JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF COMPUTING

ENHANCED CLUSTER FORMATION ALGORITHM ON ENERGY EFFICIENT UNEQUAL CLUSTERING PROTOCOL FOR WIRELESS SENSOR NETWORKS

By

Sofanit Alemu

June, 2019

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A thesis submitted to the School of graduate studies at Jimma University, Jimma Institute of Technology in partial fulfillment of the requirements for the degree of Master of Science in Computer Networking.

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DECLARATION

I, hereby declare that this thesis entitled "Enhanced cluster formation algorithm on Energy Efficient Unequal Clustering Protocol for wireless sensor networks" is my original work and has not been presented for a degree in this or any other universities, and all sources of references used for the thesis work have been appropriately acknowledged.

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DEDICATION

To The Almighty

Acknowledgments

I sincerely appreciate Almighty God for his provision of joys, challenges and grace for growth that have been bestowed upon me during this research work.

I would like to express deepest gratitude to my advisor Dr.Dawit Kifle and co-advisor Mr.Gemechu Birhanu for their support. Finally, I thank my dear family and friends.

Abstract

Wireless sensor networks (WSNs) are composed of a large number of sensor nodes with the ability to sense and process data in the physical world in a timely manner. The sensor nodes also have communication capability to transmit the sensed data to a specific location. They are usually battery operated that may run out after some time. Clustering is one of the efficient techniques that is used to prolong lifetime of a network. The group is called cluster and the elected node is called Cluster Head (CH). In multi-hop routing protocols the effect of the hot-spot problem is inevitable on the CHs nearer to the BS. CHs close to destination spend their energy sooner with heavy relaying data and die faster which is known as, Hot-spot problem. So, to deal with the unbalanced energy consumption unequal-sized clustering protocols were proposed by dividing the network into clusters of different sizes so that a certain degree of balance in energy consumption is assured among the CHs.

But during cluster formation phase, many of the existing unequal clustering algorithms consider only the nearest distance to enable nodes join to their respective CH. Here, considering only the nearest distance will lead to choosing a CH with ignoring other important factors i.e. CH with smaller residual energy and also CH which is located far apart from the BS might be selected which has a significant effect on the energy of the sensor nodes and lifetime of the network.

This Thesis focuses on modifying the existing cluster formation algorithm based on the well-known unequal clustering protocol which is called EEUC (Energy Efficient Unequal Clustering) The proposed work designs an algorithm which helps nodes to make decisions to join CH by taking into account, the minimum hop count to the BS, Residual energy of CH, and distance between nodes and CH (using the RSSI).Then from the available CHs nodes will compute the cost function and joins the CH with high cost value. This helps to utilize the energy efficiently and to extend the network life time.

The proposed algorithm is implemented and evaluated using the IDE simulation framework of OMNET++ based Castalia simulator. The Simulation results show that the proposed work performs better in terms of energy consumption and prolongs the network life time.

Keywords: Wireless Sensor Networks, EEUC, Multi-hop routing, unequal clustering.

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List of Acronyms

ADC	Analog to Digital Converter
ADV	Advertisement
APS	Ad-hoc positioning system
BCEE	Balanced-Clustering Energy-Efficient
BS	Base Station
CH	Cluster Head
COCA	Constructing optimal clustering architecture
CSMA	Carrier Sense Multiple Access
DD	Directed Diffusion
DEEC	Distribute Energy-Efficient Clustering
DUCA	Distributed Uniform Clustering Algorithm
DWEHC	Distributed Weight-based Energy-efficient Hierarchical Clustering
EAUCF	Fuzzy energy-aware unequal clustering
EECS	An Energy Efficient Clustering Scheme
EEUC	Energy-Efficient Unequal Clustering
EEVSCA	Energy efficient varying sized clustering algorithm
FBUC	Fuzzy logic based unequal clustering
FLCFP	Fuzzy Logic Cluster Formation Protocol
GAF	Geographic adaptive fidelity
GBR	Gradient based Routing
GPS	Global Positioning System
HEED	Hybrid Energy Efficient Distributed
LEACH	Low Energy Adaptive Clustering Hierarchy
LEACH-C	LEACH-Centralized
LEACH-E	LEACH-based Energy
MEMS	Micro Electro Mechanical Systems

MMSPEED	Multi path and Multi SPEED
MRPUC	Multihop Routing Protocol with Unequal Clustering
RERR	Route Error
RR	Rumor Routing
RREP	Route Reply
RREQ	Route Request
RSSI	Received Signal Strength Indicator
SAR	Sequential assignment routing
SN	Sensor node
SPIN	Sensor Protocols for Information via Negotiation
TDMA	Time Division Multiple Access
TTDD	Two-Tier Data Dissemination
UCR	Unequal Clustering Routing
UCS	Unequal Cluster Size
WSN	Wireless Sensor Networks

CHAPTER ONE: INTRODUCTION

1.1. Background

Wireless sensor network (WSN) is a distributed collection of resource constrained tiny nodes capable of operating with minimal user attendance. Rapid development in micro electro mechanical systems (MEMS) technology has provided small sized, low-power, and low-cost sensor nodes with the capability to sense various types of physical and environmental conditions. WSN improves the ability of humans to monitor and control physical locations from remote area.

To prolong the lifetime of the sensor nodes by decreasing wasteful energy drainage, nodes can be partitioned into a number of small groups, called clusters [1].In general, each cluster has a cluster-head which coordinates communication among member nodes, gathering data from member nodes, aggregate the received data, and finally send the aggregated data to sink.
In cluster formation process, nodes select their respective cluster head based on some criteria and then form their cluster around the selected CH [2].

So far many algorithms have been proposed to select cluster heads. Among them, LEACH [3] is the most famous and classical algorithm. It uses probabilistic-based cluster head selection methods. LEACH has been widely served as a benchmark, so that a lot of improvement schemes are based on this algorithm. For instance, LEACH-Centralized (LEACH-C) [4], LEACH-based Energy (LEACH-E), HEED [5], EECS [6], EEUC [7] are some of them.

One of the main issues in Wireless Sensor Network is balancing the cluster size. As the cluster size increases, the number of clusters decreases. This has positive and negative effect on the energy consumption. In large cluster size, the number of clusters become smaller. Finally, the inter communication among clusters results with less energy consumption (positive effect). On the other hand, as the size of cluster increases the number of nodes in the cluster also increases. In other words, a single cluster head is expected to handle more number of nodes (i.e., the communication overhead on CH is high). As a result, cluster heads in each cluster deplete their battery power quickly. Due to this, the frequency of cluster selection become high which leads to high energy consumption in the case of intra communication. Thus, the energy consumption by inter-cluster communication decreases, but the energy consumption by intra-cluster communication increases in proportion to the cluster size. On the other hand, an adverse situation is occurred when the cluster size decreases. To address the above mentioned issues, two types of clustering approaches are proposed, namely, equal clustering and unequal clustering.

Equal Clustering (fixed cluster size): In this approach the size of the cluster is same throughout the network and every CH have equal number of nodes in a cluster. However, in this clustering scheme lots of energy will be consumed in maintaining intra cluster and inter cluster communication. So it can be thought that the clusters near the base station will die soon thus leaving the network isolated even if the rest of the clusters are having energy left within them. This problem is called "equal clustering problem" [8]. The majority of clustering algorithms from related literature create equal size clusters. DEEC [9] and DUCA [10] are some of the clustering algorithms that have been proposed by considering equal cluster size.

The other solution to avoid the equal clustering problem is unequal clustering. In multi-hop cluster-based routing protocols, CH nearer to the Base Station (BS) exhaust their energy quickly than other nodes since data from the entire network is forwarded to BS through them. Due to this, nearby CH nodes die quickly and network get partitioned frequently. This is known as hot spot problem [11]. To address this issue, numerous algorithms on unequal clustering are contemplated. UCS [12], UCR [13], EEUC [7], EECS [6] are some of the unequal clustering routing protocols.

Unequal clustering algorithms achieve load balancing between CHs by reducing the size of the cluster which is found near to BS. Most unequal clustering algorithms are directly proportional to the distance of CHs from BS. When the distance to BS increases cluster size also increases and cluster size decreases when the distance become decreased. So the smaller clusters consumes less energy for intra-cluster traffic and concentrates more on inter-cluster traffic. Similarly larger clusters farther from BS indicate more cluster members and spend more energy on intra-cluster traffic. As a result, it spends less energy for inter-cluster traffic hence no need of spending more energy for inter-cluster routing. Unequal clustering permits all CHs to spend same amount energy so that the CHs near BS spend equal energy as CHs farther from BS.

Despite the effectiveness of unequal clustering algorithms to reduce the hot spot problem, most of them don't give an emphasis for the cluster formation (during node joining to a cluster). In these algorithms distance metric (RSSI) is a key feature to make nodes join to their CH. In fact selecting the nearest CH will save the energy of the nodes. Even though, it is good some researches have stated this can let the nodes which join with specific cluster head bring overburden for the cluster Head.

The goal of this thesis is to make further improvement with designing an algorithm by taking into account multiple parameters for the cluster formation. Beside the distance metric (RSSI) we consider the Residual energy of the CH and CH to BS distance in terms of hop count in order to diminish the energy consumption of the CH and to prolong the network lifetime. This results with the appropriate and efficient cluster formation scheme.

1.2. Statement of the Problem

In a cluster-based wireless sensor networks, cluster heads spend their energy for intra-cluster communication and inter-cluster communication [14]. The amount of energy consumed in intra-cluster communication depends on cluster size. Energy consumption rises with number of sensor nodes in a cluster.

In multi-hop cluster based WSN, CH near to BS has a lot of burden since it forwards the data to sink on behalf of its member nodes. Unequal clustering has overcome this problem by partitioning the network unequally. Most of the existing unequal clustering algorithms work efficiently to reduce the energy consumption and to extend the lifetime of the network. But there is a need of further improvement on the cluster formation.

The existing works consider only the RSSI as a major parameter to make nodes join to their respective CH. The reason behind such association algorithm is based on the assumption that transmitting data to the closest CH consumes least amount of energy. However, such design discipline may cause a CH to be chosen with less energy and also the elected CH might be far apart from the BS so that the inter cluster communication cost will be high. Hence, to perform further improvement the proposed work considers multiple parameters for cluster formation.

Generally, the proposed algorithm aimed to fill the gap of the aforementioned problems by taking into account various parameters. i.e. residual energy, RSSI and CH to BS distance using hopcount and designing an algorithm in order to have the appropriate and efficient cluster formation scheme.

Here including the hop count parameter has an important feature for reducing the cost of inter-cluster communication Cost.

1.3. Motivation

The motivation of this study is that, most clustering algorithms generally work on the CH selection and less work has been done on node association with CH. This may consumes the use of energy with the CH and may overburden a single CH. Some researchers have addressed this problem and worked on it to get energy efficient way of forming the cluster. In this study, we add and integrate different parameters in order to improve network lifetime and reduce the energy consumption.

1.4. Objectives

1.4.1 General Objective

The General objective of the proposed work is to enhance the cluster formation technique for Wireless Sensor networks by introducing additional parameters to be considered for joining a cluster.

1.4.2. Specific Objectives

In order to achieve the General objective, the following specific objectives are set:

- Investigate Limitations of existing clustering algorithms.
- Identify the possible parameters to be used in the proposed work to balance the energy consumption and to prolong network lifetime.
- Design an algorithm for the proposed solution.
- Implement and simulate the proposed algorithm to measure its impact.
- Identify evaluation metrics to be used to test the performance of the proposed work.

1.5 Methodology

In order to achieve the objectives of the study, the following methods will be employed.

1.5.1. Literature review

This phase is one of the crucial steps that is taken to get a deep understanding in order to achieve the objective of this thesis by considering different resources, i.e. like books, research papers and other documents.

1.5.2. Designing an Algorithm

In the design phase, an algorithm which uses three parameters for cluster formation is designed for our work.

1.5.3. Prototype Implementation

Simulation Experiment: for observing the performance of the systems designed and comparing the obtained result with that of the previously done system, integrated development software environments (IDEs) listed below are used in accordance with their corresponding advantages for doing simulation experiment

Omnet++ version 4.6: for generating simulations as LINUX executable from NED and C++ code and uses dedicated tools to generate make files for proper compilation. Node deployment on the network field and modules with their behaviors are modeled with it. It is the precondition for implementing Castalia IDE.

Castalia Version 3.3: is implemented for its distributed algorithms or protocols in realistic wireless channel and radio models, with a realistic node behavior especially relating to access of the radio. Castalia can also be used to evaluate platform characteristics for specific applications.

1.5.4 Testing and Evaluation

Results from the proposed solution will be tested and evaluated in terms of its goals and contributions in comparison to previous works, to show the applicability and effectiveness of the solution.

1.6 Scope and Limitations

This research work focuses on designing and implementing enhanced cluster formation algorithm. In the new algorithm nodes will use additional criteria's to join a cluster in order to reduce the energy consumption of the CH and extend the lifetime of the network. In order to simplify the process, the work is based on previous research done on unequal clustering algorithms.

This work does not consider equal cost clustering algorithms and isolated nodes. Isolated nodes are nodes that don't receive any broadcast message from the CHs.

1.7 Organization of the Thesis

The rest of the thesis is organized as follows: Chapter 2 presents the literature review on wireless sensor networks such as characteristics, design challenges, application and routing protocols in WSN also discussion about unequal clustering is included. Chapter 3 discusses about different related research works. In Chapter 4, the methodology employed and design of the proposed system is introduced. Chapter 5 presents an implementation and discussion of the experimental result and its evaluation. Finally, conclusions, and future work are presented in Chapter 6.

CHAPTER TWO: LITERATURE REVIEW

2.1. Sensor Nodes

WSNs conventionally consist of hundreds of sensor nodes (SNs) that communicate with each other in order to convey high quality information to the base station (BS) without using pre-existing infrastructure. This means that WSNs are deployed in an ad hoc manner and the SNs are self-organizing. The SNs are randomly placed in a remote area or sensor field whereby they form a connection with each other in order to measure a physical value. Besides, it is very difficult to replace these SNs after complete deployment in many scenarios or applications, especially in harsh environments such as mines, battlefields, etc. In most cases, the larger the number of SNs deployed to monitor a geographical area or an event, the more reliable and accurate is the delivered message [15].

2.1.1. WSN Node Components

A typical sensor node consists of four basic components: sensing unit, processing unit, power unit and communication unit. The figure shown below illustrates the architectural structure of a single node.

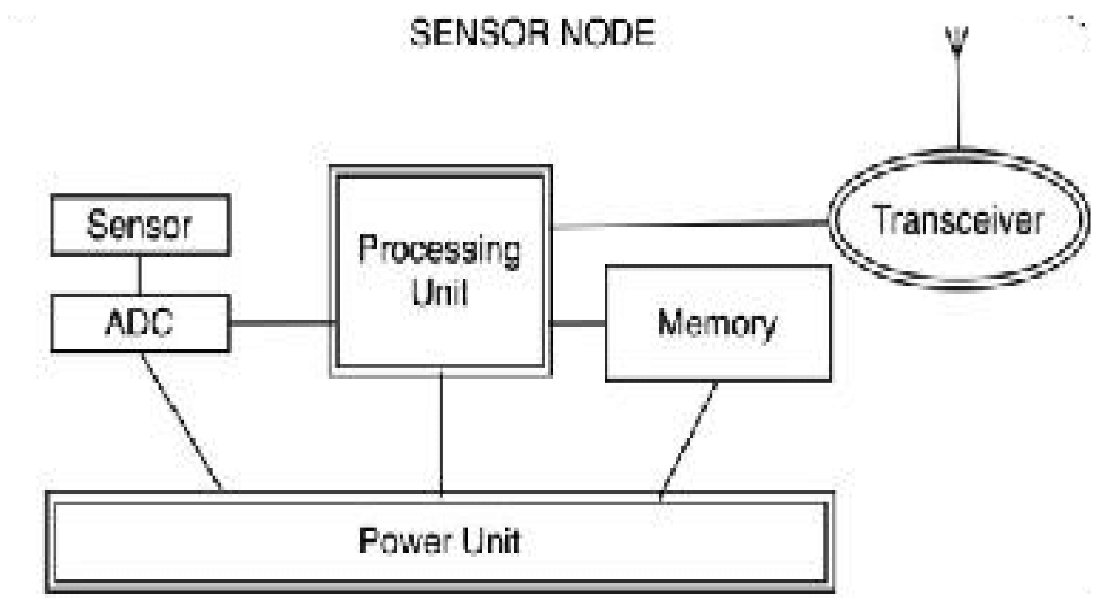

Figure 2. 1 sensor node components [35]

The different components are described as follows.

1. **Sensing Unit**

Sensing units are usually composed of two subunits: sensors and analogue to digital converters (ADCs) [35]. A sensor is an electronic component that measures the physical quantity and converts to the type that can be read by the user or other electronic device; and the analog signals produced by the sensors are converted to digital signals by the ADC, and then fed into the processing unit.

2. **Processing Unit**

It is major component responsible for processing all relevant data and executing the code that describes the behavior of the sensor node. Some common tasks of the processor are acquisition, preprocessing and processing of the incoming and outgoing information. The processing unit is generally associated with a small storage unit and it can manage the procedures that make the sensor node collaborate with the other nodes to carry out the assigned sensing tasks. [16]

3. **Communication unit**

The communication unit has both a transmitter and a receiver for establishing wireless communication between sensor nodes. The communication unit which combines both transmitting and receiving tasks are called **transceiver**. The most essential task of transceiver is to convert the digital bit stream coming from microcontroller into radio waves and vice versa The Radio Frequency (RF) based wireless communication suits to most of WSN applications. Transmit, Receive, Idle and Sleep are the operational states of transceiver.

4. **Power Unit**

The electronics of the sensor node is powered by using either stored energy or harvesting energy from other potential sources such as light, vibration, heat and radio frequency signal. It is the component whose main task is providing a stable power supply to all active components of the -sensor node system. This means it converts the input from the energy source into acceptable levels in order to power the connected units. This conversion, generally depend on the type of energy source used for the sensor nodes.

2.2. Wireless Sensor Network

The progress in modern technologies has motivated the design of small electronic low-powered sensor devices. Ordinarily, a considerable number of these sensors are deployed in remote areas in the form of a wireless network of nodes to measure different physical values. This kind of network scenarios are referred to as **wireless sensor networks (WSNs).** WSNs are serviceable in numerous industrial applications. For instance, WSNs find use in environment monitoring and disaster management applications such as forest fire detection, landslide detection, and air pollution detection [17, 18]. In intelligent surveillance and defence reconnaissance, WSNs are used in applications such as distributed situation awareness and geographic directed queries. Also, WSNs have been extensively used in health care monitoring activities such as mass-casualty disaster, cancer detection and blood glucose measurement. In these and many other applications, WSNs technology provides different advantages (such as ease of implementation, lower implementation cost, accuracy, scalability) in comparison to the traditional networking solutions [19].

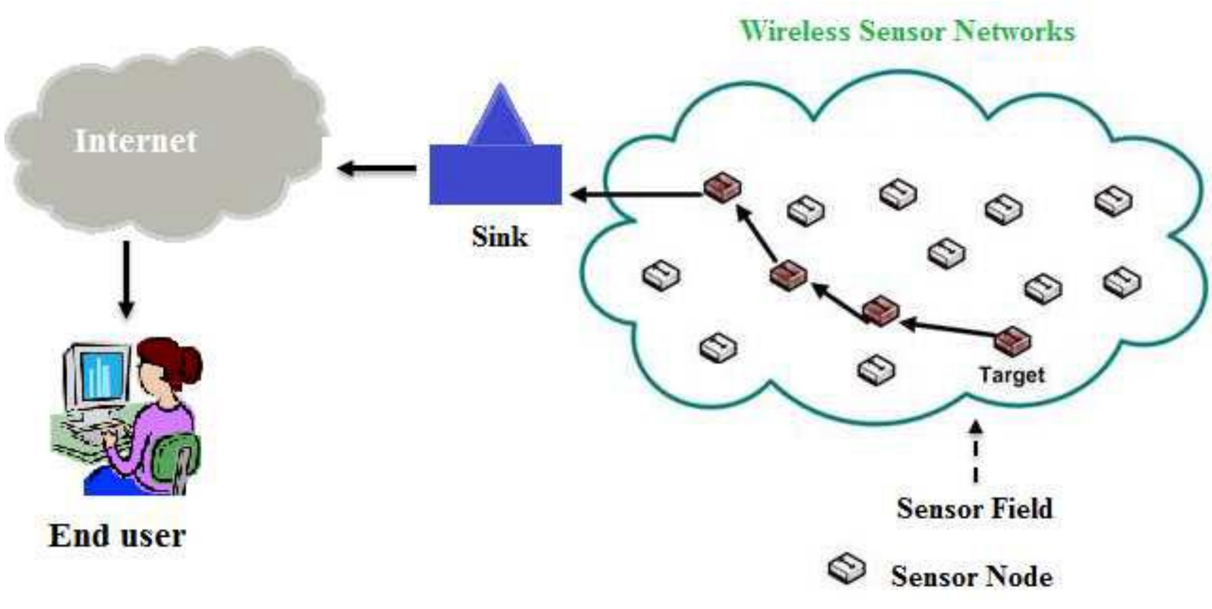

Figure 2. 2 Wireless Sensor Network Architecture [20]

2.2.1. Applications of WSN

Wireless sensor networks have gained considerable popularity due to their flexibility in solving problems in different application domain and have the potential to change our lives in many different ways. WSNs have been successfully applied in various application domains [20] [21] [22] [23] [24] [25] such as:

Military applications: Wireless sensor networks be likely an integral part of military command, control, communications, computing, intelligence, battlefield surveillance, reconnaissance and targeting systems.

Area monitoring: In area monitoring, the sensor nodes are deployed over a region where some phenomenon is to be monitored. When the sensors detect the event being monitored (heat, pressure etc), the event is reported to one of the base stations, which then takes appropriate action.

Transportation: Real-time traffic information is being collected by WSNs to later feed transportation models and alert drivers of congestion and traffic problems.

Health applications: Some of the health applications for sensor networks are supporting interfaces for the disabled, integrated patient monitoring, diagnostics, and drug administration in hospitals, tele-monitoring of human physiological data, and tracking & monitoring doctors or patients inside a hospital.

Environmental sensing: The term Environmental Sensor Networks has developed to cover many applications of WSNs to earth science research. This includes sensing volcanoes, oceans, glaciers, forests etc. Some other major areas are listed below:

- Air pollution monitoring
- Forest fires detection
- Greenhouse monitoring
- Landslide detection

Structural monitoring: Wireless sensors can be utilized to monitor the movement within buildings and infrastructure such as bridges, flyovers, embankments, tunnels etc enabling Engineering practices to monitor assets remotely without the need for costly site visits.

Industrial monitoring: Wireless sensor networks have been developed for machinery condition--based maintenance (CBM) as they offer significant cost savings and enable new functionalities. In wired systems, the installation of enough sensors is often limited by the cost of wiring.

Agricultural sector: using a wireless network frees the farmer from the maintenance of wiring in a difficult environment. Irrigation automation enables more efficient water use and reduces waste.

2.2.2. Challenges in wireless sensor network

There are a lot of challenges placed by the deployment of sensor networks which are a superset of those found in wireless ad hoc networks. Sensor nodes communicate over wireless, lossy lines with no infrastructure. An additional challenge is related to the limited, usually non-renewable energy supply of the sensor nodes. In order to maximize the lifetime of the network, the protocols need to be designed from the beginning with the objective of efficient management of the energy resources [35]. Wireless Sensor Network Design issues are mentioned in [5] [16] [26]

- ❖ **Fault Tolerance:** Sensor nodes are vulnerable and frequently deployed in dangerous environment. Nodes can fail due to hardware problems or physical damage or by exhausting their energy supply. We expect the node failures to be much higher than the one normally considered in wired or infrastructure-based wireless networks. The protocols deployed in a sensor network should be able to detect these failures as soon as possible an-d be robust enough to handle a relatively large number of failures while maintaining the overall functionality of the network. This is especially relevant to the routing protocol design, which has to ensure that alternate paths are available for rerouting of the packets. Different deployment environments pose different fault tolerance requirements.
- ❖ **Scalability**: Sensor networks vary in scale from several nodes to potentially several hundred thousand. In addition, the deployment density is also variable. For collecting high-resolution data, the node density might reach the level where a node has several thousand neighbors in their transmission range. The protocols deployed in sensor networks need to be scalable to these levels and be able to maintain adequate performance. Production Costs: Because many deployment models consider the sensor nodes to be disposable devices, sensor networks can compete with traditional information gathering approaches only if the individual sensor nodes can be produced very cheaply.

- **Hardware Constraints**: At minimum, every sensor node needs to have a sensing unit, a processing unit, a transmission unit, and a power supply. Optionally, the nodes may have several built-in sensors or additional devices such as a localization system to enable location-aware routing. However, every additional functionality comes with additional cost and increases the power consumption and physical size of the node. Thus, additional functionality needs to be always balanced against cost and low-power requirements.
- **Sensor Network Topology**: Although WSNs have evolved in many aspects, they continue to be networks with constrained resources in terms of energy, computing power, memory, and communications capabilities. Of these constraints, energy consumption is of paramount importance, which is demonstrated by the large number of algorithms, techniques, and protocols that have been developed to save energy, and thereby extend the lifetime of the network. Topology Maintenance is one of the most important issues researched to reduce energy consumption in wireless sensor networks.
- **Transmission Media:** The communication between the nodes is normally implemented using radio communication over the popular ISM bands. However, some sensor networks use optical or infrared communication, with the latter having the advantage of being robust and virtually interference free.
- **Power Consumption**: many of the challenges of sensor networks revolve around the limited power resources. The size of the nodes limits the size of the battery. The software and hardware design needs to carefully consider the issues of efficient energy use. For instance, data compression might reduce the amount of energy used for radio transmission, but uses additional energy for computation and/or filtering. The energy policy also depends on the application; in some applications, it might be acceptable to turn off a subset of nodes in order to conserve energy while other applications require all nodes operating simultaneously.

2.3. Routing protocols for WSN

Sensor Nodes (SNs) transmit the sensed information to the BS depending on the routing protocol or algorithm used. The routing protocol states how the SNs communicate with each other in order to circulate the sensed information towards the BS and it allows the SNs to select the most cost-efficient route to the BS. A cost-efficient routing protocol is developed to balance as much as possible some features such as scalability, timeliness, and robustness.

Most importantly, the routing protocol must minimize the energy consumption so as to extend the network lifetime for a reasonable period.

2.3.1. Classification of WSN Routing Protocols

WSN routing protocols may be classified in different ways, according to the way routing paths are established, according to the protocol operation, and according to the network structure.

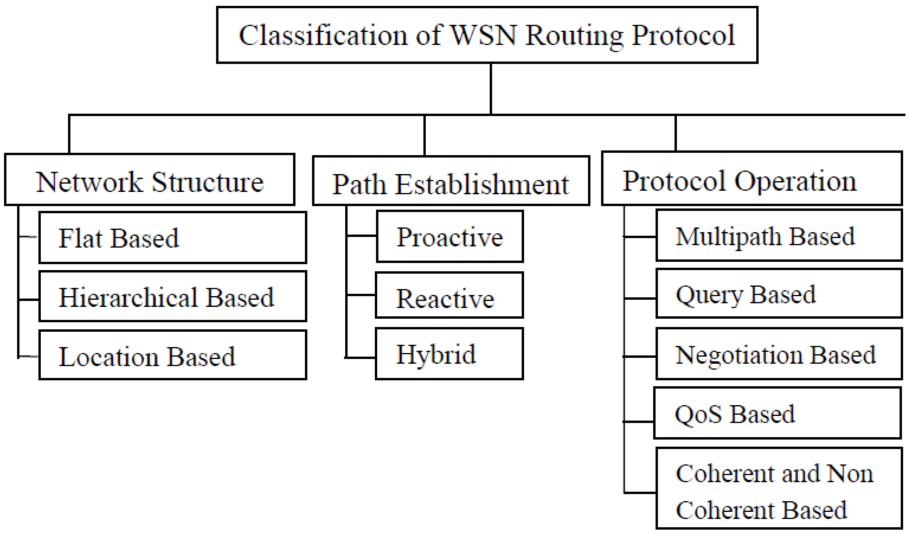

Figure 2. 3 Classification of WSN Routing Protocols [22]

a. Classification Based on Path Establishment

- Routing protocols can also be classified into three categories: **proactive**, **reactive**, and **hybrid** depending on how the source discovers a route to the destination [27].

In proactive protocols, all routes are computed and added to the routing table before they are really needed and each node has one or more tables that contain the latest information of the routes to any node in the network. The Proactive protocols are not suitable for larger networks, as they need to maintain node entries for each and every node in the routing table of every node. This causes more overhead in the routing table leading to increases energy consumption.

Reactive routing protocols discover routes on demand which means only when a source node wants to communicate with destination. The major drawback with Reactive routing technique is high routing overhead due to Route Request (RREQ), Route Reply (RREP) & Route Error (RERR) messages to maintain the network and there is higher energy consumption.

Hybrid routing protocols are combination of both reactive and proactive routing protocols. It was proposed to reduce the control overhead of proactive routing protocols and also decrease the latency caused by route discovery in reactive routing protocols.

b. Classification Based on protocol operation

The function of a wireless sensor network specifies its application. Therefore, routing protocols can be categorized according to the operation used to satisfy a WSN function [28].

❖ **Multipath based**

Multiple paths are used to enhance network performance. In case a path is down, an alternative path is directly chosen to deliver the data from source to destination. However, it may be energy consuming since these alternative paths are kept alive by sending periodic packets. Reliability is insured in the scheme. Examples:

- Directed Diffusion (DD)
- Multi path and Multi SPEED (MMSPEED).

❖ **Query based**

In this routing scheme a node sends a query asking for a certain event and any node that sense this event can send the packet back to the node that requested the query. Moreover, as the query requested moves through the network the path back to the initial node is saved. When a node sense the event needed it send it back through the saved path. Data aggregation is used to lower the energy consumption. E.g. Rumor Routing protocol, Sensor Protocols for Information via Negotiation (SPIN), Directed Diffusion (DD).

❖ **Negotiation**

The goal behind this routing scheme is to restrain duplicate data preventing redundancy through several negotiation messages before the final data is being transmitted. Examples: SPIN, Sequential Assignment Routing (SAR), Directed Diffusion (DD).

❖ **Qos (Quality of service)**

In this routing protocol, quality of data is important, but energy consumption must be taken in to consideration. Although Qos metrics such as delay and bandwidth are important, also power consumption is important and crucial, e.g. SPEED, Sequential assignment routing (SAR).

- ❖ **Coherent and Non-coherent**

Sensor nodes cooperate together to process different data surfing the network. Data processing is the most important issue in the function of wireless sensor network and it may be done in two techniques [29], Coherent routing, where minimum processing is done on the data and then forwarded to aggregators. The other technique is non-coherent, where the node will itself process the collected data before sending it. e.g. single winner algorithm, multiple winner algorithm.

c. Classification Based on Network Structure

- ❖ **Location-based routing**

Location based routing protocols need location information of the sensor nodes to relay data to the desired areas before communication. It can be obtained from GPS (Global Positioning System) signals, received radio signal strength. So nodes are addresses by their location.

e.g. Sequential assignment routing (SAR),Ad-hoc positioning system (APS),Geographic adaptive fidelity (GAF).

- ❖ **Flat-based routing**

In flat-based routing, all nodes are typically assigned equal roles or functionality [15].They all have the same information about the state of the network. Therefore, since all nodes transmit data, redundancy is likely to occur, which leads to high energy consumption. The sink or base station can ask for a certain data in a region, so all nodes in this region are to send these data after an event occurrence. **E.g. S**ensor Protocol for Information via Negotiation (SPIN), Directed Diffusion (DD), Rumor Routing (RR), and Gradient based Routing (GBR).

- ❖ **Hierarchical-based routing**

In hierarchical routing protocols, the main idea is that every sensor node within a WSN is grouped along with some other of its neighboring nodes in order to constitute a specific cluster.

2.4. Clustering in WSN

Clustering can be defined as the division of the nodes in the groups on the basis of some mechanism. Clustering provides an effective method for prolonging the lifetime of a WSN and it provides also scalability, less energy consumption. Data, collected by the sensor nodes belonging to a cluster, are not directly transmitted to the Base Station (BS). Instead, a node of the cluster, called CH, collects these data and forwards them to the BS after possibly having performed appropriate data aggregation. In this way, the number of transmitted messages to the BS is reduced and considerable power conservation is achieved. CHs use either multi-hop or single-hop routing for transmitting collected data to the base-station (BS)

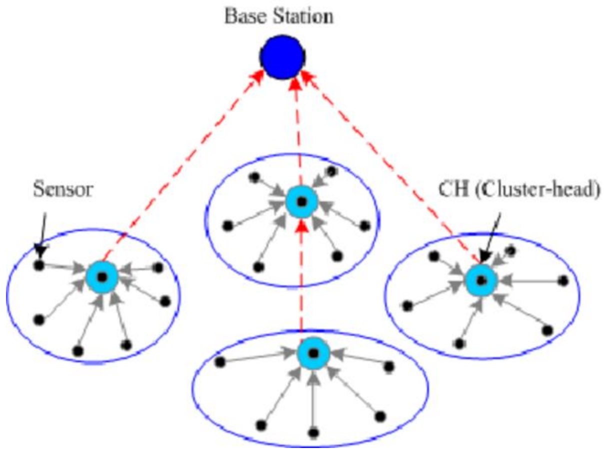

Figure 2. 4 Clustering in WSN [1]

LEACH (Low Energy Adaptive Hierarchy) [3] is one of the most popular cluster based routing technique. It uses Single-hop routing technique and randomized rotation of cluster-heads to distribute energy consumption over all nodes in the network. Sensor node chooses a random number between 0 and 1. If this random number is less than a threshold value, T(n), the node becomes a CH for the current round. Then the elected CHs broadcast an advertisement message to inform other nodes about their states. Once the advertisement message is reached to the nodes, each node decides which cluster it belongs to by picking the CH that requires the smallest transmission distance, indirectly by measuring the received power from a CH message. But considering only the distance between the CH and the node ignores other factors that affect the energy consumption and the network lifetime.

Distributed Weight-based Energy-efficient Hierarchical Clustering protocol (DWEHC), proposed by Ding et al. [30], is a distributed clustering algorithm. The main objective of DWEHC is to build balanced cluster sizes and optimize the intra-cluster topology using location awareness of the nodes. DWEHC has no assumptions about the network size and density, and considering residual energy in the process of CH election. Every node implements DWEHC individually and the algorithm ends after several iterations that are implemented in a distributed manner.

In [31], Yu et al. proposed a cluster-based routing protocol for WSN with non-uniform node distribution (EADC), whose cores are an energy-aware clustering algorithm and a cluster-based routing algorithm. EADC is a competition based algorithm, where CH is selected on the basis of the ratio between its residual energy to the average residual energy of its neighbors. To form clusters, each node chooses the nearest CH without taken into account its residual energy. Each CH chooses a next hop CH with higher residual energy and fewer cluster members as its next hop.

In order to minimize consumption of energy and prolong the network lifetime**,** MR-LEACH is proposed. It divides the entire area into various layers and forms the hierarchy of different layers of clusters. MR-LEACH produces the same size of clusters in each layer that means any normal node sends data to the BS in an equal number of hops. For this the BS allocates a time slice for each CH by using TDMA scheduling. Based on the TDMA schedule received from the BS, every CH allocates its own TDMA schedule for its member nodes. The CH in MR-LEACH is selected based on maximum residual energy. Each adjacent upper layer CH assists the lower layer CH during the data transmission to the BS. MR-LEACH protocol increases the network lifetime by adopting multi-hop transmission from lower layers to the upper layer. It is highly scalable compare to basic LEACH.

The above mentioned Clustering protocols uses different techniques to select Cluster Head and for the cluster formation process.

2.4.1. Types of clustering

Clustering algorithms based on their size are divided into two groups: equal-size and unequal-size.

2.4.1.1. Equal-size Clustering

In the equal clustering algorithms, each CH or cluster has equal cluster size (the size of each cluster is a fixed value). Multi-hop method in equal-size clustering has drawbacks because overload tasks are put on CHs that are closer to the BS. This leads the CHs to waste their energy and also causes the hotspot problem.

Many methods have been proposed in literature for mitigating the Hot spot problem, and thereby maximizing the network lifetime. Some of the approaches for overcoming Hot spot problem are listed below:

First is assistant approach, such as deployment assistance, e.g. TTDD (Two-Tier Data Dissemination) [32]. Larger initial energy nodes can be deployed in the region consuming larger energy, i.e. using energy heterogeneity. In TTDD scheme, a number of assisting nodes are deployed having larger battery capacity and larger transmission range. These assisting nodes form a relay region on upper side of the regular sensors that have lower initial energy and thus help in alleviating the Hot spot problem.

The second approach is based on node distribution strategy that has been studied in references [33] [34] [35] and more number of nodes can be deployed in the region near the BS. Also in [11], nodes are deployed with the help of a predetermined distribution function.

The third approach is based on transmission range adjustment [36] [37] [38]. The transmission range adjustment scheme has been investigated to maximize the sensor network lifetime. The Hot spot problem is solved by adjusting the radii of sensors communication ranges.

As some papers mentioned, mobility of the sink is another alternative to solve Hot spot problem [38] [39]. In [39], mobility of the base station is considered for event-driven network. The authors in [40] have proposed base station mobility and multi hop routing approach for extending the lifetime in WSN. Chiefly, with the mobile BS approach, the BS moves back and forth around the sensor field so as to collect the aggregated information conveyed from each CH.

The mobile sink approach is still a very recent technique used in solving the energy-hole problem but has been shown to protract the network lifetime and functionality. The major drawback with these approaches is that they are not feasible. These methods involve high cost and provide lower energy efficiency.

Using mobile relays to share the load of sensor nodes around the base station. Wang and others [41] used mobile relays to prolong the lifetime of wireless sensor networks.

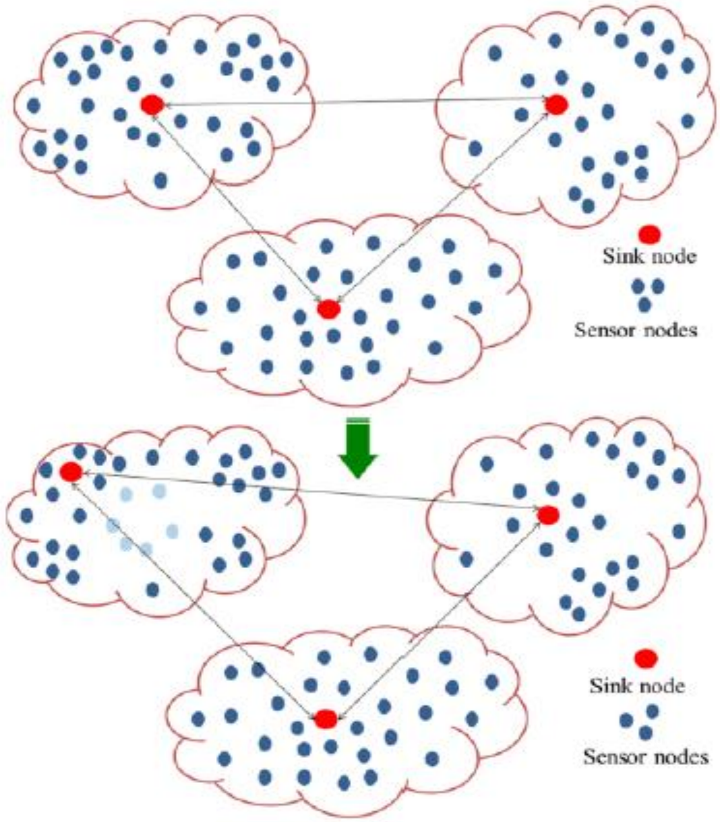

Figure 2.5. Movement of sinks to maintain energy balance in monitored region [39]

It has been pointed out that the hotspot problem is the inherent phenomenon in data gathering network. However, it can greatly weaken the impact of this phenomenon and prolong the network lifetime via effective methods and mechanisms.

In addition to the above methods, unequal Clustering methods are also one of the energy-efficient algorithms. Its Network structure helps to prolong the lifetime of the network and also balances the energy consumption well among all sensor nodes.

Many energy efficient algorithms perform using the unequal clustering approach to overcome the hotspot problem. In this research also, we consider the unequal clustering methods to achieve our goal.

2.4.1.2. Unequal Clustering

In order to prevent the network from hot spot issue, unequal clustering techniques can be utilized for load balancing between the CH. In unequal clustering the network is partitioned into clusters of different sizes. The clusters close to the base station are smaller than the clusters far from the base station. Smaller cluster near the BS indicates less number of cluster members and less intra cluster traffic. So, the smaller clusters consume less energy for intra-cluster traffic and concentrates more on inter cluster traffic. Similarly, larger clusters farther from BS indicate more cluster members and spend more energy on intra-cluster traffic. As a result, it spends less energy for inter-cluster traffic hence no need of spending more energy for inter cluster routing.

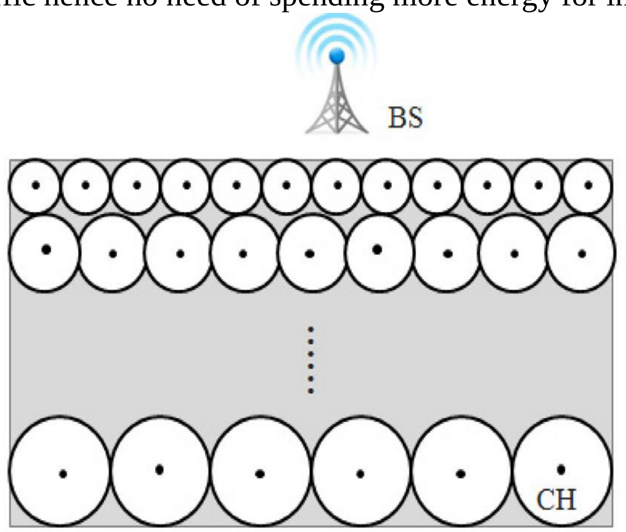

Figure 2. 6 Architecture of unequal clustering in WSN.[13]

The first algorithm proposed utilizing unequal cluster size is an unequal cluster size (UCS) model [12], which forms unequal clusters for easing the overburdened cluster heads, and ensuring better balancing of energy dissipation among nodes. The work considered heterogeneous network and the deterministic deployment of cluster heads at pre-computed locations for controlling the cluster size. The sensing field is assumed to be circular and is divided into two concentric circles, called layers. In order to simplify the theoretical analysis, the authors approximate the sensing field as pie shaped field with a multiple-layer network. It is assumed that all clusters in one layer have the same size and shape, but the sizes and shapes of clusters in the two layers are different. The position of a CH within the cluster boundaries determines the overall energy consumption of nodes that belong to the cluster. To keep the total energy dissipation within the cluster as small as possible, every CH should be positioned at the center of the cluster. CHs are deterministically deployed in the network and are assumed to be super nodes which are much more expensive than MNs (member nodes). By varying the radius of the first layer around the BS, while assuming a constant number of clusters in every layer, the area covered by clusters in each layer can be changed, and accordingly the number of nodes contained in a particular cluster can be changed. Data transmission is done through multiple hops, where every CH chooses to forward its data to the closest CH in the direction of the BS.

Unequal clustering routing (UCR) protocol groups the nodes into clusters of unequal size for mitigating the hot-spot problem in wireless sensor networks [48]. UCR does not require special node capabilities, such as location-awareness or heterogeneity. UCR consists of two parts, one is an Energy-Efficient Unequal Clustering (EEUC) algorithm for topology management, and the other is a greedy geographic and energy-aware routing protocol for inter-cluster communication. At the network deployment stage, the base station broadcasts a beacon signal to all sensors at a fixed power level. Therefore each sensor node can compute the approximate distance to the base station based on the received signal strength.

In Improved Leach [42] the network is partitioned unequally. Initially the BS broadcasts Hello message to all nodes at a certain power level and each node can compute the approximate distance to the base station based on the received signal strength, then send a report message (initial energy and location) to base station. Base station forms matrices of the distance and the residual energy, then broadcasts the distance matrix to each node in the network, correspond with node ID. They use single hop routing method. The CH selection is done based on the round robin algorithm. When the node is elected as cluster head, it broadcasts a message to inform its adjacent nodes, and adjacent nodes make a decision to join the cluster for this round, according distance, then clusters are formed.

COCA [43] is also an unequal clustering algorithm for WSN. It divides the entire region into units. The node with highest energy among its neighbor will get elected as CH and there is a possibility of more than one cluster in a unit. The clusters are larger in size when it is away from the BS and gradually the size reduces when it comes close to the BS.

CHAPTER THREE: RELATED WORKS

To accomplish the objectives of our thesis, an evaluation of work done by other authors related to our objectives was studied, Following papers in particular were considered.

Hybrid Energy Efficient Distributed (HEED) [5] is a distributed clustering algorithm in which two parameters are used to determine the eligibility of a node to become a CH. Since prolonging the network lifetime is the main goal, residual energy is used as the first parameter, which allows nodes with higher residual energy to become CH, thus balancing the overall energy of the network. The second factor intra communication cost, which is cluster density, it allows a node to join a CH with the least number of nodes so as to reduce the load of the intra-cluster traffic on the CH. However, HEED does not make any consideration about the hotspot problem.

EECS [6], present a novel, autonomous, energy efficient and load balanced clustering scheme applied for periodical data gathering applications. EECS produces uniform distribution of cluster heads across the network through localized communication with little overhead. It elects cluster heads with more residual energy in an autonomous manner through local radio communication with no iteration while achieving good cluster head distribution. Each HEAD node broadcasts the HEAD ADV_MSG across the network, while the nodes receive all the HEAD ADV_MSGs and decide which cluster to join by considering two distance factors distance from the node to the CH and distance from the CH to the BS. But EECS adopts the single-hop model.

Energy-Efficient Unequal Clustering (EEUC) algorithm [7], is a clustering and distributed competitive algorithm. It is proposed for making the cluster unequal based on distance based competitive range. This makes EEUC approach for the purpose of balancing energy consumption among CHs and solving the hot spot problem. Basically EEUC is divided in to two phases, set-up and a steady-state phase.

a. Set-up Phase

For the information collection process, the base station broadcasts a “hello” message to all nodes at a certain power level. Then each nodes can compute the approximate distance to the base station based on the received signal strength.

- **CH Selection Phase**

Initially, in the CH selection phase, each node generates a random number, and only the node whose number is greater than a threshold will be activated for CH election by broadcasting compete message within a competition radius which is determined by its distance to the BS. The competition radius of node *si* is given by:

$$Si.Rcomp = \left[1 - c\,\frac{dmax - d(si,BS)}{dmax - dmin}\right] R^0 comp \qquad (3.1)$$

Where R^0comp is the maximum competition radius which is predefined, *dmax* and *dmin* denote the maximum and minimum distance between sensor nodes and the BS, *d*(*si*, *BS*) is the distance between node *si* and the BS, *c* is a constant coefficient between 0 and 1. According to Equation (3.1), the node's competition range decreases as its distance to the BS decreasing. Accordingly clusters closer to the BS have smaller cluster sizes, thus they will consume lower energy in the intra-cluster data processing, and can preserve more energy for the inter-cluster relay traffic. If a sensor node decides to participate to the competition, a certain number of nodes participant to be CHs according to the predefined Threshold (T). Each node picks a random value and compare with the threshold (T), then if the value is lower than the threshold value the node will be a Tentative CH. Then, tentative CHs in local regions compete in order to become a real CH.

After tentative CH nodes exchange with each other the message COMPETE-HEAD-MSG which includes (id, Rcomp, RE), where Rcomp represents the competition radius and RE is Residual energy, then each Tentative CH node competes with other Tentative CH nodes which located within its competition radius and the final CH will be the node with highest residual energy. Then FINAL-CH-MESSAGE send out to inform other nodes for cluster formation.

- **Cluster formation Phase**

After cluster heads have been selected each cluster head broadcasts an advertisement message across the network area. Each node joins its closest cluster head with the largest received signal strength and then informs the cluster head by sending a join cluster message. Based on the number of nodes in the cluster, the CH creates a TDMA schedule and inform member nodes when they can send their data.

b. Steady state phase

Once the clusters are created and the TDMA schedule is established, data transmission can begin. Assuming nodes always have data to send, they send it as per their allocated transmission time to the CH. When all the data has been received, the CH node performs signal processing functions to compress the data into a single signal. The cluster-head must keep its receiver on to receive all the data from the nodes in the cluster. Once the cluster-head receives all the data, it can operate on the data and then the resultant data are sent from the cluster-head to the base station. During the relaying process threshold value is considered. If a node distance to the BS is less than the threshold value it will transmit the data directly, otherwise it should find a relay node to forward its data. Moreover the CHs which serves as a relay node uses energy aware multi-hop routing based communication.

Multihop routing protocol with unequal clustering for wireless sensor networks (MRPUC) [11] is a distributed approach aims to equalize the energy consumption in all nodes for hot spot problem. It operates in rounds and has 3 phases: Cluster setup, inter-cluster Multi hop routing and data transmission. In the Cluster set-up phase BS broadcasts ADV message at a certain power level, and each node compute its approximate distance according to the RSSI. MRPUC selects CH with more residual energy and the regular nodes joins the cluster as cluster members in which the CH contains maximum residual energy and are closer to them. In inter-cluster Multi-hop routing each CH selects its neighbor node based on its relay energy consumption and residual energy; and the relay node with the minimum cost among the neighbor clusters will be chosen. Finally data transmission phase will take place; here each regular node turns off the radio until its allocated transmission time, and then sends the sensing data to the cluster head during its time. The cluster head keeps its receiver on to receive the data from the nodes in the cluster. After all the data has been received, the cluster head aggregates data packets into a single packet and sends data to the relay node which forwards the received packet toward BS. Their work ensures the minimum energy consumption in relay process.

The authors' proposed fuzzy energy-aware unequal clustering algorithm (EAUCF) to make further improvement in maximizing the lifetime of the WSN.[44] EAUCF is a distributed competitive algorithm. Unlike EEUC, the Cluster radius of each tentative CH is calculated using distance to Base station and residual energy. As the Cluster radius of the tentative CH decreases its battery power decreases. To achieve their objective they use Fuzzy inference technique called the

Mamdani method, which is one of the most frequently used methods. After the determination of the Cluster radius Cluster Heads will be selected based on the residual energy. Once the cluster head is elected, nodes join with the cluster head nearest to them.

An energy efficient varying sized clustering algorithm (EEVSCA) and routing protocol are introduced for non-uniform node distributed wireless sensor network system [45]. EEVSCA helps for the construction of clusters of varying size. The unequal competition radius is used for the construction of varying sized clusters and is calculated using the distance to the base station and residual energy of the node. It elects cluster heads based on the ratio between residual energy of the node and maximum initial energy. For the relaying process each CH choose node with higher energy as their next hop. But during the cluster formation phase each nodes compare the value of distance to CH, from where the Head_Msg is received. Then select the CH which is located nearest to them.

[46] Fuzzy Logic Cluster Formation Protocol (FLCFP), which uses Fuzzy Logic Inference System (FIS) in the cluster formation process. They use multiple parameters to form the cluster and reduces energy consumption using the Fuzzy Logic approach that uses the energy- level of the CH, distance between the BS and the CH, and distance between the CH and the node as parameters. For cluster formation, each node applies the three descriptors for each CH using the Mamdani Fuzzy Inference System and joins the CH that has the maximum chance value to form the cluster. They compared their work with LEACH and state that their approach extends the network lifetime significantly. But the algorithm is implemented without giving consideration for hot spot problem.

In BCEE [47], CH is selected by using K-means algorithm. To form clusters, BCEE does not require position of each node but uses the idea of receive signal strength indicator (RSSI). To route the data to the sink, the techniques of ant colony optimization is used to establish an optimal multi-hop route from CH to the sink using rational and hop-selecting technique.

Authors in [48] present a novel energy efficient cluster formation algorithm based on a multi-criterion optimization technique. Their work is closely related with EECS but is inspired by preference function modeling which has been used to find an optimal path based on multiple user constraints. The Authors consider multiple criteria such as distance of node to the CH, distance between CH and sink and residual energy. A decision matrix is built to find the optimal choice for a given parameters using weigh based approach. The maximum weight indicates the best choice of the CH. But their work still focuses on the single hop clustering.

An unequal clustering algorithm has been developed for WSN based on fuzzy logic called FBUC [49]. To compute the cluster radius they consider residual energy, distance to the base station and node degree. After the competition radius for each tentative cluster head is computed, the final cluster head is elected based on the highest residual energy. The members join the cluster head based on the distance and cluster head degree to utilize the energy efficiently and to extend the network lifetime. Here, considering the node degree parameter has an influence on the efficiency of FBUC. Despite its effectiveness there is a situation where the performance of the protocol degrades. Thus, it ignores the residual energy of CHs while assigning the sensor nodes to their respective CHs. This may cause energy inefficiency of the WSN and also the performance the network will degrade.

Summary

Author	**Title**	**Approach used for cluster formation**	**Drawbacks**
Mao YE, Chengfa LI, Guihai Chen	An Energy Efficient Clustering Scheme [6]	-Use single-hop communication -Use distance-based method to balance the load among the cluster heads. -Nodes join clusters taking into intra-cluster communication cost and cluster heads’ cost of communication to the BS.	-Nodes join only based on RSSI
Chengfa Li, Mao Ye, Jie Wu	Energy-Efficient Unequal Clustering [7]	-Solves hotspot problem with unequally clustering. Choose CHs with more residual energy. -Nodes joins its closest cluster head with the largest Received Signal Strength.	-Nodes join to their respective CH based on only RSSI.

Bencan Gong, Layuan Li, Shaorong Wang	Multihop Routing Protocol with Unequal Clustering [11]	-it selects the nodes with more residual energy as cluster heads -Nodes join to CH based on the remaining energy of CH and node distance to CH.	-If there is a tie b/n CHs, nodes choose CH's randomly. -They don't consider the inter-cluster communication cost.
Hakan Bagci, Adnan Yazici	An energy aware fuzzy approach to unequal clustering [44]	-A fuzzy logic approach(mamdani) used for cluster radius computation.(Residual energy and distance to BS) -Cluster Heads will be selected based on the residual energy, and nodes join with the cluster head nearest to them.	Nodes join only based on RSSI
Rogaia Mhemed, Nauman Aslam	An Energy Efficient Fuzzy Logic Cluster Formation Protocol [46]	-Use fuzzy approach - Considers Energy- level of the CH, distance between the BS and the CH, distance between the CH and the node when node joins its cluster.	-They don't consider the hotspot problem. -Single hop communication
R. Logambigai, A. Kannan	Fuzzy logic based unequal clustering [49]	-Compute radius based on RE, distance to BS, and node degree -Members join the cluster head based on distance and cluster head degree	They don't consider energy of CH when node joins to its CH.

Table 3.1 Summary of related works

Despite the works explained earlier, our proposed approach uses cost function based cluster formation algorithm when a node joins its CH. Also using both multi-hop routing and unequal clustering scheme helps sensor nodes dissipate their energy at a much more balanced rate.

CHAPTER FOUR: DESIGN OF THE PROPOSED WORK

4.1. Overview

Nodes which are close to the Base station generally troubled with a heavy relay traffic and may deplete their energy rapidly, accordingly, the network will become partitioned. To overcome this problem unequal cluster-based routing protocols have been proposed taking into consider the nearest and further nodes having different cluster size based on their transmission distance. According to a random probability or its residual energy level, each node determines whether it can become a CH candidate node of its layer to participate in the election of CHs. Then, candidate nodes self-configure themselves as CHs through a series of competition process and broadcast advertisements to release the CH information, so that the nodes select the nearest one as its own CH via the received signal strength of advertisement message.

One of the well-known protocols which is designed for this purpose is EEUC (Energy Efficient unequal clustering). The protocol divides the network into unequal clusters as shown in Eq(3.1). To partition the network into unequal clusters makes EEUC energy efficient routing protocol compared to the equal cluster based routing protocols. However, still it considers a node always chooses a CH that is closest to it. Hence, to perform further improvement we consider multiple parameters for cluster formation as described in the following section:

In this work, the following assumptions are made:

- ✓ Nodes and BS are static after deployment.
- ✓ A node transmits its data directly to its respective cluster head within a particular cluster.
- ✓ Cluster heads use the multi-hop routing scheme to send their data to the next cluster head and then to the BS.
- ✓ There is a base station (i.e., data sink) located far from the sensing field.
- ✓ The sensor network used in our system is homogeneous, i.e., the sensor nodes are similar in terms of sensing and computation capabilities.
- ✓ All sensor nodes have the same energy at the starting point.
- ✓ Nodes needn’t to be equipped with GPS-capable unit to get precise location information.

4.2. Network model for the proposed work

The proposed algorithm is EEUC-based clustering algorithm. We adopt the same process of unequal clustering and Cluster head election process but differ in the node association operations between cluster heads and the rest of the nodes. The operation of the proposed work is divided into rounds, and each round consists of the Setup Phase and the Steady State Phase. Let's further explain in detail the operations for each phase as below.

4.2.1. Set-up Phase

At the beginning of this phase nodes will be deployed in the network and the information collection process is performed. The base station broadcasts HELLO message which contains also the hop count value to all the nodes in the network at a certain power level. Nodes will receive the message and record the values in their information table.

4.2.1.1 Cluster Head Selection Phase

In this phase CH selection algorithm is same as in [7] which is a distributed cluster heads competitive algorithm. Selection is based on the residual energy as described below:

```
R_comp - Cluster Radius

RE - Residual Energy

SCH - Set of CH

1.  Input node N
2.  Node N choose a random number between 0 and 1
3.  IF(random number<T(n))
4.      Node  become Tentative Cluster-head
5.      Node   send   message(Id,R_comp,RE)   within
    cluster radius calculated as eq(3.1)
6.     END IF
7.     Ni receives message from Nj
8.      IF d(Ni,Nj) < Ni.R_comp OR d(Ni,Nj)< Nj.R_comp
9.       then
10.          Add Nj to Ni.SCH
11.      END IF
12.  Tentative CH maintains set SCH of its adjacent
    Tentative CH
13.      IF Ni.RE > Nj.RE ,  ∀ Nj ϵ Ni.sCH
14.         Node  become  CH  and  send  Final  Head
    message to get member nodes
15.          END IF
```

Figure 4. 1 Pseudo-code for CH Selection [7]

The above pseudocode describes how the cluster heads become selected. From 1-4 if the random values become less than the threshold value nodes become Tentative_CH. In Line 5 Tentative_CH will broadcast Compete_Head_Message which contains energy and competition radius. After the construction of S_{CH} in the next lines each CHs checks its set of CH and competes based on the residual energy of nodes. Once *Ni* finds that its residual energy is more than all the nodes in its *SCH*, it will win the competition and broadcast a FINAL HEAD MSG. (Line 12 -14).

4.2.1.2. Cluster formation phase

The next phase is cluster formation. Once cluster heads are selected in a specific round, the other nodes would associate one of the existing CHs. Each cluster head broadcasts an advertisement message (ADV) with in the communication radius to let the other nodes know about their status. The Advertisement message includes CH_ID, residual energy, and hop count to BS. The message is send using non-persistent CSMA-MAC protocol to invite the other nodes to join its cluster. Nodes record this information in their neighbor information table for each CH from which they receive.

Nodes (non-CH nodes) which receive the advertisement message determines to which cluster it belongs by choosing the CH based on highest residual energy, minimum Hop count to BS and highest RSSI. Then to decide which cluster it belongs, they will compute the cost for each CH and compare the cost value then choose a CH with maximum cost value.

In our proposed algorithm cost of joining the CH, N_j can be calculated as follows:

$$\text{Cost}(Ni, Nj) = \quad (RE + RSSI)/N\_HC \qquad (4.1)$$

To further explain the cost formula: let $\mathbf{N_i}$ is the node which will become a member of the cluster and $\mathbf{N_j}$ is the CH node. RE is the residual energy of the CH node which can be calculated as follows:

$$Residual\ energy = \quad E\_initial - E\_consumed$$

The energy consumed can be computed based on eq (4.1) and eq(4.2) according to the energy model.

RSSI is the signal indicator: It is known that highest RSSI (larger signal strength) indicates the node is with the nearest distance from the CH.

N_{HC}_is the number of hops from a CH to BS in which nodes can determine the hop count values from the BS as mentioned in the beginning of the set-up phase.

Equation (4.1) shows the principle to select the CH. Finally the node with high cost value will be selected. Instead of using only the single parameter i.e RSSI, choosing CH with concern of multiple parameters helps the CH to expend its energy in a balanced manner.

After each node has decided to which cluster it belongs, it must inform the CH node that it will be a member of the cluster. To do so each node transmits a join request message (Join_REQ) back to the chosen CH using non-persistent CSMA-MAC protocol. As soon as the CH receives the join request packet it will add the node to its member list.

Subsequently the CH node sets up a TDMA (Time Division Multiple Access) schedule and broadcasts this schedule to the member nodes in the cluster. Each node is assigned a unique time slot in which it can transmit its data to the CH and also ensures there are no collisions among the transmitted data. After the TDMA schedule is known by all nodes in the cluster, the set-up phase is completed and steady-state phase will begin.

4.2.2. Steady state Phase

Steady state phase of the proposed work is similar to the EEUC protocol. The information sensed by the sensor nodes is transmitted to the sink through the CH. Inter-cluster data transmission is based on multi-hop communication. In order to transmit the sensed data to the BS nodes will select a relay node. The cluster head in the relay mode gathers the data from its cluster members, compresses and forwards the compressed data to the base station. The relay nodes are selected based on the highest residual energy.

```
// CH Broadcast message

IF(Node == CH)
Broadcast HEAD_Adv messages (id,RE,HC);
Wait for JOIN_CLUSTER_MSG
   ENDIF
IF (node == non-CH) then
   Receive HEAD_ADVMSGs;
Find the cost for each CH based on:
```

$$\text{Cost}\ (Ni, Nj) = \frac{RE+RSSI}{N\_HC}$$

```
Choose CH with high cost function;
SEND JOIN_CLUSTER_MSG;
  ELSE IF
    Each CH_Cost value is equal then
     Choose CH with the highest RSSI;
 END IF
   END IF
```

Figure 4. 2. Pseudocode for the proposed cluster formation

Generally based on the above scenario the proposed cluster formation strategy is as follows:

- ✓ A new round begins and a cluster head selection algorithm runs.
- ✓ The chosen out cluster heads then broadcast their advertisements including the information of hop count and the remaining energy.
- ✓ Each node collects all received advertisements and calculates the cost function and choose the CH with high cost value.
- ✓ Find out the appropriate CH and it is the head that the cluster member belongs to.
- ✓ Send join request message and become a member.
- ✓ Each members will be assigned TDMA and steady state takes place.

4.3. Energy Model for wireless sensor nodes

The energy model used for the radio equipment energy dissipation is as proposed by [7], [13]. The transmitter disperses energy to run the radio equipment and the power amplifier. The receiver also dissipates some energy to run the radio gadgets. Both the free space (d^2 power loss) and the multi-path fading (d^4 power loss) channel models are utilized, depending upon the distance between the transmitter and receiver. The energy spent for transmission of k-bit packet over distance *d* is:

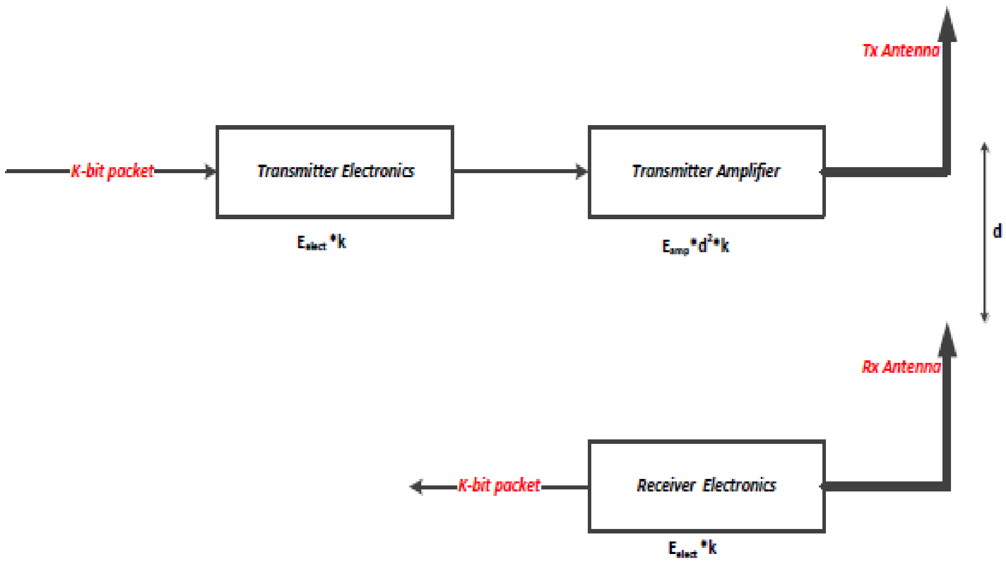

Figure 4. 3. Wireless sensor node energy model [48]

Depending on the distance d between transmitter and receiver, the required transmitting and receiving energy for k-bit packet can be expressed as follow. Eq. (4.3) for transmitting energy, whereas Eq. (4.4) for receiving. Both free space and multi-path fading channel models are used in this energy model.

$$ETx\,(k,d) = KEelect + Eamp(k,d)$$

$$= \begin{cases} KEelect + Kefsd^2, & d \leq d0 \\ KEelect + KEmpd^4, & d > d0 \end{cases} \qquad (4.2)$$

Where ETx is energy dissipated per bit at transmitter and d is distance for transmitting k-bit packet.

$$E_{Rx}(\mathrm{k}) = Eelec * k \qquad (4.3)$$

E_{elec} represents energy consumed to transmit or receive K bit message, K is number of transmitted data bits and E_{Rx} is energy dissipated per bit at receiver.

If the distance between transmitter and receiver is larger than crossover distance do, multi-hop model is employed. Otherwise, free space model is adopted to measure the energy dissipation. Here do represents distance threshold value and it is calculated as equation.

$$do = \sqrt{\frac{Efs}{Emp}} \qquad (4.4)$$

E_{amp} = amplification factor, e_{fs} =free space coefficient, e_{mp} = multi path coefficient

CHAPTER FIVE: SIMULATION AND PERFORMANCE EVALUATION

5.1. Overview

In this chapter, discussion about the simulation procedure and the simulation results is presented and we compare the performance of our proposed work with the original EEUC through simulation using OMNET++ based Castalia simulator.

5.1.1. Simulation Tools

There are many simulation tools provided for the researchers to evaluate their work. Some of the simulators are: MATLAB, OPNET, NS2, NS3, and OMNeT++. [50] [51]

Among those we have selected OMNeT++ simulator with Castalia framework for the following reasons. First, Castalia supports networks of low-power embedded devices such as WSNs. Second, it can be utilized to test the distributed algorithms and protocols in realistic radio models and wireless channel. Third, Castalia embraces additional features such as: several popular routing protocols and MAC protocols, a model for temporal variation of path loss, and RSSI calculation, which can provide more convincing and accurate simulation results [50]. And also OMNeT++ provides a powerful GUI and supports high scalability. This strong GUI also makes the tracing and debugging much easier than using other simulators. In addition, OMNeT++ can simulate power consumption problems in WSNs.

OMNeT: is powerful object oriented discrete event network simulator used in various problem domains such as modeling of wired and wireless communication. It is more generic than ns-2. The architecture of OMNeT++ is modular and the platform is assumed to be extended using a rich library. Likewise ns-2, there is a framework to extend OMNeT++ specifically for WSN. It is called Castalia.

OMNeT ++ is written in C++ and has well documented features of graphical environment that simplifies development and debugging. Additionally, a wide community of contributors supports OMNeT++ by continuously providing updates and new frameworks. Its model consists of C++ files with .h/.cc suffix, and also .ned and configuration file that defines the simulation scenario (.ini).

- ✓ **.ned Language:**

NED language stands for network description language with which the structure of the model that is going to be simulated is defined. NED is used to define simple modules and assemble them into compound modules. It is also used to define gates and channels for simple modules and compound modules through which those modules communicate. Simple modules contain the algorithms and form the lowest level of module hierarchy. The user implements the simple modules in C++, using the Omnet++ simulation class library. Modules communicate by message passing which may be a complex data structure. Modules may send messages directly to their destination or through a series of gates and connections to other modules.

The messages can represent frames or packets in a computer network simulation. The local simulation time advances when the module receives messages from other modules or from the same module as self-messages which is the representation of timers in simulation world. These self-messages are used to schedule events to be executed by itself at a later time. Each of the modules has input and output interfaces called gates through which message passing between modules is achieved. Messages are sent out without-Gate and received through the in-Gate. Connections are created between the sub modules or between sub module and compound module depending on the requirement of the system or the topology.

- **Castalia**

Castalia is a simulator for WSN, body area networks (BAN) and generally networks of low-power embedded devices. It is based on the well-known Omnet++ platform. It can be used by researchers and developers who want to test their distributed algorithms in realistic wireless channel and radio models, with a realistic node behavior especially relating to access of the radio. Castalia can also be used to evaluate different platform characteristics for specific applications, since it is highly parametric, and can simulate a wide range of platforms [51].Castalia offers comprehensive models for simulating both the radio channel and the physical layer of the radio module. Castalia’s basic module structure is shown in the diagram below.

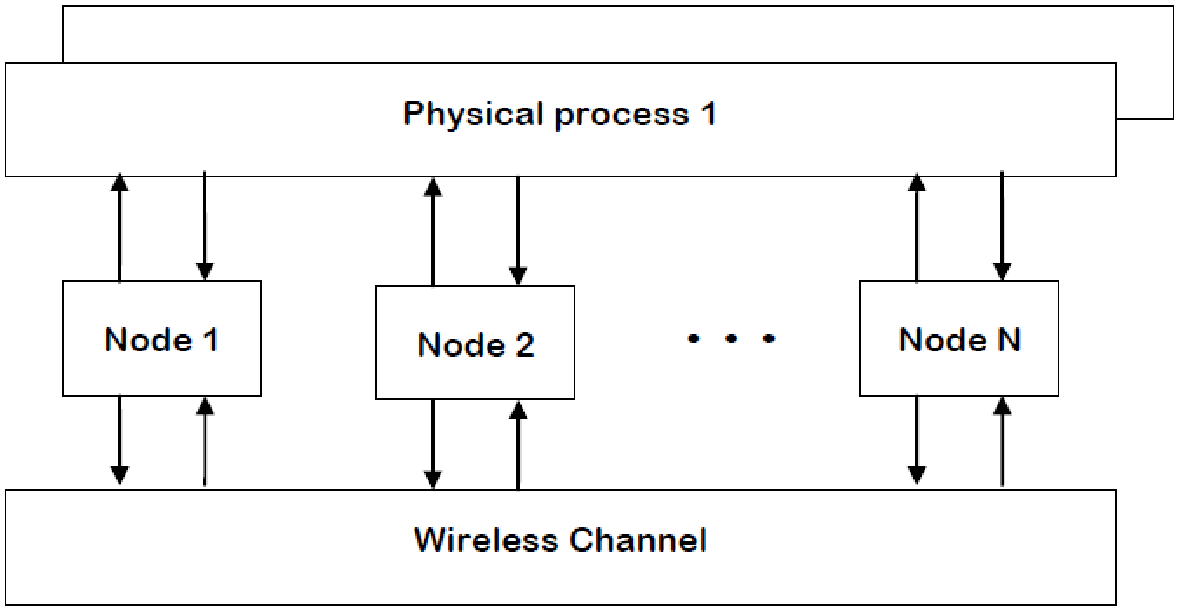

Figure 5.1 The modules and their connections in Castalia [51]

As shown in the above fig. the nodes do not connect to each other directly but through the wireless channel modules. The arrows signify message passing from one module to another. When a node has a packet to send this goes to the wireless channel which then decides which nodes should receive the packet. The nodes are also linked through the physical processes that they monitor. For every physical process there is one module which holds the "truth" on the quantity the physical process is representing. The nodes sample the physical process in space and time (by sending a message to the corresponding module) to get their sensor readings [51].There can be multiple physical processes, representing the multiple sensing devices (multiple sensing modalities) that a node has.

To evaluate the performance of our proposed protocol we used the OMNET++ based Castalia Simulator. The simulator allows us to observe and measure the performance of the proposed protocol under the given conditions. The latest version 3.3 of Castalia implemented is used by integrating on Omnet++ version 4.6 platform.

5.2. Simulation Setup and Assumption

5.2.1. Simulation Parameters

For the Simulation environment, the field size is chosen to be $100m^2$ with static sensor nodes scattered in the network area. The BS is located at (100,250) which is remotely located. The configuration of simulation parameters are shown in Table 5.1. For fair comparison, simulation parameters kept similar for EEUC and the proposed one.

Parameter	Value
Network Area	$100*100m^2$
Number of nodes	100
BS position	(100,250)
Initial Energy	1J
Transmitter Electronics (EelectTx)	50nJ/bit
Receiver Electronics (EelectRx)	50nJ/bit
E_{fs} (Energy consumed to transmit amplifier)	$10pJ/bit/m^2$
E_{DA}(Energy for Data Aggregation)	5nJ/bit/signal
Simulation time interval	100 sec
Packet length	4000bit

Table 5. 1 Simulation Parameters

5.3. Evaluation Metrics

To measure the performance of the proposed work, we used the following metrics.

- ✓ **Residual energy**- This is the total amount of energy left on the network over a certain number of rounds, in which, CHs collect data, aggregate and route it to the BS.
- ✓ **Network lifetime** - is defined as the duration from the beginning to the time when any or a given percentage of sensor nodes die.

  - Here, the network lifetime as first node death (FND) is considered.

We present the result using graph to compare our proposed work with the EEUC protocol.

5.4. Simulation Result and Evaluation

In this section the simulation result of the proposed work is analyzed and discussed. The performance of the proposed work is compared with the performance of EEUC. As mentioned before, two performance metrics i.e Residual energy and network lifetime are used to evaluate the performance of the proposed work.

5.4.1. Residual Energy

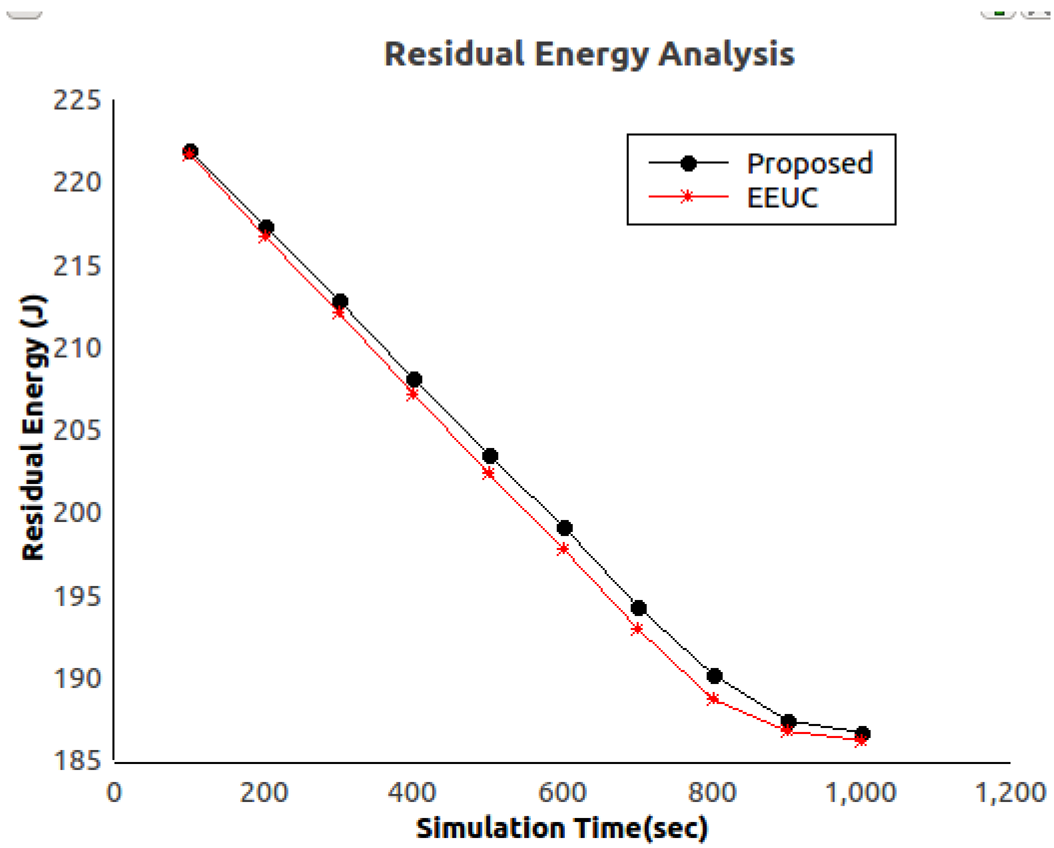

Figure 5. 2 Comparison of Energy Consumption

In order to see the difference between the two protocols, we vary the processing time. From the graph we can see that comparing with the existing protocol (EEUC), our proposed work has shown a good performance with regard to the Residual energy. Therefore we can conclude the proposed work has less energy consumption compare to EEUC.

5.4.2. Network lifetime

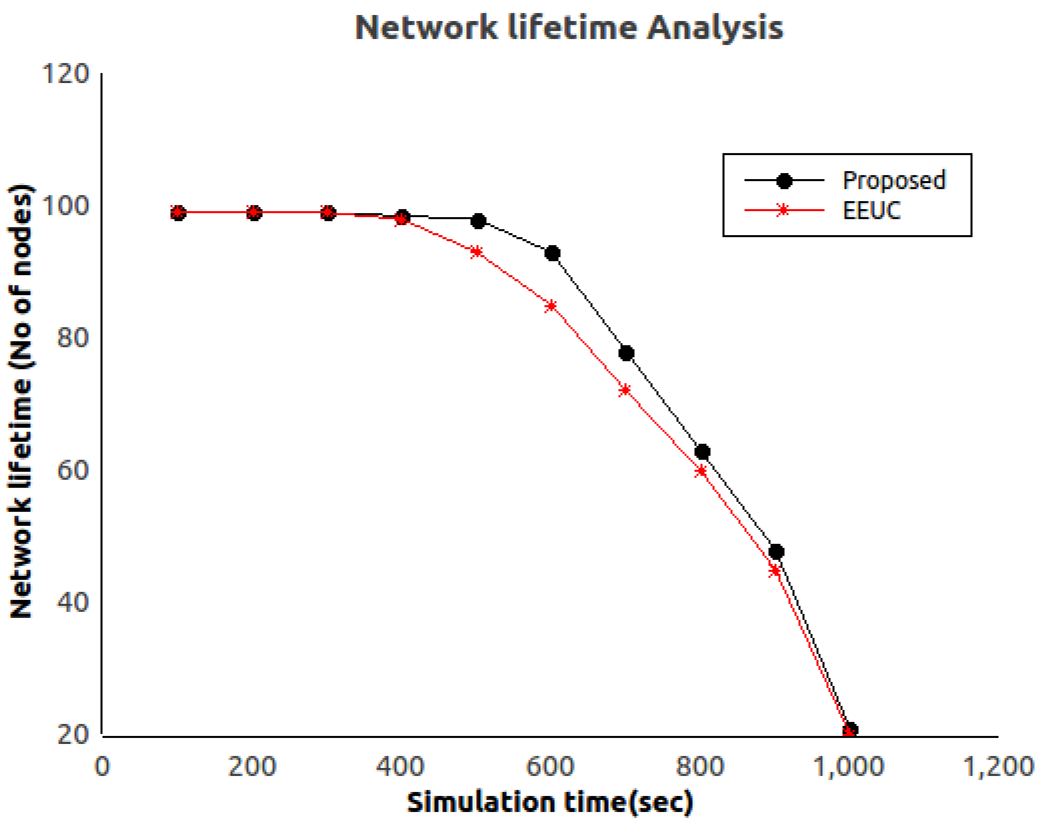

Figure 5.3. Comparison of Network life time

The above Fig shows the comparison of network lifetime between the proposed and EEUC protocol. To observe the difference the time duration until the first node dies is analyzed for both. Initially both perform in the same manner but after some rounds (when simulation time increase) the difference become feasible and it can be seen that the proposed one performs better than the EEUC protocol.

CHAPTER SIX: CONCLUSIONS AND FUTURE WORKS

Clustering is a promising and popular approach to organize sensor nodes into a hierarchical structure, reduce transmitting data to the base station by aggregation methods, and prolong the network lifetime. However, a heavy traffic load may cause the sudden death of nodes due to energy resource depletion in some network regions, called hot spots that lead to network service disruption. This problem is very critical, especially for data-gathering scenarios in which Cluster Heads (CHs) are responsible for collecting and forwarding sensed data to the base station. To overcome such problems unequal clustering has been introduced to distribute energy load uniformly among CHs. This is achieved by tuning the cluster size according to the CH conditions i.e CH near to the Base Station will handle less amount of nodes relative to further CHs based on their distance to BS. This helps nodes near to BS to save their energy for the inter-cluster communication.

In this paper, to mitigate the hot spot problem the network is partitioned unequally. Cluster radius of the CHs is adjusted based on the distance metric and Cost function based cluster formation algorithm is proposed, in which nodes select their respective CH based on the highest cost value. This is based on RSSI, Residual energy and CH to BS distance in terms of hop count. Simulation results demonstrate that the proposed work can balance the energy consumption and prolong the network lifetime.

Future Works

- The proposed work doesn’t take into account the isolated nodes, nodes which doesn’t receive any Advertisement message. So further improvement can be performed to let this nodes member of a cluster with less energy consumption.

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Appendix : EeucRouting.ned

```
package node.communication.routing.eeucRouting;


simple EeucRouting like node.communication.routing.iRouting
{
parameters:
        bool collectTraceInfo;
        int maxNetFrameSize = default (0);
        int netDataFrameOverhead = default (14);
        int netBufferSize = default (32);
        bool isSink = default (false);

        double percentage;
        double roundLength @unit(s);
        double slotLength;

        //routing layer packet sizes
        int advPacketSize = default (9); // Type + Source + Destination = 9 bytes
        int joinPacketSize = default (9);
        int tdmaPacketSize = default (150); // Type + Source + Destination + tdma = 150 bytes
        int dataPacketSize = default (9);

        //Parameters used to power control.
        xml powersConfig;
        //EEUC STUFF
        double DMax = default (60);
        double DMin = default (5);
        double C = default(0.3);
        double RZeroComp = default(30);
        double K = default(2);
```

```
        double TD_Max = default(35);

gates:
        output toCommunicationModule;
        output toMacModule;
        input fromCommunicationModule;
        input fromMacModule;
        input fromCommModuleResourceMgr;
}
```

Appendix : eeuc.ini

```
[General]
## Network         #####
#######################
include ../Parameters/Castalia.ini
include ../Parameters/MAC/CSMA.ini
sim-time-limit = 100s
SN.field_x = 100
SN.field_y = 100
SN.numNodes = 100

SN.deployment = "[1..99]->uniform"
 #Base station position
SN.node[0].xCoor = 100
SN.node[0].yCoor = 250

#Node deployment
SN.node[1..49].xCoor = uniform (120,1400,0)
SN.node[1..49].yCoor = 15

SN.node[50..99].xCoor = uniform(120,1400,0)
SN.node[50..99].yCoor = 60

#Resource manager parameters
SN.node[1..99].ResourceManager.initialEnergy = 40
SN.node[*].Communication.Radio.mode = "normal"



## Traces          #####
#######################
```

```
SN.wirelessChannel.collectTraceInfo = false
SN.node[*].Communication.Radio.collectTraceInfo = false
SN.node[*].Communication.MAC.collectTraceInfo = false
SN.node[*].Communication.Routing.collectTraceInfo = true
SN.node[*].Application.collectTraceInfo = false
SN.node[*].SensorManager.collectTraceInfo = false
SN.node[*].ResourceManager.collectTraceInfo = false
## MAC              #####
########################
#-----CSMA-CA-----#
## Routing         #####
SN.node[*].Communication.RoutingProtocolName = "EeucRouting"
SN.node[*].Communication.Routing.netBufferSize = 1000
SN.node[0].Communication.Routing.isSink = true
SN.node[*].Communication.Routing.slotLength = 0.2
SN.node[*].Communication.Routing.roundLength = 30s
SN.node[*].Communication.Routing.percentage = 0.05
SN.node[*].Communication.Routing.powersConfig = xmldoc("powersConfig.xml")

## Application      #####
########################
SN.node[*].Application.packet_rate = 1
SN.node[*].Application.constantDataPayload = 2000

## Wireless Channel #####
#########################
SN.wirelessChannel.onlyStaticNodes = true
SN.wirelessChannel.sigma = 0
SN.wirelessChannel.bidirectionalSigma = 0
SN.wirelessChannel.pathLossExponent = 2.0 # Free Space
```

```
## Radio          #####
########################
SN.node[*].Communication.Radio.RadioParametersFile = "../Parameters/Radio/CC2420.txt"
#SN.node[*].Communication.Radio.TxOutputPower = "-10dBm"
```