prasad, R. (2016). Design of optimal input–output scaling factors based fuzzy PSS using bat algorithm. Engineering Science and Technology, an International Journal, 19(2), 991-1002.
109. Senthil kumar, J., Chandrasekaran, M., Suresh, Y., Arumugam, S., & Mohanraj, V. (2011). Advertisement timeout driven bee's mating approach to maintain fair energy level in sensor networks. Applied Soft Computing, 11(5), 4029-4035.
110. Shankar, T., Shanmugavel, S., Rajesh, A. (2016). Hybrid HSA and PSO algorithm for energy efficient cluster head selection in wireless sensor networks. Swarm and Evolutionary Computation, 30, 1-10.
111. Shokouhifar, M., Jalali, A.(2015). A new evolutionary based application specific routing protocol for clustered wireless sensor networks. AEU-International Journal of Electronics and Communications, 69(1), 432-441
112. Siew, Z. W., Wong, C. H., Chin, C. S., Kiring, A., & Teo, K. T. K. (2012, July). Cluster heads distribution of wireless sensor networks via adaptive particle swarm optimization. In 2012 Fourth International Conference on Computational Intelligence, Communication Systems and Networks (pp. 78-83). IEEE.
113. Singh, B., & Lobiyal, D. K. (2012). Energy-aware cluster head selection using particle swarm optimization and analysis of packet retransmissions in WSN. Procedia Technology, 4, 171-176
114. Singh, G., Kumar, N., Verma, A.K. (2014). OANTALG: An Orientation Based Ant Colony Algorithm for Mobile Ad Hoc Networks. Wireless personal communications, 77(3), 1859-1884.

115. Singh, G., Kumar, N., & Verma, A. K. (2012). Ant colony algorithms in MANETs: A review. Journal of Network and Computer Applications, 35(6), 1964-1972.
116. Singh, R., Verma, A.K.(2017)a. Energy efficient cross layer based adaptive threshold routing protocol for WSN. AEU-International Journal of Electronics and Communications, 72, 166-173.
117. Singh, R., Verma, A.K. (2017)b . Efficient image transfer over WSN using cross layer architecture. Optik-International Journal for Light and Electron Optics, 130, 499-504.
118. Singh, S., Chand, S., Kumar, B. (2016). Energy efficient clustering protocol using fuzzy logic for heterogeneous WSNs. Wireless Personal Communications, 86(2), 451-475.
119. Smaragdakis, G., Matta, I., & Bestavros, A. (2004). SEP: A stable election protocol for clustered heterogeneous wireless sensor networks. Boston University Computer Science Department.
120. Srivastava, J. R., & Sudarshan, T. S. B. (2013, August). ZEEP: Zone based energy efficient routing protocol for mobile sensor networks. In 2013 International Conference on Advances in Computing, Communications and Informatics (ICACCI) (pp. 990-996). IEEE.
121. Srivastava, J.R., Sudarshan, T.S.B.(2015). A genetic fuzzy system based optimized zone based energy efficient routing protocol for mobile sensor networks (OZEEP). Applied Soft Computing, 37, 863-886.
122. Su, S., & Zhao, S. (2018). An optimal clustering mechanism based on Fuzzy-C means for wireless sensor networks. Sustainable Computing: Informatics and Systems, 18, 127-134.
123. Sudevalayam, S., & Kulkarni, P. (2011). Energy harvesting sensor nodes: Survey and implications. IEEE Communications Surveys & Tutorials, 13(3), 443-461.
124. Suryadevara, N. K., Mukhopadhyay, S. C., Kelly, S. D. T., Gill, S. P. S. (2015). WSN-based smart sensors and actuator for power management in intelligent buildings. IEEE/ASME Transactions on Mechatronics. 20(2), 564-571.
125. Toh, C.-K., 2001. Maximum battery life routing to support ubiquitous mobile computing in wireless ad hoc networks. IEEE Communications Magazine 138–147.
126. Tomar, G.S., Sharma, T., Kumar, B.(2015). Fuzzy based ant colony optimization approach for wireless sensor network. Wireless Personal Communications, 84(1), 361-375.
127. Tong, M., & Tang, M. (2010, September). LEACH-B: an improved LEACH protocol for wireless sensor network. In Wireless Communications Networking and Mobile Computing (WiCOM), 2010 6th International Conference on (pp. 1-4). IEEE

128. Vergados, D.J., Pantazis, N.A., Vergados, D.D., 2008. Energy-efficient route selection strategies for wireless sensor networks. Mobile Networks and Applications (MONET) 13 (3–4), 285–296.
129. Villas, L.A., Boukerche, A., Ramos, H.S., de Oliveira, H.A.F., de Araujo, R.B., Loureiro, A.A.F.(2013). DRINA: a lightweight and reliable routing approach for in-network aggregation in wireless sensor networks. IEEE Transactions on Computers, 62(4), 676-689.
130. Vimalarani, C., Subramanian, R., & Sivanandam, S. N. (2016). An enhanced PSO-based clustering energy optimization algorithm for wireless sensor network. The Scientific World Journal, 2016
131. Wahid, A., Lee, S., & Kim, D. (2011, June). An energy-efficient routing protocol for UWSNs using physical distance and residual energy. In OCEANS 2011 IEEE-Spain (pp. 1-6). IEEE.
132. Wang, A., Yang, D., Sun, D. (2012). A clustering algorithm based on energy information and cluster heads expectation for wireless sensor networks. Computers & Electrical Engineering, 38(3), pp.662-671.
133. Wang, F., Bai, X., Guo, B., & Liu, C. (2016, November). Dynamic clustering in wireless sensor network for target tracking based on the fisher information of modified Kalman filter. In Systems and Informatics (ICSAI), 2016 3rd International Conference on (pp. 696-700). IEEE.
134. Wang, J., Cao, Y., Li, B., Kim, H.J., Lee, S. (2016). Particle swarm optimization based clustering algorithm with mobile sink for WSNs. Future Generation Computer Systems.
135. Wang, K., Gao, H., Xu, X., Jiang, J., & Yue, D. (2016). An energy-efficient reliable data transmission scheme for complex environmental monitoring in underwater acoustic sensor networks. IEEE Sensors Journal, 16(11), 4051-4062.
136. Wang, K., Shao, Y., Shu, L., Zhu, C., & Zhang, Y. (2016). Mobile big data fault-tolerant processing for ehealth networks. IEEE Network, 30(1), 36-42.
137. Wang, K., Wang, Y., Sun, Y., Guo, S., & Wu, J. (2016). Green industrial internet of things architecture: an energy-efficient perspective. IEEE Communications Magazine, 54(12), 48-54.
138. Wankhade, S.B. and Ali, M.S., 2011. Route failure management technique for ant based routing in MANET. International Journal of Scientific & Engineering Research, 2(9), pp.1-5.
139. Winter, T., Thubert, P., Brandt, A., Hui, J., Kelsey, R., Levis, P., & Alexander, R. (2012). RPL: IPv6 routing protocol for low-power and lossy networks (No. RFC 6550).

140. Wu, Y. C., & Tuan, C. C. (2015). K-hop coverage and connectivity aware clustering in different sensor deployment models for wireless sensor and actuator networks. Wireless Personal Communications, 85(4), 2565-2579.
141. Xiangning, F., & Yulin, S. (2007, October). Improvement on LEACH protocol of wireless sensor network. In 2007 International Conference on Sensor Technologies and Applications (SENSORCOMM 2007) (pp. 260-264). IEEE.
142. Xie, P., Cui, J. H., & Lao, L. (2006, May). VBF: vector-based forwarding protocol for underwater sensor networks. In International conference on research in networking (pp. 1216-1221). Springer, Berlin, Heidelberg.
143. Xu, J., Jin, N., Lou, X., Peng, T., Zhou, Q. and Chen, Y., 2012, May. Improvement of LEACH protocol for WSN. In Fuzzy Systems and Knowledge Discovery (FSKD), 2012 9th International Conference on (pp. 2174-2177). IEEE
144. Yadav, R. K., Gupta, D., & Lobiyal, D. K. (2017). Energy Efficient Probabilistic Clustering Technique for Data Aggregation in Wireless Sensor Network. Wireless Personal Communications, 96(3), 4099-4113.
145. Yan, R., Sun, H., Qian, Y. (2013). Energy-aware sensor node design with its application in wireless sensor networks. IEEE transactions on instrumentation and measurement, 62(5), 1183-1191.
146. Yang, J., Xu, M., Zhao, W., & Xu, B. (2010). A multipath routing protocol based on clustering and ant colony optimization for wireless sensor networks. Sensors, 10(5), 4521-4540
147. Yang, J.S., Kang, K., Cho, Y.-J., Chae, S.Y., 2008. PAMP: power-aware multi-path routing protocol for a wireless ad hoc network. In: Proceedings of IEEE WCNC, 31March–3 April 2008, Las Vegas, USA, pp. 2247–2252.
148. Yang, T., Barolli, L., Ikeda, M., Xhafa Xhafa, F., & Durresi, A. (2009). Performance analysis of OLSR protocol for wireless sensor networks and comparison evaluation with AODV protocol. In Proceedings of the 12th International Conference on Network-Based Information Systems, 19-21 August 2009, Indianapolis, Indiana, USA (pp. 335-342). Institute of Electrical and Electronics Engineers (IEEE)
149. Yang, X., Lim, H. B., Özsu, T. M., & Tan, K. L. (2007, June). In-network execution of monitoring queries in sensor networks. In Proceedings of the 2007 ACM SIGMOD international conference on Management of data (pp. 521-532). ACM.
150. Yang, Y., Fonoage, M. I., & Cardei, M. (2010). Improving network lifetime with mobile wireless sensor networks. Computer communications, 33(4), 409-419.
151. Ye, Z., & Mohamadian, H. (2014). Adaptive clustering based dynamic routing of wireless sensor networks via generalized ant colony optimization. Ieri Procedia, 10, 2-10.

152. Younis, O., & Fahmy, S. (2004). HEED: a hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks. IEEE Transactions on mobile computing, (4), 366-379.
153. Zahedi, Z.M., Akbari, R., Shokouhifar, M., Safaei, F., Jalali, A. (2016). Swarm intelligence based fuzzy routing protocol for clustered wireless sensor networks. Expert Systems with Applications, 55, 313-328.
154. Zeng, B., & Dong, Y. (2014, December). An energy efficient harmony search based routing algorithm for small-scale wireless sensor networks. In 2014 IEEE 17th International Conference on Computational Science and Engineering (pp. 362-367). IEEE.
155. Zeng, B., Dong, Y. (2016). An improved harmony search based energy-efficient routing algorithm for wireless sensor networks. Applied Soft Computing, 41, 135-147.
156. Zhang, D. G., Wang, X., Song, X. D., Zhang, T., & Zhu, Y. N. (2015). A new clustering routing method based on PECE for WSN. EURASIP Journal on Wireless Communications and Networking, 2015(1), 162.
157. Zhang, D. G., Zheng, K., Zhao, D. X., Song, X. D., and Wang, X., 2016. Novel quick start (QS) method for optimization of TCP. Wireless Networks, 22(1), 211-222.
158. Zhang, D.G., Song, X.D., Wang, X., Ma, Y.Y. (2015). Extended AODV routing method based on distributed minimum transmission (DMT) for WSN. AEU-International Journal of Electronics and Communications, 69(1), 371-381.
159. Zhang, D.G., Wang, X., Song, X.D., Zhang, T., Zhu, Y.N. (2015). A new clustering routing method based on PECE for WSN. EURASIP Journal on Wireless Communications and Networking, (1), 1-13.
160. Zhang, Y., & Chen, H. H. (Eds.). (2007). Mobile WiMAX: Toward broadband wireless metropolitan area networks. CRC Press.
161. Zhao, X., & Wang, N. (2010, May). An unequal layered clustering approach for large scale wireless sensor networks. In 2010 2nd International Conference on Future Computer and Communication (Vol. 1, pp. V1-750). IEEE.
162. Zungeru, A. M., Ang, L. M., & Seng, K. P. (2012). Classical and swarm intelligence based routing protocols for wireless sensor networks: A survey and comparison. Journal of Network and Computer Applications, 35(5), 1508-1536.