Energy and QoS Aware Routing for WSNs

Kingston University London

Ahora Mehdi Toussi

Faculty of Science, Engineering and Computing

Kingston University

A thesis submitted for the degree of

Doctor of Philosophy (PhD)

January 2017

ABSTRACT

The advancement of Wireless Sensor Networks (WSNs), necessitate optimisation of their algorithms and their performance. More specifically, network coverage and preservation of nodes energy to increase the network's lifetime are among the core objectives of routing and clustering methods.

This thesis constitutes of a literature review of WSNs' routing protocols in a categorised manner followed by proposing an energy efficient and QoS aware paradigm (PUSH) for flat network that outperform other similar paradigms in terms of collective delay and energy dissipation within the network. We have proposed a new clustering model, known as Energy Aware and Address Free Clustering (EAAFC) in which, no global addressing is required. In other words, nodes are assigned with an ID, based on local information. EAAFC clusters nodes with minimum number of cluster heads which in turn results in less in network energy consumption. Cluster heads are then re-elected frequently based on nodes' energy and distribution. EAAFC does not require geographical location of nodes nor time synchronisation. We compare performance results of our proposed clustering model, against two of well received algorithms, namely LEACH and EECF to demonstrate the advantages of EAAFC.

In chapters 1 and 2, the major routing protocols have been studied over the years of research and strength and weaknesses of each protocol has been scrutinised. Further, objectives, motivation and methodology of the research are discussed. In chapter 3 and 4 the proposed routing paradigm for flat networks (PUSH) as well as the clustering protocol, EAAFC, and its advantages over other protocols is discussed in depth. Several scenarios based on similar well-known routing protocols have been implemented and tested to use as comparison and to evaluate the performance of paradigm and protocol presented in this thesis. These scenarios have been implemented in the simulator environment. The simulation results confirm the theoretic evaluation and support that PUSH and EAAFC outperforms the other protocols in compared criteria as they can achieve less latency, better coverage, preserve more energy and achieve more equally distributed energy dissipation across the network which result in longer network life time and full functionality.

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Professor Christos Politis, for his guidance, help and support during my PhD research. His advice, motivation and guidance on areas not only limited to research was most valuable to fulfil the challenging requirements of a PhD student journey. Importantly, his passion towards research was hugely encouraging and provided the proper platform for progress. I would also like to thank my family who have always provided me with proper guidance and moral support, and I would like to acknowledge their contributions towards all my achievements. Finally, many thanks to all the staff at Kingston University for all the trouble you have gone through to support PhD students like myself. The next names that spring to mind Jackie Deacon, Rosalind Percival, Bee Tang, Anne Williams and Jan Francis.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

GLOSSARY OF ACRONYMS

ACQUIRE	Active Query forwarding in sensor networks
AIO	All in One
AODV	Ad-hoc On-demand Distance Vector
APTEEN	Adaptive Threshold Sensitive Energy Efficient Sensor Network
C1WSNs	Category 1 Wireless Sensor Networks
C2WSNs	Category 2 Wireless Sensor Networks
CBN	Chemical Biological and Nuclear
CH	Cluster Head
DSDV	Destination Sequenced Distance Vector
DSR	Dynamic Source Routing
EAAFC	Energy Aware and Address Free Clustering
EAP	Energy Aware Protocol
ECMP	Energy Constrained Multipath routing
EECF	Energy Efficient Cluster Formation
EECS	Energy Efficient Clustering Scheme
EEQR	Energy Efficient and QoS aware Routing
ELCH	Extending Lifetime of Cluster Head
ES	Environmental Sensing
FEAR	Fuzz Energy Aware tree based Routing
HEED	Hybrid Energy Efficient Distributed Clustering Approach
H-Spread	Hybrid Spread
IEEE	Institute of Electrical and Electronics Engineers
LEACH	Low Energy Adaptive Clustering Hierarchy
LQSR	Link Quality Source Routing
MAC	Medium Access Control
MANET	Mobile Ad-hoc Network
MCF	Minimum Cost Forwarding
MCMP	Multi-Constrained Multi-Path routing
MMSPEED	Multi-path and Multi-Speed Routing Protocol
NS2	Network Simulator Version 2
PCPO	Path Constrained Path Optimisation
PEACH	Power Efficient and Adaptive Clustering Hierarchy
PRODUCE	Probability Driven Unequal Clustering Mechanism for Wireless Sensor Networks
QoS	Quality of Service
RF	Radio Frequency

SAR	Sequential Assignment Routing
SBD	Source Based Directing
SEER	Simple Energy Efficiency Routing
SNGF	Stateless Geographic Nondeterministic Forwarding
SNR	Signal to Noise Ratio
SPEED	Stateless Protocol for Real-Time Communication in Sensor Networks
SPIN	Sensor Protocols for Information via Negotiation
SQL	Structured Query Language
TDMA	Time Division Multiple Access
TEEN	Threshold sensitive Energy Efficient Sensor Network
WMSN	Wireless Multimedia Sensor Networks
WSN	Wireless Sensor Networks
ZCS	Zone Cooperation at Sensors

CHAPTER 1

1 INTRODUCTION

1.1 RESEARCH BACKGROUND

1.1.1 ROUTING IN WIRELESS SENSOR NETWORKS (WSN)

Wireless Sensor Networks (WSNs) comprise of small nodes that help to detect and collect desired information from the environment in which they are implemented, aggregate such information, process them and provide the results to enquirer. Over years several routings, power execution, and data circulation protocols were built for WSNs where energy perception is an important plan but they were difficult or impractical to implement. A few years ago, an accelerated research indicated the possibility of interaction between sensors used in data collection and transforming, and in the allocation and administration, the sensing movement was managed. Routing in WSNs is asserting because the fundamental components determine these systems from other wireless networks, such as mobile ad hoc systems or cellular networks. Initially, due to numerous sensor nodes, it did not seem feasible to form a universal design that could address the formation of numerous sensor nodes. This was because of the upward ID resources being large. Hence, conventional IP-oriented protocols may not be utilised for WSNs (Al-Karaki, 2004).

In several WSN operations, the formation of sensor nodes can be done in an ad-hoc style. Usually, it is highly complex and hopeless to modify or regenerate batteries for the sensor nodes. The conventional routing protocols have many drawbacks on WSNs, one of them owes to the energy-strained quality of the systems (Zheng & Jamalipour, 2009). For instance, flooding is a method wherein, a node transforms data and rule folders that have been acquired from the remaining nodes in the system. This course re-runs and the expected target node is attained. It is noteworthy that this method does not endure into consideration the energy pressure enforced by WSNs.

The outcome reveals that whenever data routing is applied in WSNs, various difficulties such as breakdown and overlapping occurs (Villalba, et al., 2009) (Akyildiz, et al., 2002). Akyildiz and Vuran have mentioned that whenever a node acquires a packet, it broadcasts this packet to all neighbours in flooding (Akyildiz & Vuran, 2010). This continues until the entire network nodes have received the packet. As an outcome, a packet can then be flooded throughout the complete network. The flooding can be managed by restricting the rebroadcast until the packet meets the destination, or the maximum number of hops is met.

Flooding is a reactive protocol in which a node does not require any neighbourhood data, therefore, one can conclude simplicity is among the advantages of flooding protocol. furthermore, this protocol make the need for an expensive topology maintenance, and complex algorithms of route discovery redundant. However, flooding has various deficiencies such as implosion, resource blindness and overlap. This protocol does not limit nodes from broadcasting the similar packet to the similar destination in implosion. An essential resource in wireless sensor networks is the feasible energy which must be consumed efficiently by protocols of the network. This is referred to as “resource blindness”. However, the protocol of flooding does not acquire the feasible resources of energy. Energy resource-aware protocols must consider the quantity of energy that is feasible to it at all times.

The information sent by sensor nodes is related closely to their sensing areas in the overlap. As an outcome, the neighbour nodes acquire duplicated messages. Kadiyala argues that though the algorithm of flooding is simple to implement, it is still complicated and poses several drawbacks (Kadiyala, 2008). Flooding is not effective in network bandwidth utilisation terms because every node receives and transmits numerous data packets, thus wasting the bandwidth of the network. To overshadow the drawbacks of flooding, another method named as “gossiping” can be utilised (Zanaj, et al., 2007). By applying gossiping, a provided sensor would acquire only one carbon of a folder being issued. As for gossiping deals with managing the breakdown issues, there is an essential suspension for a folder to grasp all the sensors in a system. Additionally, these annoyances are intensified, when the count of nodes in the system increases. Similarly, Krishnamachari et al., argue that gossiping is also a compelling interaction paradigm with several applications in sensor networks such as aggregating data, maintaining complex overlays and disseminating queries to mention a few (Krishnamachari, et al., 2014) the core principle of gossiping is that each node broadcasts repeatedly to its neighbours based on its own local state. Similarly, the node combines the received states from the neighbours with its own local state. The overall result of these repetitive exchanges of local state is that data is disseminated among overlay. The dissemination process, however, does not need any infrastructure of routing. Moreover, it is robust in dynamics network which is essential in mobile node. The gossiping robustness occurs at a cost, though the repeated node state broadcasts permit protocols based on gossip, to manage failures, mobility and packet loss, introducing a huge redundancy in traffic. The resources of redundancy waste node, receive processes, transmit redundant data, drain the energy node and decrease the efficiency throughout the channel. In extreme cases, such as mobile nodes concentration in a region, the resulting storms of broadcast may even lead to a collapse of the complete process of dissemination. Gossiping in sensor networks necessitates the handling of redundancy. On the other side, redundancy must be adequate to manage the dynamics of the network, along with reducing the negative effects of its performance. A gossiping protocol can make probabilistic decisions on whether to rebroadcast its state or not, or it can wait for counting its neighbour's broadcasts so that its own can be suppressed hopefully.

The benefit of capably exclusive qualifiers such as the MAC (Medium Access Control) or the GPS integration is not suggested as it can impact an essential charge in the information (Lin, et al., 2007). Once nodes are recognised, routing protocols form and regulate the routes among isolated nodes. There are various ways in which the routing protocol function stands conveniently for carrying out specific operations.

To achieve a better QoS (Quality of Service), the routing protocols must carry a high data transmission proportion, low intermission and low power utilisation (Biradar, et al., 2004). Based on this the wireless sensor networks (WSNs) can be grouped into two main categories:

Category 1 WSNs (C1WSNs): Consisting of a mesh-form topology of the variety of nodes with the capability of communicating with each other, as well as the gateway using a dynamic routing. An example is scattering the nodes in a forest for collecting the targeted data. Nodes must be able to establish a route to forward the detected events to the gateway or an interested node.

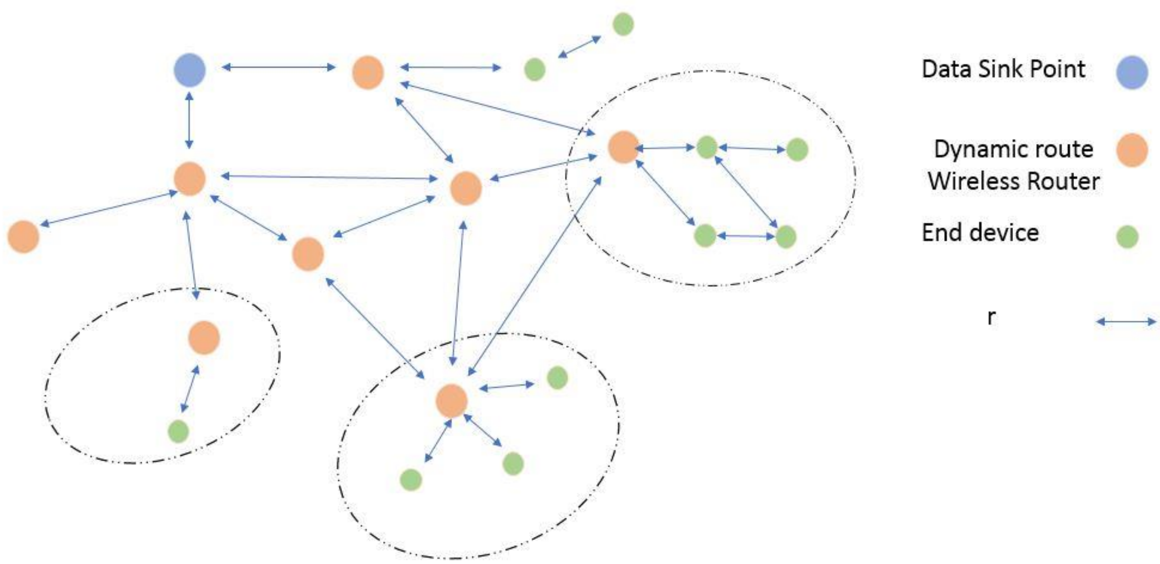


Figure 1-1: C1WSNs: multi point to point, using dynamic routing (Sohraby, et al., 2007)

Category 2 WSNs (C2WSNs): Consisting of a star-form topology in which nodes are the single hop away from the forwarding node. The routing protocol used in these networks is predetermined and therefore static. An example of this category can be residential monitoring and controlling systems.

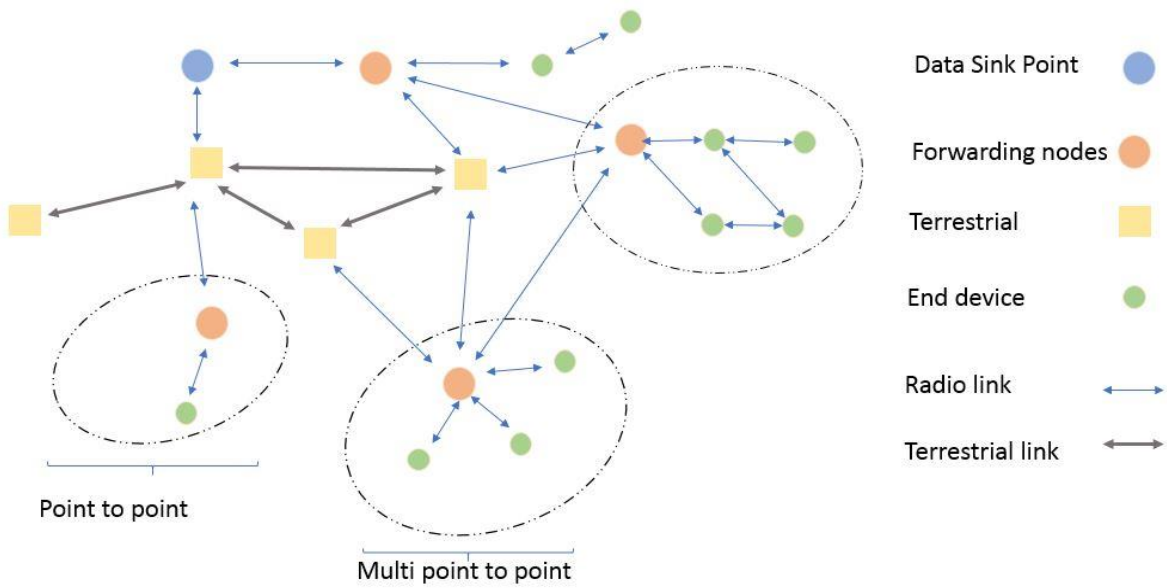


Figure 1-2: C2WSNs: Point to point, typically single hop systems using static routing. (Sohraby, et al., 2007)

C1WSNs usually are applied to large networks with multi-point to point configuration, whereas C2WSNs are used in small networks mainly with a point to point configuration.

1.1.2 MULTIPATH ROUTING IN WSN

A pragmatic approach for handling the constraints of single-path routing methods is the multipath routing strategy.

By using the multipath routing, we can utilise the feasible basics for every node in a very short time. Multipath routing can help to overcome the major hindrances of a single path routing plan and provide steady data communication, an even circulation of network influx, and enhanced data guarantee. At intervals, too, many data packets can source network crowding which may reduce the data packet (Sharma, et al., 2010).

On the other hand, by applying multipath routing, data accuracy is enhanced by assigning the data in multiple inessential paths (Mueller, et al., 2004).

The Quality of Service (QoS) support regarding data delivery ratio and end-to-end latency is an essential objective in designing multipath routing protocols for various kinds of networks. Fonseca, mentions that as the distribution of traffic is not equal in the entire network links, spreading the traffic along multiple routes can enhance congestion in certain connections and barriers (Fonseca, 2010). Tsai and Moors (Tsai & Moors, 2006) assert that the delay is reduced in multipath routing because backup routes are recognised at the time of the initial discovery of route. Splitting information to similar destinations into numerous streams while all data is routed through a different path, the efficient bandwidth can be aggregated. This strategy is beneficial specifically when a node has several reduced link of bandwidth, but it needs a bandwidth that is larger than the one which an individual link can offer.

1.1.3 ENERGY-AWARE QOS ROUTING

Woo et al. (Woo, et al., 2012) explain that lowering the delays is the fundamental prerequisites to facilitate constant data flow. It must be noted that in many real situations both real and non-real data present and this makes the issue more complicated. One example would be the applications like battlefield surveillance which requires live data flow at all time to ensure the target is not missed. In such scenario, it is imperative to prioritise the various data based on their critical level. The portrayed QoS directing issue is fundamentally the same to run Path Constrained Path Optimisation (PCPO) issues that are ended up being NP-finished.

Queuing model: The model is particularly intended for the instance of a conjunction of real and non-real movement in every sensor hub. The model utilised is roused from class-based lining model. Fundamentally, there is a continuous movement and non-real activity whose parcels are named in like manner (Zamalloa & Krishnamachari, 2007). On every hub, a classifier checks the approach's kind packet and sends it to the appropriate line. Additionally, a scheduler decides the request of packets to be located from the lines as indicated by the transfer speed proportion "*r*" of all sort of activities on that connection.

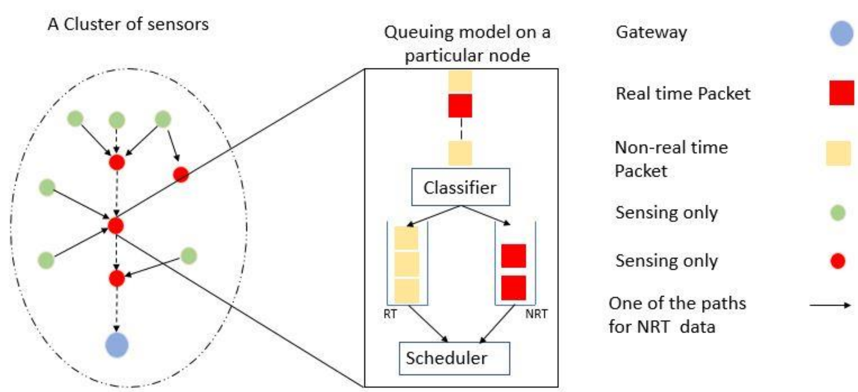


Figure 1-3: Queuing model in cluster-based sensor network, Source: (Akkaya & Younis, 2005)

The transmission capacity proportion *r*, is a starting quality that is set by the passage and deals with measuring the data transfer capacity that can be devoted both to the non-real and real movement in an active connection for blocking an event. Besides, both the classes can acquire data transfer capacity from one another, when one of the two activities are non-existent or under the breaking points (Tarique, et al., 2009). As the queuing postponement relies upon this *r*-esteem, the researcher cannot compute the end-to-end delay in a specific way without knowing the *r*-esteem. In this manner, the researcher must first discover a record of the least expensive ways, and then must select one way that meets the daily needs (Alwan & Agarwal, 2009).

1.2 THE PROBLEM

Essential challenge in wireless sensor network is the restricted power of the battery of the sensor nodes. Sensor nodes are left in unattended surroundings where the replacement and recharge of their batteries are not feasible. The lifetime of the sensor nodes relies on their battery power. Thus, an efficient sensor network lifetime is dependent directly on the battery of its nodes. Hence, the consumption of energy consumption is the major design problem of a protocol (Maraiya, et al., 2011). The restricted size of memory and computational power is another challenge as a single sensor node can process and store a limited amount of data. Fault tolerance is another major challenge of WSNs (Eiko, 2005). The sensor nodes are prone to failure because of unattended surroundings. A sensor node may fail due to the software or hardware issue or energy exhaustion. If a small number of sensor nodes fail, then the working protocol must manage these failures to prolong the lifetime and connectivity of the network. Another challenging and the essential parameter of wireless sensor networks are security. An efficient and effective compromise must be accomplished between the demands of security for protective communication and reduced bandwidth that is needed for the interaction in sensor networks. Feng (Feng, et al., 2002) highlights scalability as another challenge encountered in the wireless sensor network. The number of sensor nodes deployed could be in the order of 100s, 1000s or even greater. It relies on the application, and initially deployed sensor nodes are not enough to supervise the surroundings. In this circumstance, the wireless sensor network that is performing must be scalable and capable to accommodate a huge number of wireless sensor nodes.

Narottam (Narottam, 2012) researched on accommodating reserving which enables sharing of data among various nodes diminishes the level of communications over the wireless channels, and this is what improves the lifetime of a wireless sensor network. The objective of their research was to suggest an accommodating reserving scheme which is called Zone Cooperation at Sensors (ZCS) for WSN. The simulation results indicate that the ZCS caching scheme achieves significant enhancements in byte hit ratio and link, average query potential with the other caching strategies.

One of the merits of WSNs is that it can be positioned or installed at any geographical region in an unplanned fashion. During the procedure of data sensing, data gathering and data transmission, the control of the power unit which is being related to any node get low, after some time, i.e., each node presents its own lifetime. The life span of nodes used to affect directly the life span of the sensor network. As the cost associated with each node is not high, it is needless and problematic too, to renew them once their energies are shattered (Rakesh, 2012).

Even though many security schemes are available in the field of wireless sensor networks, yet the information regarding it, is still visible. Such information can be for attack. The prevailing privacy systems protect against a political challenger. Wireless Sensor Networks contain two major privacy protection; data privacy and context privacy. Location Privacy has also been discussed in this research paper. Location privacy is being considered as a significant factor in Wireless Sensor Networks. Information which is present on the location of events or on location of the base stations can be of major concern for the challenger. Location privacy is also vital in hostile environments (George & and Kumar, February 2013).

Both security and privacy have become major issues for the researches recently. Most surviving researches which are related to wireless sensor network's security, reflect standardised sensor networks. To accomplish better security and performance, a heterogeneous wireless sensor network mode is being adopted which consists of various types of sensor nodes. It is argued that a message distribution scheme which is much secured with configurable privacy for Heterogenous WSNs (HWSNs) is useful because of the powerful high-end sensor nodes. This sort of scheme creates a message circulation topology in an effective and protected way. The sensor node requires making only one signature for all the messages, for every existing user, which can protect the communication and the division cost of the sensor node (Yahui & al., 2010).

Essentially the quality of service in WSNs has three major characteristics: Throughput, error rate and data pattern delay. Nodes sense and gather various type of events and then these events must be prioritised by request conditions in the application service. They should also give a certain degree of quality to the service guarantee (Huang & and Fang, 2008). For each sensor node that provides quality of service, it is required that it maintains data reliability, collective network delay and energy efficiency. Therefore, the routing protocol must reflect the quality of service information required in this process. In WSNs, nodes and as result network status frequently change. Therefore, the routing protocol must adopt and respond to such dynamic modifications appropriately. Limiting energy consumption among sensor nodes is also considered to maximise the lifetime of the network. Information on routing receives the broadcast information from the sink node, and transmits it by the fixed time (Felemban, et al., 2006). Therefore, this research intends to focus on energy and Quality of Service aware routing for wireless sensor networks.

1.3 AIM AND OBJECTIVE OF THE RESEARCH

The aim of the present research is twofold. The first and foremost is to propose an enhanced routing paradigm in which the delay and energy dissipation is improved. The second fold is to design and propose a scalable clustering protocol which can perform without requiring a global addressing scheme, nor the geographical location of nodes, and to provide the maximum coverage while preserving the nodes energies and maintain low collective delays among the network.

Objectives of the research are as follows:

i. To setup and test several wireless sensor networks

ii. To study major routing protocols for wireless sensor networks

iii. To observe and evaluate the implemented routing protocol with the wireless sensor networks and their performances

iv. To examine and justify the design parameters in aware routing for wireless sensor networks

v. To compare the performance of the developed protocol with the existing routing protocols

1.4 RESEARCH QUESTIONS

The research intends to find answer or solutions for the following questions:

i. How to study major routing protocols for wireless sensor networks?

ii. How to observe and evaluate the implemented routing protocol to the wireless sensor networks and their performances?

iii. How to examine and justify the design parameters in the aware routing for wireless sensor networks?

iv. How to compare the performance of developed protocol with the existing routing protocols?

1.5 SIGNIFICANCE OF THE RESEARCH AND ITS CONTRIBUTIONS

The present research will be helpful to understand the scalable wireless sensor network routing approaches that encompass quality of service that is latent and coverage and energy-aware protocols as well. This research will assist in identifying the major routing protocols for wireless sensor networks. Also, it will compare the performance of developed routing protocol with the existing routing protocols and simultaneously will evaluate the performance of the already established routing protocol. Apart from these, this research will also focus on designing a unique energy and quality of service aware routing clustering modelling that have been obtained and derived from investigations. The proposed model acts as a guide to define and examine the adaptive routing protocols for wireless sensor networks. In addition to it, developed model in this research is used to analyse both effectiveness and efficiency of existing routing protocols. This research contributes primarily towards a coverage preservative and conservative energy framework for wireless sensor networks. This study will act as an eye-opener for the future researchers to make them understand the energy and quality of service aware routing for wireless sensor networks.

The contributions of this thesis are based on work that has been carried out in the field of Wireless Sensor Networks routing approaches using QoS and energy aware routing methods. One of the aspects of the contributions of this thesis relates to the derivation of models for routing approaches in order to describe, understand and evaluate the operation of popular routing protocols. The other main contribution of this thesis consists of work carried towards designing a novel routing protocol that is designed without requiring any addressing methods or any node awareness mechanism such as GPS. The thesis also includes our innovative design of a cluster based routing algorithm that guarantees all nodes contribution to data collection and/or data forwarding while significantly enhances the network coverage. Thus, the overall contribution of our thesis is towards an energy and QoS (coverage and latency) aware routing protocol for WSNs.

From a network modelling point of view, we derive a mathematical model in order to gauge the performance and a number of well-known WSN routing approaches. The contributions of this thesis are based on work that has been carried out in the field of scalable WSN routing approaches using new ID assignment methods and ensuring all nodes belong to a cluster.

The mathematical model is derived considering a probabilistic approach for measuring the routing performance of protocols in multi-hopped data transmissions between nodes, cluster heads and base stations in terms of network coverage, energy efficiency and end to end delay. Our network cluster model derivations are presented at two levels of granularity. Firstly, our ID assignment method derivation provides a guaranteed addressing of every node in the entire network within a fixed amount of time regardless of the network size. Then, we present an algorithm that will outperform other related works in terms of QoS parameters and nodes life time. The algorithm is validated using the widely-used ns-2 simulator.

1.6 STRUCTURE OF THE THESIS

The following section explores the outlines of each chapter that are included in this research:

Chapter Two: Second chapter is the literature review which takes a deeper look at the existing works related to wireless sensor networks. This chapter explores the overview of wireless sensor networks, their applications and the significance of efficiency in sensor nodes. The focus will then shift to aware routing protocols for such networks. Special attention is drawn to energy aware routing techniques and quality of service (latency and coverage) aware protocols. Further, we discuss major routing protocols in the wireless sensor networks. A vast body of literature on existing studies related to energy and quality of service aware routing will be examined throughout this chapter. Chapter two will then identify the existing research gaps in the studies conducted by previous researchers, identifying the niche areas to direct our further research as will be described in following chapters.

Chapter Three: Third chapter is elaborating on our attempt to develop a wholly new paradigm for routing technique in energy aware and quality of service aware WSNs. To this end, limitations and challenges of WSNs are studied in details, and is concluded that exiting paradigms, such as those used in mobile networks are not adequate for WSNs, hence there is a need for such paradigm. Thereafter, the theoretic basis of a new model is proposed and further, such model is implemented in a simulator environment to put its validity in the test. The chapter then delves deep into empirical results of our proposed model, proving the validity of such proposal. Chapter three, then concludes with evaluation of our paradigm, and paves the way for us to design whole new routing protocol which will be delineated in a subsequent chapter.

Chapter Four: Equipped with our findings from literature review (Chapter Two) and inspired by the paradigm we proposed in Chapter Three, we are aware of the shortfalls and gaps in the existing energy and quality of service aware protocols that well justifies the development of new routing protocol altogether. Hence, we design and then implement a routing protocol which we called it Energy Aware and Address Free Clustering (therefore EAAFC). Our design is then put to test in the simulator environment which in turn proves the success of our model in addressing the shortcomings and challenges in the existing protocols. Results of our tests then informs us on our future works and angels to be explored for betterment of our proposed protocol.

Chapter Five: Fifth chapter is the conclusion and recommendations together with insights for the way forward. this section describes the summary of outcomes that were acquired throughout the thesis and also provides a conclusion to the research. The chapter concludes with a list of our publications in so far.

CHAPTER 2

2 LITERATURE REVIEW

2.1 INTRODUCTION

The literature review takes a deeper look at the existing work related to the wireless sensor networks. This chapter explores the overview of wireless sensor networks. Next to that, it focuses on energy aware routing techniques for wireless sensor networks. Subsequent section concentrates on the quality of service (latency and coverage) aware protocols. Moreover, this research discusses major routing protocols in wireless sensor networks. Apart from these, this chapter explores various existing studies related to energy and quality of service aware routing for wireless sensor networks.

2.1.1 MEANING AND DEFINITION OF WSN

A Wireless Sensor Network (WSN), in its simple design, can be described as a structure of (probably small-size and small-compound) gadget including various small nodes that can be deployed in the environment. These nodes can feel and sense the surroundings and collect the information from it, which is then broadcasted over wireless channels. The data is delivered, probably through many hops communicating, to a source that can use it narrowly, or is united to other networks for example, the Internet over a portal (Malfa, 2010).

A wireless sensor network is a compilation of nodes that are formed into a coordinated system (Hill, et al., 2000). Each node is developed for preparing efficiency comprising of one or more microcontrollers, CPUs or DSP chips; and may consist numerous kinds of memory for instance program, data and flash memories; carry a Radio Frequency (RF) transceiver usually with an individual Omni - directional antenna; carry an energy source, for example, batteries and solar cells; and entertain different sensors and actuators. The nodes can broadcast without wire and always self-structure after being arranged in an ad hoc network style. Networks of thousands or even tens of thousands nodes are foreseen.

A WSN can be commonly defined as a structure of nodes that collectively feel and may restraint the surrounding permissive communication between people or computers and the surrounding habitat (Verdone, et al., 2008). On the one hand, WSNs empower new operations and hence enables new probable retails; on the other hand, its structure is disturbed by many restraints that hail for new criteria. The movement of sensing, preparing, and broadcasting under the finite amount of power, inflames a cross-layer structure access that demands the joint application of scattered signal/data transmission, medium ingress control, and broadcasting protocols (Verdone, 2008)

Wireless sensor networks (WSNs) are structures that are regularly scattered and comprises of enclosed gadgets, each furnished with a processing element, and a wireless transmission interface, besides sensors and actuators. Up until now, several operations have been suggested that reveals the adaptability of this hi-tech, and few studies identify their path into the dominant. Frequently, in these networks, small battery-powered gadgets are applied for the comfort of distribution and enhanced adaptability (Akyildiz, et al., 2002).

Wireless sensor network (WSN) is broadly examined as one of the most significant technologies in the 21st century. In the previous decades, it has acquired dreadful consideration from both the academic community and the industries worldwide. A WSN comprises of a huge number of low-expense, low-energy, and multi-operational wireless sensor nodes, carrying sensing, wireless transmissions and computation abilities (Singh, et al., 2010). These sensor nodes broadcast data through short length through a wireless mean for achieving a general task, for instance, environment observing, military vigilance, and technical course restraint (Zheng & Jamalipour, 2009). The key ideology behind WSNs is that, as the ability of each single sensor node is finite, the combined energy of the complete structure is enough for completing the desired task.

2.1.2 ENERGY AWARE ROUTING FOR WSN

Hierarchical clustering routing protocol are suggested as an efficient approach for data gathering in wireless sensor networks, known as Energy Aware Routing Protocol, and fulfilling essential needs for a clustering algorithm. It has been proved that Energy Aware routing protocol accomplishes a better performance in lifetime terms. Most of the Energy Aware routing protocols are only energy savers and do not involve the energy balancing. The protocols of energy saver try to reduce the consumption of energy of network as whole. However, the energy manager protocols balance the consumption of energy in the network to avoid partitioning of the network. The lifetime of WSN is depended strictly on the use of energy. Therefore, the management of energy is an important task to be regarded (Liu, et al., 2009). Extending network life time, given that sensor nodes are only used to fortify with limited energy batteries, is another challenge to which the solution is clustering sensor nodes, and then directing the transmission of data to the base station through the cluster heads. This issue is also the main objective of this paper is to examine the issues of selecting cluster centres as CHs which used to rapidly deplete their energy.

One of the points to pay attention to in such routings is the One-hop as opposed to multi hop models. One hop model is the easiest and foremost delivery method which makes the link by directly communicating along with any two nodes. Multi-hop model with store-and-forward method provides data by accelerating to one of its adjacent nodes which are nearer to the destination. In cluster model, mobile nodes are being gathered into a group. It has profits of delivery potential and route management.

2.1.3 THE PRINCIPLES OF QOS-AWARE ROUTING FOR WSN

The QoS routing is an essential subject in sensor structure analysis, and it has been an important part of the aimed targets of the study association of WSNs. Akkaya (Akkaya & Younis, 2005) and Chen (Chen & Varshney, 2004) have analysed the QoS oriented routing protocol in WSNs. Several routing technologies particularly structured for WSNs have been suggested. In these efforts, the exclusive effects of the WSNs have been taken into consideration. These routing methods can be categorised depending on the protocol function into mediation-based, objection-based, QoS-based, and multi-path based.

The QoS oriented protocols permit sensor nodes to form a concession among the power utilisation, and few QoS metrics prior to distribution of information to the sink node (Martirosyan, et al., 2008).

The nature of administration includes the quality administration needed by the tool; it might be the life time length, the information solid, vitality proficiency, and area mindfulness, communitarian preparing. These elements will influence the determination of routing conventions for a specific application. In a few applications (e.g. military tools), the information must be conveyed within a specific timeframe, from the minute it is detected.

One of the previously suggested routing protocols that give few QoS is the Sequential Assignment Routing (SAR) protocol (Sohrabi & Pottie, 2000). SAR protocol is a multi-path routing protocol that forms routing opinions depending on three aspects; power resources, QoS on every path, and packet's preference level. Multiple paths are formed by making a tree entrenched at the cause to the target. During the building of paths, those nodes which carry fewer QoS and low enduring energy are averted. Consequent to the formation of the tree, a maximum of nodes will accord to multiple paths. To broadcast data to sink, SAR counts a stocked QoS metric as an output of the supplement QoS metric, and a stocked accessory combined with the preference level of the folder to choose a path. Applying multiple paths enhances defect resistance, but SAR protocol endures from the upward of managing routing counters and QoS metrics at every sensor node. Akkaya and Younis (Akkaya & Younis, 2003) have suggested a cluster-oriented QoS-aware routing protocol that involves a queuing pattern to tackle both actual-time and non-actual time traffic.

In the traditional data network, QoS describes specific restrictions such as packet fall, delay, jitter, bandwidth, etc. Nonetheless, the QoS demands in WSNs such as data efficiency, gathering delay, coverage, fault resistance, network existence, etc. are function-distinct, and they are different from the conventional end-to-end QoS demands owing to the variance in operation domains and network stuff. Despite the few QoS solutions (e.g., IntServ, DiffServ, etc.) that are promoted for conventional networks, these cannot be plainly ported in WSNs because of the following reasons:

- Caustic resource pressures in sensors nodes
- Extensive and random formation of sensors nodes and
- Operation distinct and data-centric transmission protocols in WSNs

Analysers have been struggling frequently related to QoS backing in WSNs, and have suggested few techniques for that aspiration. To mention a few, Network Layer based QoS support in points of routing protocols (Felemban et al., 2006),Cross-Layer based QoS support (Zhang & Zhand, 2008) and Middleware layer based QoS support (Sharifi, et al., 2006) are the most outstanding kinds of paths for QoS backing in WSNs.

QoS-aware routing is one of the most important factors of the Quality of Service structure for wireless networks. Beneath QoS routing plans, the information distribution routes are measured with the awareness of different resources possibility in the network preceding with the QoS demands of the comparable streams. There are many problems to be examined during the structure of the QoS-based routing methods for multi-hop wireless sensor networks. They are:

- Metric selection (e.g., bandwidth, delay, etc.) and route estimation
- QoS state generation and conservation
- Flexibility
- Realm of QoS such as accuracy or well-timed (or both).

In a structure like wireless sensor network, the QoS-aware routing protocols require trading with uncertain state data because of the regular topology variations. Also, a QoS-aware routing method for multi-hop WSNs should also moderate readiness and flexibility as regulating low

2.2 PROTOCOLS

This study focuses on a number of protocols for QoS Aware routings for WSNs which are relevant to the research objectives.

2.2.1 LOCATION BASED PROTOCOLS

2.2.1.1 LOW ENERGY ADAPTIVE CLUSTERING HIERARCHY (LEACH)

Heinzelman (Heinzelman, et al., 2002) asserts that Low Energy Adaptive Clustering Hierarchy-Centralised (LEACH Centralised) is a developed scheme of LEACH in which a centralised algorithm at base station makes possible the formation of a cluster. Every node sends data about present energy and location level, to the base station. Then, the base station uses its worldwide data of network to generate better clusters that need reduced amount of energy for the transmission of data. Similarly, Younis and Fahmy (Younis & Fahmy, 2004) have described Hybrid Energy Efficient Distributed Clustering Approach (HEED) for prolonging the lifetime of the network. The selection of CH in this protocol, is based mainly on the residual energy of every node. To develop the efficiency of energy, and further prolong the lifetime of the network, a secondary parameter of clustering regarding the intra-cluster cost of communication is used, which can be a function of cluster density or neighbour proximity. The aim of Hybrid Energy Efficient Distributed Clustering is to distribute the consumption of energy to prolong the lifetime of the network, reduce energy during the selection phase of CH and reduce the network’s control overhead. However, Hybrid Energy Efficient Distributed Clustering requires wide broadcasting for the formation of clusters, and thus, consumes the huge amount of energy.

2.2.2 DATA CENTRIC PROTOCOLS

2.2.2.1 SPIN (SENSOR PROTOCOLS FOR INFORMATION VIA NEGOTIATION)

Braginsky Estrin (2002) portrays that the researches show a group of versatile conventions, called SPIN (Sensor Protocols for Information using Negotiation), that proficiently scatter data among sensors in a vitality obliged remote sensor system. Hubs running a SPIN correspondence convention name their information utilising abnormal state information descriptors as meta-information. They utilise meta-information transactions, to take out the transmission of repetitive information all throughout the system. Also, the SPIN hubs can construct their correspondence choices, on the application-particular information of the endless supply of the sources that are accessible to them. This permits the sensors to productively convey information given a restricted vitality supply. Four particular SPIN conventions were mimicked and dissected; SPIN-PP and SPIN-EC that are upgraded for a point-to-point system, SPIN-RL, and SPIN-BC that are streamlined for a telecasting system.

In point-to-point, the sender declares that it has new information with an ad message to every neighbour. At the time, when the neighbour gets the message, the hub checks the metadata to know whether it can store the information. On the off chance that the neighbour is keen on the data, it reacts with a solicitation message. Intanagonwiwat (Intanagonwiwat, et al., 2000) holds that after getting it, the sender transmits the data in an information message. The neighbour that gets the information, advises about its accessibility to its neighbours, with an ad message. The three-handshake convention is then rehashed. The depicted procedure is known as SPIN-PP. The calculation SPIN-EC presents a system in the hubs, so when their present vitality assets do not surpass a foreordained edge that permits them to finish the three hand-shake conventions, they do not partake simultaneously. The SPIN-BC and SPIN-RL variations widen the calculation to motivate the telecast transmissions. Along these lines, one notice message can achieve each of the neighbours. For this situation, the neighbours do not react promptly with a solicitation message, yet they should hold up an irregular time. To advance the procedure, a hub not the same as the promoting one wipes out its solicitation message when it identifies another comparable message. Considering the show transmission, the promoting hub additionally reacts with only one information message, notwithstanding when it has obtained various solicitation messages.

According to Kulik (Kulik, et al., 2002), SPIN-RL joins some quality elements. In particular, hubs monitor the promotion messages that they and their comparing originators get. If they send a solicitation message, and the declaring hub does not react in a given interim, the hub again approaches for the information with a solicitation message. Contrasting the SPIN conventions, with other conceivable methodologies, the SPIN conventions can convey 60% more information for a given measure of vitality than customary methodologies in a point-to-point system, and 80% more information for a given measure of vitality in a telecasting system. Also, as far as spread rate and vitality utilisation are concerned, the SPIN conventions perform near the hypothetical ideal in both point-to-point and show systems. One of the real favourable circumstances of these conventions is that hubs are just required to know its 1-bounce neighbourhood (Tilak, et al., 2002).

2.2.2.2 DIRECTED DIFFUSION

As information driven convention, the applications in the sensors, name the information utilizing characteristic quality sets. A hub that requests the information, produces a solicitation where a hobby is indicated by property estimation-based plan characterized by the application. The sink more often than not, infuses an enthusiasm for the system for every application errand. The hubs overhaul an inside interest store, with the interest messages derived. The hubs likewise, keep an information reserve, wherein the late information messages are put away. This format assist on deciding the information rate. On getting this message, the hubs set up an answer connection to the originator of the situation. This connection is called “angle”, and is described by the information rate, span and close time. Furthermore, the hub enacts its sensors to gather the planned information. The gathering of an interest message makes the hub set up numerous inclinations (or first bounce in a course) to the sink. Keeping in mind, the end goal to recognize the ideal angle, positive and negative fortifications are utilized. Their calculation works with two sorts of angles: exploratory and information slopes. Exploratory slopes are planned for course set-up and repair though information angles are utilized for sending genuine information. (Karl & Willig, Oct 2007) (Intanagonwiwat, et al., 2000).

Directed Diffusion is a turning point in routing protocols, in a sense that it does not require any form of addressing mechanism since all communication is cluster reliant and the data is value attributed. In Chapter 3 we will further elaborate on significance of Directed Diffusion as our reference protocol.

2.2.2.3 RUMOR

Akyildiz (Akyildiz, et al., 2005) explain that in this calculation, the inquiries created by the sink are spread among the hubs, that have watched an occasion identified with the questions. To do as such, a hub that watches an occasion infuse a seemingly perpetual bundle called "specialists". The specialists are spread in the system, so that the far-off hubs have the required information about that hubs that have seen certain occasions. To enhance the conduct of specialists, when an operator achieves a hub that has recognized another occasion, the specialist is still sent the new found occasion. Also, the specialists keep up a rundown of the currently visited by hubs, so that the circles are in part dodged. On gathering of specialists, hubs can procure upgraded data about the occasions in the system. This information is reflected in the nodes occasion reserves. As Akkaya & Younis (Akkaya & Younis, 2005) assert, by utilizing the occasion store, a hub can favourably send an inquiry message, as a few hubs may not know about the events originator. Under these situations, the question is successively proliferated to one of the neighbours chosen randomly. Once the question touches the base at a hub, with a section identified with the requested occasion in its occasion store, the inquiry is then sent through the learnt way. Taking after this system, the expense of flooding the system with the inquiry is unmistakably stifled.

2.2.2.4 COUGAR

In this method, the system is anticipated as a disseminated database, wherein a few hubs containing the data are temporarily inaccessible. Since the hub stores memorable qualities, the system carries on as an information distribution centre. Furthermore, it is significant that the poor spread conditions might prompt the capacity of wrong data in the hubs. Considering this condition, COUGAR gives a SQL-like interface stretched out to join a few statements to display the likelihood appropriation. The sink is in charge of producing a question arrangement that gives the indications to choose an uncommon hub called the “pioneer”. The system pioneers perform accumulation and transmit the outcomes to the sink (Boukerche, et al., 2009)

2.2.2.5 ACQUIRE (ACTIVE QUERY FORWARDING IN SENSOR NETWORKS)

This calculation likewise considers the remote sensor system as a conveyed database. In this plan, a hub infuses a dynamic question parcel into the system. The neighbouring hubs that distinguish that the bundle contains out-of-date data, discharge a redesign message to the hub. At that point, the hub arbitrarily chooses a neighbour to proliferate the question that needs to determine it. As the dynamic question progress throughout the system, it is logically determined into small segments until it is totally comprehended. At that point, the inquiry is returned back to the questioning hub as a finished reaction (Lin, et al., 2007).

2.2.2.6 SIMPLE ENERGY EFFICIENCY ROUTING (SEER)

Hancke and Leuschner (Hancke & and Leuschner, 2007) have mentioned that the Simple Energy Efficiency Routing (SEER) protocol reduces the number of transmissions, but it is inefficient for energy balancing and energy management. Chilamkurti (Chilamkurti, et al., 2013) assert that the Simple Energy Efficient routing protocol aims to optimise the lifetime of the network. Simple Energy Efficient Routing uses source initiated communication along with even driven reporting to decrease the number of user data messages. The decisions of routing are based on distance to sink that is the hop count as well as on remaining energy levels of the battery of sensor nodes on the path towards the sink. When the energy of the node falls below some threshold, it sends the message of energy to its neighbours about its remaining energy. The sink node periodically sends a broadcast message "Hello" to update the sensor nodes neighbour tables.

2.2.2.7 LEARNING AUTOMATA BASED ENERGY-AWARE ROUTING PROTOCOL

Similarly, Abolhasani (Abolhasani, et al., 2007) proposes the Learning Automata Based Energy-aware Routing Protocol which tries to balance the consumption of energy. But it has certain issues such as reduced accuracy in updating energy and greater control overhead. In the Learning Automata Based Energy-aware Routing Protocol only, the acknowledgement packet is forwarded to the previous sender, but the other neighbours cannot update the level of energy of sender of low accuracy acknowledgement.

2.2.2.8 MINIMUM COST FORWARDING (MCF)

This protocol identifies the reduced expenditure path in a huge sensor network. It is an easy and flexible protocol. The particulars of this protocol can be noticed in the works of Ye (Ye, et al., 2005). A cost application is applied for noting the delay, throughput and power utilization, from any sensor node to sink node in the sensor structure. The protocol is classified into two aspects. In the initial phase, the cost expense in each node is firm, initiating from the sink node and distributes beyond the network. Each node determines its cost by extension of the cost expense of the node acquired from an information, and the value of the link. In the next phase of the protocol, the origin node begins transmitting the data to its bystanders. When a node gains this transmission data, it computes the broadcast cost to the sink node, to the value of the packet and reviews the resting cost in the packet.

Fardin and Joao (Fardin & Joao, 2011) presented a routing protocol for wireless sensor networks (WSN), which has been established on the basis of the essential concepts in Source-Based Routing (SBR) for ad-hoc networks and Minimum Cost Forwarding (MCF) approaches for mixed WSNs. Neither routing tables nor network topology facts are being maintained at the sensor level, which create a suggested protocol portion of the responsive routing protocols class. In spite of the absence of network figures, at the sensor the packets travel from the sink node to the sensors, and conversely, always tend to follow the ideal communication path with minimum cost. And simulation results have exposed that the proposed protocol performs better than the MCF protocol, and the nodes always track the packets over the finest path up to the destination.

The MCF convention is a neat strategy for directing bundles in a responsive sensor system. Zhou (Zhou, et al., November, 2005) explains that this routing technique is a cost field based method and endeavours the way that the routing heading of information, spilling out of sensors to sink, is constantly known and that the cost is constantly less. In this technique, the sink hub begins to setup the system with television, its cost esteem and all hubs get least cost quality to achieve the sink hub. With this technique, sensor hubs have neither directed tables nor data about the system topology. It is discernible that this methodology applies just for the information sent from the sensor hubs to the sink. In the event, that the sink hub needs to send information to a particular hub, different strategies like flooding must be utilized. In circumstances, wherein the Base Station (BS) hub goes about as a sink and server at the same time, and creates a lot of information, the implosion, covering and asset visual impairment issues, coming about because of the flooding technique, will decrease the system execution. In this way, the MCF is suitable just for those applications where the sink hub acts as a practically selective part of information gatherer. For the BS to send information to a committed sensor, routing and designation way should be characterized at the BS hub like in Source Based Directing (SBR). To actualize base routing, the parcel contains the location of every hub on the directing way. Base routing requires deciding the location of all hubs and directing ways from source to end, as is done in conventions such as Dynamic Source Routing (DSR) for remote specially appointed system and Link Quality Source Routing (LQSR) created by Microsoft for remote lattice systems. LQSR and DSR conventions are receptive methodologies and do not require routing tables. These conventions decide a course on-interest, when the source hub needs to send information to the destination hub and keep the directing data while conveying.

The source hub sets up a course in the middle of source and destination hubs, by communicating a Route Request bundle. At the point, when the destination hub gets the Route Request bundle, it answers with Route Reply parcel to the source hub. This bundle conveys the routing way from source hub to destination hub. Amid the correspondence among the hubs, the moderate hubs course the parcels by utilizing the routing data that is conveyed in the bundle headers. A higher association setup delay in correlation with table-driven conventions and the nonattendance of a system for nearby repair of fizzled connections are a portion of the drawbacks of the LQR and DSR conventions (Zanaj, et al., 2007)

2.2.3 HIERARCHICAL PROTOCOLS

2.2.3.1 ENERGY EFFICIENT CLUSTERING SCHEME (EECS)

Ye (Ye, et al., 2005) suggest Energy Efficient Clustering Scheme (EECS) is a constant number of nodes of a candidate for the role of CH, who are elected with a probability T and are rival according to the residual energy with the range Recomplete. The candidate will be a head if it does not predict another candidate of energy. Otherwise, it will provide rivalry with the first predicted higher energy candidate. The size of the cluster must be justified such that, the bigger the distance between the base station and smaller size of the cluster will be accommodated by CH. It is true that the chosen CH is the candidate with bigger residual energy in recomplete range, but the group of candidate nodes in the rivalry is chosen randomly before the rivalry. This may result in a non-optimal selection of CH.

2.2.3.2 POWER EFFICIENT AND ADAPTIVE CLUSTERING HIERARCHY (PEACH)

Sangho (Sangho, et al., 2007) proposes Power Efficient and Adaptive Clustering Hierarchy (PEACH) as another energy aware routing protocol in wireless sensor network. The main aim of Power Efficient and Adaptive Clustering Hierarchy is to reduce the consumption of energy of every node. By using overhearing features of wireless communication, the Power Efficient and Adaptive Clustering Hierarchy forms clusters without extra overhead and assists adaptive multi-level clustering. Power Efficient and Adaptive Clustering Hierarchy can also be used for both location aware and location unaware WSN.

2.2.3.3 PROBABILITY DRIVEN UNEQUAL CLUSTERING MECHANISM FOR WIRELESS SENSOR NETWORKS (PRODUCE)

Kim (Kim, et al., 2008) holds that Probability Driven Unequal Clustering Mechanism for Wireless Sensor Networks (PRODUCE) organises the network with unequal sized clustering decided with multi-hop routing and localised probabilities based on stochastic geometry. A huge number of clusters from the base station are made to have larger sizes of clusters that permit focusing on the intra-cluster processing of data rather than inter-cluster processing. It results in consumption balancing of energy, developing coverage and lifetime.

2.2.3.4 FUZZ ENERGY AWARE TREE BASED ROUTING (FEAR)

Ahvar (Ahvar, et al., 2011) suggests Fuzz Energy Aware tree based Routing (FEAR) as another energy aware routing protocol in wireless sensor networks. Fuzzy Energy Aware tree based routing is a reactive protocol which employs a lazy approach whereby nodes discover routes to the destination, only when required. Fuzzy energy aware tree based routing consumes a reduced bandwidth, as compared to the proactive protocols such as Destination Sequenced Distance Vector (DSDV) protocol. But the delay in deciding a route can be considerably large.

FEAR protocol is an energy aware routing protocol which comprises of forwarding data, neighbour discovery and update of energy. The FEAR does not need any energy message because the level of energy of every sender is updated into its neighbour table by piggybacking and overhearing techniques automatically.

2.2.3.5 TEEN AND APTEEN

According to Manjeshwar and Agarwal (Manjeshwar & Agarwal, 2001) for wireless sensor networks subject to sudden changes in the environment, the Threshold sensitive Energy Efficient sensor Network (TEEN) protocol is one of the energy-aware routing protocol. The wireless sensor network architecture is hierarchical, in which the closer nodes form clusters. This method is repeated at the second level until the sink is met. In this architecture, every CH broadcasts to its members of soft threshold and hard threshold. Threshold Sensitive Energy Efficient Sensor Network accomplishes the efficiency of energy by using the threshold values. Whenever the sensed attribute parameter has met its complicated values of threshold, the node initiates transmitting the sensed data. In other cases, the node remains idle and senses the environment and saves energy.

Similarly, Manjeshwar and Agarwal (Manjeshwar & Agarwal, 2002) mentioned that the Adaptive Threshold Sensitive Energy Efficient Sensor Network (APTEEN) protocol is a developed version of Threshold sensitive energy efficient sensor network. It periodically gathers data and reacts to time critical incidents. After the formation of the cluster, the CHS broadcast the environmental attributes of interest, the values of threshold, and schedule of transmission to entire nodes in the cluster. Since the environmental data are correlated, it is wasteful to forward the entire volume of received data from sensor nodes of a cluster to sink. Therefore, after the formation of the cluster, the data aggregation is carried out by the CHs, which saves the huge amount of energy by sending only the aggregated information. Adaptive Threshold sensitive energy efficient sensor network is much energy efficient than Threshold sensitive energy efficient sensor network, but is much complex and has greater latency due to delays in aggregation.

2.2.3.6 EXTENDING LIFETIME OF CLUSTER HEAD (ELCH)

Lotf, Bonab and Khorsandi (Lotf, et al., 2008) introduce Extending Lifetime of Cluster Head (ELCH) as another energy aware routing protocol in wireless sensor network. It is a cluster-based algorithm, where the cluster heads are determined by mutual consent of neighbours through the process of election. This protocol has two phases wherein the first phase is the setup process when the CHs and clusters are formed by the process of election. The most voted sensor becomes the CH. The second phase is the steady state phase, where the results of an election are regarded to establish clusters, forward user information to CHs and transmitting from CHs to sink is undertaken. The clusters comprise of sensor nodes and CH resided in a radius less than the CH ratio radius. Then, the Time Division Multiple Access (TDMA) is used for every member of the cluster to transmit data to the CH. Additionally, every CH manages a table with maximum power for every member of cluster. Once the clusters have been organised, the CHs form a multi-hop routing backbone towards the sink. The data are sent directly to CH by its members of a cluster. Extending the lifetime of Cluster

Head, reduces the energy of transmission and the network can be much balanced in energy efficiency terms.

2.2.3.7 SAR (SEQUENTIAL ASSIGNMENT ROUTING)

SAR is the fundamental routing protocol giving QoS backing in WSN. This is a multi-path table forced routing protocol which attempts to perform both power competence and fault resistance (Sohrabi & Pottie, 2000)This protocol forms a tree of sensor nodes carrying root at the one hop bystander of the sink node. It yields into consideration the QoS metrics, power resource in every path, and lead of every packet. SAR guards the decline restoration by accomplishing routing table firmness among complicated and uncomplicated node on every path.

Sequential assignment Routing is a kind of routing protocol which takes the precedence of the packet into account. It has both, consumption of energy and node precedence, as QoS metrics. In SAR, the first formation of the multiple trees are done. The root of every tree upholds a single hop distance from BS. And, the tree produces externally from the BS. Here, packet communication is mainly focused on the precedence of the packet. If a node encompasses low priority packets then it will may prefer to choose longer path in order to reach BS. The main objective of Sequential assignment routing is to sustain QoS along the certain network. (Krishnaveni & Sujatha, 2012).

Yao and Gehrke (Yao & Gehrke, 2002) explain that Sequential Assignment Routing is a convention that takes the need of the bundle into account. It takes both vitality utilization and hub need as QoS measurements. In SAR, the first formation of various trees are finished. The base of every tree keeps up a solitary bounce separation from BS, and the tree establishes itself outside from the BS. Here, parcel transmission is primarily in light of the need of the bundle. In the event, that a hub contains low need parcels then it will pick longer way to achieve BS or it picks briefest separation to the BS. The fundamental goal of SAR is to keep up QoS along the system. At the time, when a hub moves far from one gathering, a way re-calculation is required. To conquer this issue, way re-calculation is done in an intermittent way. In an arrangement of calculations that performs association and portability, administration in sensor systems is proposed. The Sequential assignment Routing (SAR) calculation makes numerous trees, where the foundation of every tree is a one-bounce neighbour of the drop.

Every tree becomes outward from the sink, and maintains a strategic distance from the hubs with a low throughput or high postponement. Towards the end of the technique, most hubs have a place with numerous trees (Sadagopan, et al., May, 2003). An example of tree development, is outlined in the Figure beneath. The trees established at A and B, two of the one-bounce neighbours of the sink, are appeared. Hub C has a place with both trees, and has way lengths of 3 and 5, individually, to the sink, utilizing the two trees. Every sensor hub records two parameters about every way through it: the accessible vitality assets on the way and an added substance QoS metric, for example, delay.

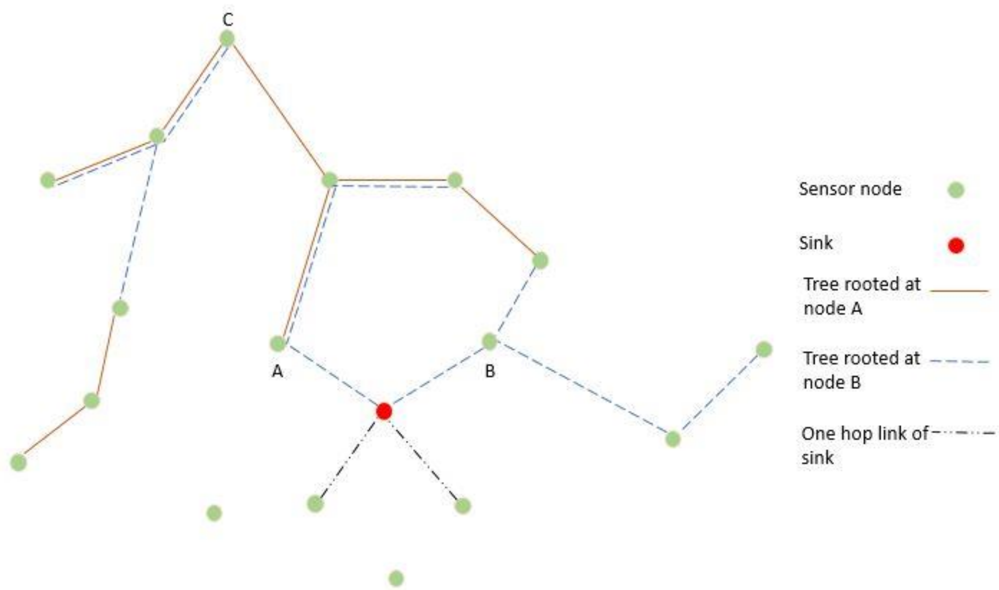


Figure 2-1: Sequential assignment routing. (Rao, et al., 2003, Sept.)

2.2.4 LOCATION BASED PROTOCOLS

2.2.4.1 SPEED

Stateless Protocol for Real-Time Communication in Sensor Networks (SPEED) is defined as a QoS-aware easy actual time routing protocol in Wireless Sensor Networks that assures end-to-end QoS assurances (Akkaya & Younis, 2005). Three kinds of real time transmission services have been given by this protocol. These are actual-time uni-cast, actual- time area multicast, and actual time area any cast (He & et al., 2003). Every node in this protocol regulates the messages about its bystanders, and it uses the geographic promoting method to identify a path. It also attempts to control a specific transmission speed for each packet in the structure. SPEED controls this speed by relaxing the traffic at the network zone and maintaining the traffic directed to the MAC layer narrowly. The task of executing this is to calculate end-to-end lag for the packets by splitting the length to sink by the speed of the packet. This is completed before taking an entry judgment. SPEED can also give traffic evasion in the case of traffic in the network. SPEED has a routing module known as Stateless Geographic Nondeterministic Forwarding (SNGF).

QoS routing protocol for sensor networks can also work readily with best-attempt congestion. Characterised services on the Internet (Carpenter & Nichols, 2002) say on the QoS for the Internet and establish/encourage the Characterized Services method. QoS is applied to define a firm of perceptible criterions, such as delay, throughput, and fall rate that can be adhered to some detectable subspace of the traffic of IP packets over a provided network concern (Chen & Varshney, 2004). The suggested protocol is formed with specific applications about the network pattern and the queuing pattern.

Minimising the waste of power induced by wiretap, collisions, enormous upward, and hollow hearing is the primary aspiration of maximum MAC-layer protocols. QoS appliances in the MAC layer trades primarily with the organising of packets on the wireless network topic to local constraints. The approach to the network that is regulated by the protocols is based on a program. Channel approach is set to one sensor node at a point. Applying programming collision of packets over approaching the network can be evaded. Nonetheless, owing to the aggressive nature of WSN, giving specific quality of service (QoS) assurances in a multi-hop wireless structure, where designing data packets and offering various services depend on function particulars, is very essential. PRIMA is an energy capable and QoS-aware MAC protocol that has been structured for huge wireless sensor structures. PRIMA protocol is comprised of two elements namely, a clustering method for giving flexibility, and a channel approach method for giving multi-hop transmissions (Barua, et al., 2014).

Felemban et al (Felemban, et al., 2006) have presented a packet delivery mechanism which is called Multi-Path and Multi-SPEED Routing Protocol (MMSPEED) for probabilistic QoS assurance in wireless sensor networks. The QoS providing is being performed in two quality provinces, timeliness and reliability. Multiple QoS points are delivered in the timeliness domain through assuring multiple packet delivery speed options. In the consistency domain, various consistency requirements are being supported with the help of forwarding probabilistic multipath. These devices for QoS provisioning are comprehended in a localised way without any information of global network by retaining limited geographic packet forwarding amplified with active compensation, which used to reimburse for local decision imprecisions as a packet travels to its purpose.

2.3 NETWORK SIMULATOR ENVIRONMENT

As Meeneghan and Delaney (Meeneghan & Delaney, April 2004) present, simulation for a network is a technique where models for programs which behaves the wireless or wired network to calculate the communication between various entities for network routers or hosts, packets and links for data and so on. Network behaviour and different services and applications it supports is noticed in a test lab, different attributes are changed in a controller way to evaluate how the network can be performed under various conditions. Typically, a simulator for a network is a piece of hardware or software which forecasts the network behaviour without an exact network being included. Many simulators are driven based on graphical user interface, at the same time few simulators in the network need commands or input scripts. Parameters for network explain the network state that is the placement of node and existing links and events. A significant output of network simulation is the file for trace. Some of the examples in the software of network simulation are OPNET, NetSim, Network Simulation (version 2) known as NS2, Network Simulation (version 3) and so forth. Simulators for a network are adopted for designing different type of networks, simulating and analysing the impact of different parameters on the performance of the network.

Network Simulator (Version 2) is commonly referred as NS2, is a tool for simulating event drive which is helpful to study the dynamic nature of networks for communication. Simulation for the functions of the wireless and wired network and protocol such as transmission control protocol, user datagram protocol and routing algorithms are done using NS2. Because of its modular nature and flexibility, NS2 has obtained constant fame and popularity among the networking researchers since its first introduction in 1989. NS2 gives clients with executable commands that include input argument, the name of scripting file for *Tcl* simulation. Clients are feeding the *Tcl* simulation script name which establishes a simulation as an input argument in the version 2 of network simulator executable command number (Meeneghan & Delaney, April 2004); (Sundani, 2011). In many cases, trace file for simulation is developed and adopted for plotting graph and to develop animation. NS2 utilises two main languages such as command language for object-oriented tool and C++. Command language for object-oriented tool establishes the simulation by arranging and configuring the discrete scheduling events that are at front end and objects. C++ on the other hand, explains the back end mechanism that is the internal mechanism of the objects for simulation. Command language for object oriented tool and C++ are combined using *TclCL*. Animator for a network is a *Tcl/TK* based tool for animation adopted to view traces in the network simulation and traces real world packet. It is aimed as a companion animator to the simulator for the network as pointed out by Issariyakul et al., (Issariyakul & al., 2008).

Sundani et al., (Sundani, 2011), illustrated that the latest advances in communication, storage and processing technologies have developed and potential of cost-effective and small scale senor systems for support various applications. A sensor network is explained as a wireless network, multi-hop, autonomous with non-deterministic routes over a set of probably physical layers which is heterogeneous. In addition to these, the NS2 environment for simulation produces great flexibility in examining the sensor networks characteristics since it previously has flexible energy-constrained unfixed ad hoc networks model. In such environment, network for the sensor can be constructed with numerous same set of characteristics and protocols as those present in the real world. The environment for mobile networking in NS2 encompass support for every protocols and paradigm. The unfixed model also supports movement in the node and constraints for energy.

NS2 must expand and many uses includes:

- For evaluating the existing protocols of network performance
- For evaluating new protocols for network prior use
- For executing large scale experiments not probable in real experiments
- For simulating a different internet protocol networks.

In addition to that, Sriporamanont (Sriporamanont & Liming, 2006), notes that NS2 is a free tool for simulation. It runs on different platforms such as Linux, Unix, Mac systems and Windows. NS2 is developed in the environment of Unix and can be easily installed in that. Source codes in the NS2 are circulated in either of these two forms: component-wise, and All-in-One suite (AIO). With the AIO suite package, clients obtain all the needed components additionally with few optional components. Such package is suggested the choice for beginners. Such package gives a script for installing that configures the environment in NS2 and develops an NS2 executable file with the help of "make" utility.

Present AIO suite involves the following key components such as *Tcl/TK* release 8.5.8; NS release 2.35, *TclCL* release 1.20 and *OTcl* release 1.14 and the optional components in the all-in-one suite are as follows:

- **NAM release 1.15:** NAM release 1.15 is a tool which is adopted for animation to view packet and network simulation traces
- **Zlib version 1.2.3**: this version of Zlib is needed library for NAM release
- **Xgraph version 12.2:** Xgraph is a plotter for data with interactive buttons for selecting, zooming, printing and panning display options.

At the same time, it is noted that the norm behind the approach of component-wise is to acquire the above-mentioned pieces and install them separately. This would save more quantity of downloading time and space for memory. It may be a trouble for the beginners, and it is suggested only for experienced users.

2.4 RESEARCH GAP

This study analyses the energy and quality of service aware routing for wireless sensor networks. There are numerous studies that have been previously undertaken to develop an efficient routing protocol that is constrained by energy, and limited regarding transmission power, computation and memory capacity. The existing protocols fall into either of the categories as grouped in Table 2-1.

Routing Protocol	***Data-Centric***	***Hierarchical***	***Location-Based***	***QoS***	***Network Flow***	***Data Aggregation***
SPIN	✓					
Directed Diffusion	✓					
RUMOR	✓					✓
COUGAR	✓					✓
ACQUIRE	✓					

SAR				✓		
MCF	✓					
SPEED			✓	✓		
LEACH		✓				✓

Table 2-1: Comparative Analysis of Routing Protocols as Reviewed

As evidenced, the research gap predicted in this study is the efficiency of energy and quality of service aware protocols in wireless sensor network approaches in a manner to maintain independence from global addressing and full network coverage, together with energy efficiency. This study mainly focuses on models derivation for wireless sensor networks clustering approaches to perceiving, explain and estimate the popular routing protocols operation. Another reason to conduct this study is to design an efficient energy and quality of service aware routing protocol based on related examinations and derived models. The routing protocol predicts the quality of service paths for real-time information with some end-to-end delay needs. To assist both real time traffic and best effort at the same time, a queuing model is employed. The queuing model permits service sharing for non-real time and real time traffic. The preferred model of queuing for the protocol permits the throughput for normal data not to destroy by using that service rate on every node. The protocol effectiveness is validated by simulation. The outcomes of simulation show that the routing protocol performs well consistently on the quality of service metrics average delay and throughput, in contrast to a baseline non-quality of service aware protocol that uses the similar link cost. Thus, for a routing protocol the energy efficiency and quality of service aware information will be essential.

2.5 SUMMARY

The sensor data routing has been one of the challenging areas in WSN, and it includes multi-hop interaction. Through the sensor nodes cooperation, the wireless sensor networks send and gather different types of messages about the monitored surroundings to the sink node which performs the data and reports it to the user. For every sensor node to offer a quality of service, the wireless sensor network must manage the routing data based on reliability, delay and efficiency of energy. This study highlights the gaps in existing protocols as absence of a comprehensive protocol which addresses independence from global addressing, full coverage and energy preservation all at the same time. The research hence proposes a clustering model that can offer the quality of service that reflects changes properly in the status of network regarding delay and reliability, even in situations with a deficiency in resources of a sensor node. The algorithm proposed in this study has the benefit of reducing the messages of routing control and therefore, can operate safely from the energy efficient prospect. This is because the algorithm uses messages of broadcast transmitted by the sink node regularly. It can be concluded that decreasing the amount of interaction by aggregating or eliminating redundant sensed information and using the link of energy saving would save the huge amount of energy, thus prolonging the wireless sensor networks lifetime.

CHAPTER 3

3 AN ENERGY AND QOS AWARE EVENT DRIVEN ROUTING PARADIGM

3.1 INTRODUCTION

In so far, detailed investigation and literature review has been carried out and it is pointed out that one of the core problems in WSNs is the problem of energy scarcity. To overcome this problem a multitude of techniques have been developed to enable the nodes to use energy more efficiently.

In this chapter, we take Directed Diffusion routing protocol as a platform based on which we then propose a noble paradigm for a specific event-driven category of applications. We begin with elaborating directed diffusion in details and the distinctions of this paradigm in comparison to other related works. It will be further demonstrated that our “push paradigm”, enhances the energy efficiency, and at the same time reduces the latency of such “event-driven” WSNs. We will then, first in theory; and then by use of a simulator environment prove the validity of our paradigm for a generic scenario. To this end, a generic scenario based on aforesaid class of applications is proposed as an example. This scenario is then implemented and compared to directed diffusion.

Exploiting global addressing, and solutions like IP based routing protocols, is not practical in WSNs because:

- Vast number of nodes will create a significant overhead on the limited computing and power source of WSNs.
- Multi point to point nature of data flow in WSNs as opposed to point to point or point to multi point data flow in typical networks that exploit global addressing.

Therefore, data centric as opposed to address centric routing is a solution to overcome such issues.

To this end, we will first propose a data centric routing protocol based on the famous Directed Diffusion protocol that can outperform directed diffusion in terms of energy consumption and QoS in specific type of networks.

We will then, examine the shortcomings of such initial paradigm and endeavour to optimise it by proposing a wholly new paradigm based on clustering. Finally, the clustering paradigm will be put in to test and the results will be compared against the popular directed diffusion.

3.2 DIRECTED DIFFUSION PARADIGM

Directed Diffusion protocol is based on naming data, using an attribute-value pairs to aggregate the data forwarded from several routes; eliminate the redundancy; and optimize the number of transmissions. In this protocol, sink sends a query to certain nodes and asks for specific data. This query, called *interest,* is created based on the attributes and value of the data. This is the first phase of directed diffusion. These attributes and values are application dependent, and there is no standard for defining them. For example, data properties can be the name of the object, the time interval which the object is desired to be monitored and the duration of monitoring. Other elements of directed diffusion are data message, gradients and reinforcement. Nodes can cache this interest. These cached interests can then be used to compare the received or detected data with the attribute-values of the interests. The dissemination of interests in the network set up a gradient. Nodes send the data matched with the interest, back to the requesting node using this gradient. This is the second phase of directed diffusion. Gradient's properties can be data rate, time interval, duration and expiry. The interests flow towards the originator of the interest using one or more gradients already set up (in the first phase). The network then reinforces some of the routes for transmission of the data (in second phase). Subsequently, the interest will be resent to the nodes with smaller intervals through the reinforced route(s) in order to receive data more frequently.

In case of a failure in the established routes, directed diffusion associates reinforcement among routes with lower data rate or less valuable gradients.

Directed diffusion does not need any addressing mechanism since all communication is neighbour-to-neighbour and the data is value attributed. The capability of in-network data aggregation and caching significantly reduces the energy consumption and delay. Furthermore, due to the on-demand nature of directed diffusion, there is no need for global topology retaining. The default Directed diffusion (2-pull phase) is an appropriate method for *query based* applications. We introduce a new application of directed diffusion routing protocol in a peculiar yet vastly used type of WSNs with multiple number of sinks and sources and limited types of data. For such WSNs, a particular mode of directed diffusion (Push) is prescribed to enhance both QoS and energy efficiency of the network in an event based network with limited data typology and multiple sinks/sources. This paradigm is later validated by implementing said WSNs in a simulator and evaluating the results compared to the default mode of directed diffusion (2-Pull phase). To this end, in the following section, the characteristics of QoS and the effect of data dissemination on energy efficiency is elaborated.

3.3 QOS IN WSNS

Due to specific features of each network, different QoS expectations may be requested from the network. The limitation of bandwidth and mobility of ad hoc networks require completely different type of QoS and this makes it challenging. This is worse in case of WSNs as the power constraint is more severe and the processing power is even lower. Therefore, new QoS parameters must be defined to deliver the data in an efficient way in WSNs. Should a set of parameters is defined for QoS, designers will be able to determine which parameter(s) is applicable to their network.

3.3.1 NETWORK AND APPLICATION BASED QOS

There are many types of sensors with their own applications and QoS expectations. Therefore, it is not feasible to examine them individually. However, since the QoS is imposed by applications to the networks, aspects other than networking aspect of QoS can be considered. Different interpretations exist for QoS, depends on the area it applies to. For example, in an event detection application such as temperature or humidity detection, failure or wrong detection of event may happen due to management or deployment of network, for instance lack of coverage in the event area. Thus, the coverage could be one of the parameters of QoS. Another reason for failure may be inaccurate or low rate of observation of sensors. Therefore, accuracy and error rate can be another parameter of QoS. Further, information loss can be considered as a QoS parameter

From network point of view, the way that underlying network delivers QoS by utilizing the network"s resources is concerned. It is not feasible to examine each application in WSNs individually. Applications should be examined in classes, clustered by their common characteristics and requirements from the network. In effect, the application itself is not considered from QoS point of view, but the way that data are delivered from sensors to the sinks is important. For an event driven application the situation is as below:

The event-driven applications are non-end-to-end, interactive, delay intolerant (real-time) and mission critical. The application detects the events and acts appropriately. The actual application is non end-to-end, since there is a sink in one end, and a range of sensors on the other end. Thus, the redundancy might be very high since the sensors are intensively correlated. Also in case of an event, a large traffic may propagate towards the sink from the sensors within the range of the event called “event shower”. Event-driven data delivery includes many WSN applications which needs to take an action in case of occurrence of an event, for example actuating an alarm in case of temperature raise/humidity drop in forests.

3.3.2 PARAMETERS OF QOS IN WSNS

It can be seen that end-to-end QoS parameters are inappropriate for non end-to-end applications. Hence, some non end-to-end parameters must be proposed for WSNs. The below parameters are called collective QoS:

- Collective latency
- Collective packet loss
- Collective bandwidth
- Information throughput

WSNs are not mainly utilised for video and voice streaming, therefore jitter is not a major parameter of QoS. Collective latency is the time difference between the first and last packet collected with sensors reaching the sink. Collective packet loss is the number of lost packet during data collection of an event. Collective bandwidth is the required bandwidth for delivering the data of an event to sink(s)

3.4 DATA DISSEMINATION IN DIRECTED DIFFUSION

The fundamental of directed diffusion was discussed before. Hereby, we consider directed diffusion as an open paradigm that can be tailor designed for a class of applications.

As discussed earlier, directed diffusion is completely different from IP-based paradigms where nodes have a unique address in the whole network and the data forwarding is layered on top of this end-to-end addressing. In directed diffusion, a code is run throughout the network to aware the nodes of the application. This code allows diffusion to undertake in-network message processing such as caching and aggregating. This in turn, decreases the end-to-end traffic, and results in significantly better energy savings. Each node which is interested in receiving data, should subscribe for that desired data using publish-subscribe API. Nodes become the sink once they subscribe to receive data. The nodes which detect that particular data publish it and in turn, they become the source. The next step is the dissemination of this interest from sinks in the network and in response, the dissemination of the data back to the sinks from the data generators (the sources). Since communication uses significantly more energy than computation [15], the methodology for data dissemination in the network is the most important point for energy efficiency of the routing. Non-optimised data dissemination can result in excessive delay and packet-loss in the network. Therefore, the appropriate dissemination of data should be decided and designed based on the application of the network. For example, for tracking a mobile object in the network, the sinks should send their interest based on the attribute and value of the data, as well as the time interval and the duration that they desire to receive that particular data. This interest should be periodically sent towards the sources to ensure that data arrives reliably and the best routs are always selected. The default directed diffusion propagates the data based on a technique called 2-pull-phase. As the name indicates, data propagation constitutes of two phases. This method tries to establish several routes between sources and sinks. The sinks subscribe for a particular data and create a message in accordance to naming concept which comprises of key, type, operator and value. The key and the value of the data define the specification of the desired data, for example, 4-wheel truck with 80% confidence. The type defines whether a data is string, integer, binary data, floating number, etc. The operator enables the attribute to have the comparison option, for example, EQ (equal), GT (greater), LE (less than) and so on. The purpose of this exercise is to examine the effect of the dissemination technique exploited in directed diffusion to optimise it for the specific set of applications, explained later in this section. Therefore, the attribute and value of the data and the filtering methods used in directed diffusion is kept as simple as possible and identical in all scenarios to ensure the performance is merely the effects of data dissemination methodology and not the other parameters.

Having the interest defined based on the naming concepts, it is propagated throughout the network with simply broadcasting it in the whole network unless other techniques such as geographically dividing network into different regions is used such as the techniques exploited in GEAR; or sending the interest to some selected nodes possibly chosen by a random selection. Sending the data to some nodes rather than broadcasting it is of course a trade-off between delay and energy efficiency. Each node upon receiving the interest from its neighbours, sets a gradient towards that neighbour based on parameters that can be defined such as data-rate derived from time interval attribute, time duration derived from start/stop time and possibly some aspects of “operator” defined in naming aspect, for example greater than 80% confidence. The node then, cashes the interest in its interest table and forwards it to its next hop neighbours. If a node receives a similar interest from more than one node, it simply discards it. Two interests are similar if all attributes of them are similar. If two interests are different in time duration but same in all other parameters they can be considered as two different interests. This process continues until the interest reaches the sources where the nodes switch on their sensors to detect the interested event. Upon detecting the relevant data, the sources forward it in the network to the nodes that they received the corresponding interest form. Sources send the data to the nodes from which they receive the interest, according to the gradients that they have set towards that node. This process continues until the data reaches the interested sink(s). If a source has received one interest from several nodes but with different data rate, it sends back the data to each one based on the data rate that they have specified in the data rate field. When an interest expires, it is removed from the interest table and the corresponding gradients are removed as well. The propagation of interest in the network and return of the data to the sinks is called exploratory interest and exploratory data. Exploratory interest and data comprise the first phase of the 2-pull phase. In the second phase, the actual data should start flowing towards the sinks. This is done by a technique called reinforcement. Sink, upon receiving the data from several routes decides which route is better for receiving the data onward. Therefore, the sink starts sending the interest with higher data rate into that route in order to reinforce that route to bring the data. The better route is selected according to several parameters such as delay, packet loss ratio and the data deficiency rate. Sink also can reinforce more than one route for receiving the data in case of node or channel failure in one or more of the routes, to receive data from other routes. This technique trades off energy conservation for fast data recovery. The reinforcement can be positive reinforcement as explained, aiming to increase the data rate in the desired route. Otherwise it can be negative reinforcement by sending lower rate interest to undesired route(s) in order to tear apart those undesired routes. The sink keeps sending interest but with lower data rate to keep the routes alive and to adapt to the network dynamics. The propagation of actual data from sources to sinks is the second phase of the 2-pul phase.

3.5 DIRECTED DIFFUSION FOR EVENT BASED APPLICATIONS WITH LIMITED DATA TYPOLOGY AND MULTIPLE SINK/SOURCES

A significant amount of time and energy is consumed in the first phase of the 2-pull phase directed diffusion, which is necessary in query-driven applications. This, however can be omitted in an event driven scenario where the nodes are fixed and the event is static.

Temperature detection in an area is a typical example. In such scenario, there is no need for a sink to send the interest to the sources on a regular interval and asks for the temperature to be read and sent back. The sinks can subscribe for the data and instead of propagating the interest, and wait for the data to be sent back when the event occurs, the nodes in directed diffusion are application aware; therefore, the sources can be set to detect the required data and broadcast it throughout the network. In this scenario, one of the exploratory phases is omitted and there is only the data exploratory phase which follows sources to the sinks. The reinforcement and path selection is based on the data received from sources. This method is more effective when there is no geographical division in the network and there are several sources to send the data and several sinks interested in that data because in this case, large scale data dissemination is nullified by eliminating the broadcasting in the first phase of directed diffusion.

Default directed diffusion (2-pull phase) maintains at least one active route between a source and a sink, even when there is no event detected.

Below scenarios is illustrating the inefficiency of 2-pull phase and the advantage of using push instead:

Consider an event-driven network comprised of several nodes interested in a data and several nodes which can generate this data; the data-rate is low and once the sources detect this data, they forward it to the sinks. In this case, there is no need for propagating the interest throughout the network. Instead, the interest can be kept local in the sink while sources broadcast the exploratory data upon detecting an event, until they reach the sinks. Positive reinforcement is created in this phase recursively towards the sources from the sink and the actual data is propagated back from sources merely on this positively reinforced path.

To evaluate the effectiveness of this method (which is known as push, because the data is pushed by the source as opposed to being pulled by the sinks), the network is considered to have several sources and sinks. All sinks are interested in data generated by all sources. In fact, there are only few types of data generated in the whole network and sinks are interested in these particular data to act accordingly upon receiving it. Study of various sources and literatures on WSNs, concludes that our described scenario constitutes for one of the most common and realistic utilizations of WSNs. In fact, although the applications of WSNs are unlimited, the case that the whole network is interested in one or few types of data is common.

As an example, consider an industrial machine in which that the temperature or the level of lubricant in several parts of it should be checked and in case of passing the threshold level the data should be sent towards the sinks in several other parts for taking the necessary actions. Plausibly, battery replacement is nodes may be difficult and expensive, as the production line should be stopped and machine get knocked down. In such case, the data rate is usually low; thus, there is no need to maintain an active route from each sink to each source at all times. The routes are created once the event is detected, and the data is forwarded at the same time (Toussi, et al., 2010). In the following section, the efficiency of energy conservation by this method, and its competitive advantage comparing to default direct diffusion will be further elaborated by presenting a scenario in NS2 simulation (Sundani, 2011); (Sriporamanont & Liming, 2006) environment followed by the results.

3.5.1 EXPERIMENT SETUP

Now it is the time to evaluate the effectiveness of the aforesaid method. To this end, a network with three different sizes is designed with following attributes:

- 25 nodes (5x5) in a 160 sqm,
- 36 nodes (6x6) in 200 sqm
- 49 nodes (7x7) in a 240 sqm

The logic behind increasing of the physical size of network as well as the increases in the number of nodes in each scenario, is to keep the network density intact, and also to omit any possibility for in-network connectivity effect.

Each scenario is implemented with different number of sinks and sources to study the performance of the network in different situations. Each scenario is simulated twice, once with 2-pull-phase and once with push to compare the result in different situations.

Nodes are positioned on a flat grid with 40 meters' distance from each other in both. Nodes are selectively positioned and not randomly scattered, to make sure the topology is the same in all simulations, specifically in terms of in-network connectivity.

Data propagated in the network is nothing but a ping packet, which is broadcast in the network during a pre-defined time interval. Such a neutralised data packet which is of no attribute-value pair, is with an identical transmission time which in turn avails an equal condition for both 2-pull and push.

We further consider the assumptions:

i. Initial energy of nodes is set to 1000 Joules.

ii. The network runs for 100 seconds.

iii. The queuing type is drop-tail with only 50 packets queue long to increase the chance of packet drop for better result assessment.

iv. The antenna is an omni-directional with 1.5 meters height in the middle of the nodes with flat gain to nullify the antenna gain effect during reception and transmission.

v. The MAC layer is 802.11.

vi. The bandwidth of the shared media is set to 28.8 kbps.

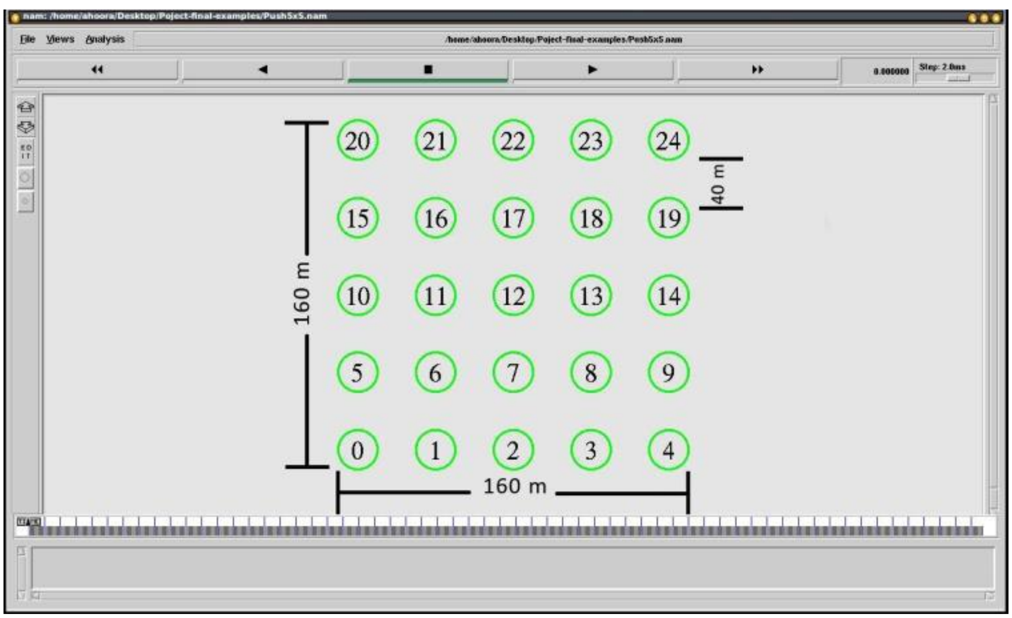


Figure 3-1: Network of 25 nodes in 160 sqm with 40 m distance between nodes in each direction captured in NAM

Sources and sinks are selected from the most left column and the most right column respectively in four different manners:

- 3 sources and 2 sinks.
- 3 sources and 3 sinks.
- 5 sources and 2 sinks.
- 5 sources and 3 sinks.

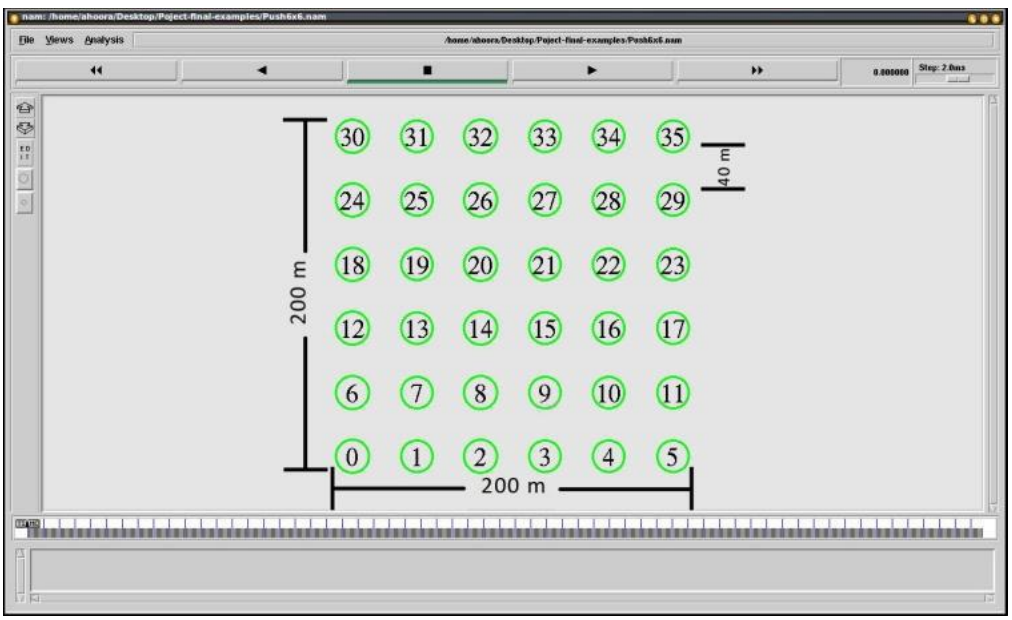


Figure 3-2: Network of 36 nodes in 200 sqm with 40 m distance between nodes in each direction captured in NAM

Sources and sinks are selected from the most left column and the most right column respectively in four different manners:

- 3 sources and 2 sinks.
- 3 sources and 3 sinks.

- 6 sources and 2 sinks.
- 6 sources and 3 sinks.

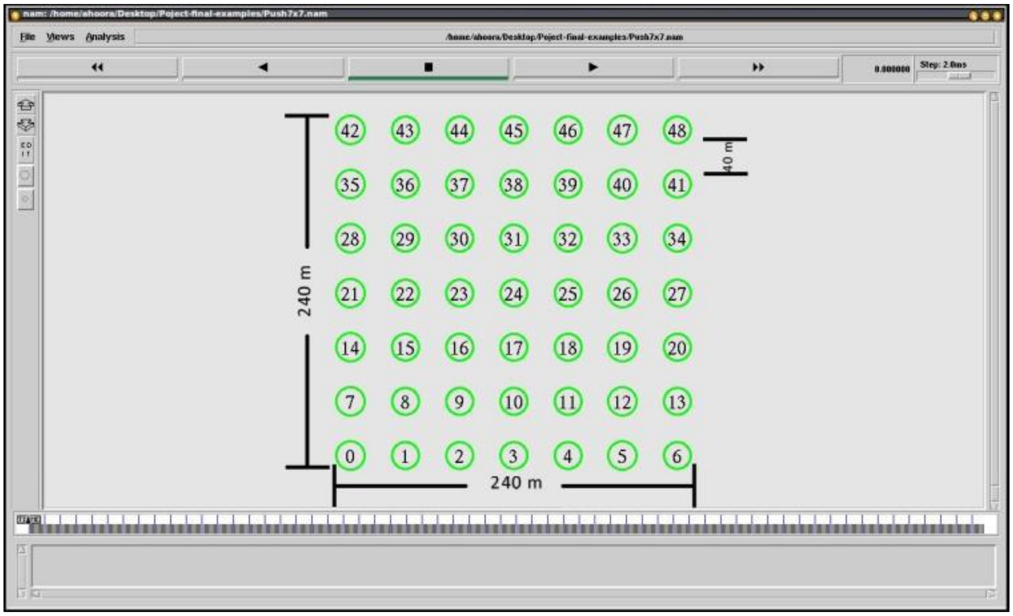


Figure 3-3: Network of 49 nodes in 240 sqm with 40 m distance between nodes in each direction captured in NAM

Sources and sinks are selected from the most left column and the rightest column respectively in four different manners:

- 4 sources and 3 sinks.
- 4 sources and 4 sinks.
- 7 sources and 3 sinks.
- 7 sources and 4 sinks.

3.5.2 EVALUATION OF ENERGY EFFICIENCY

The result of the simulation in terms of energy dissipation and efficiency of each network scenario with corresponding numbers of sources and sinks is illustrated in below figures.

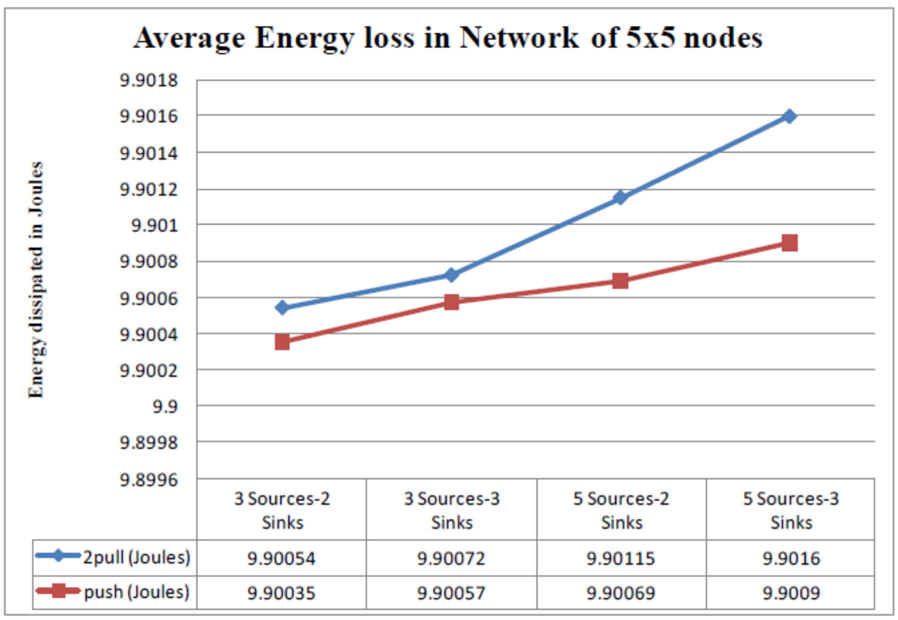


Figure 3-4: The average energy dissipation in 5x5 nodes network

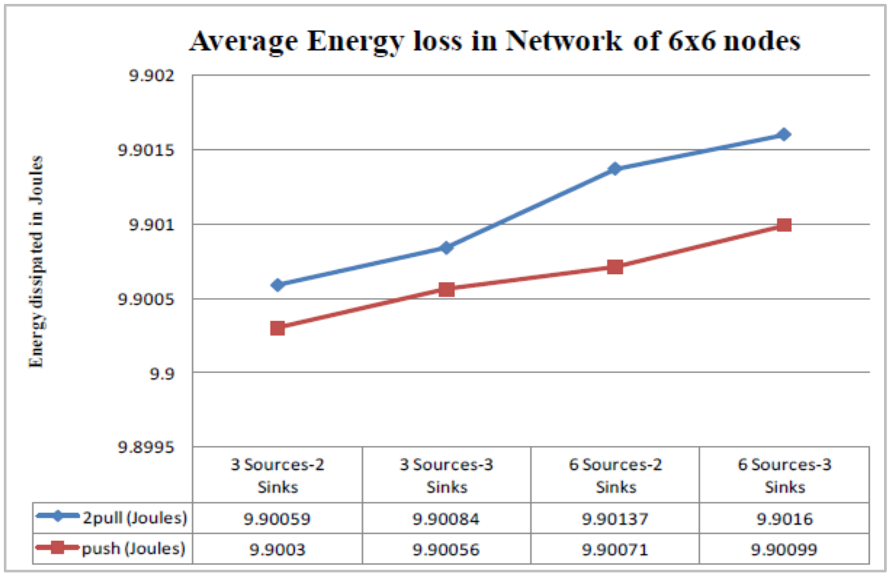


Figure 3-5: The average energy dissipation in 6x6 nodes network

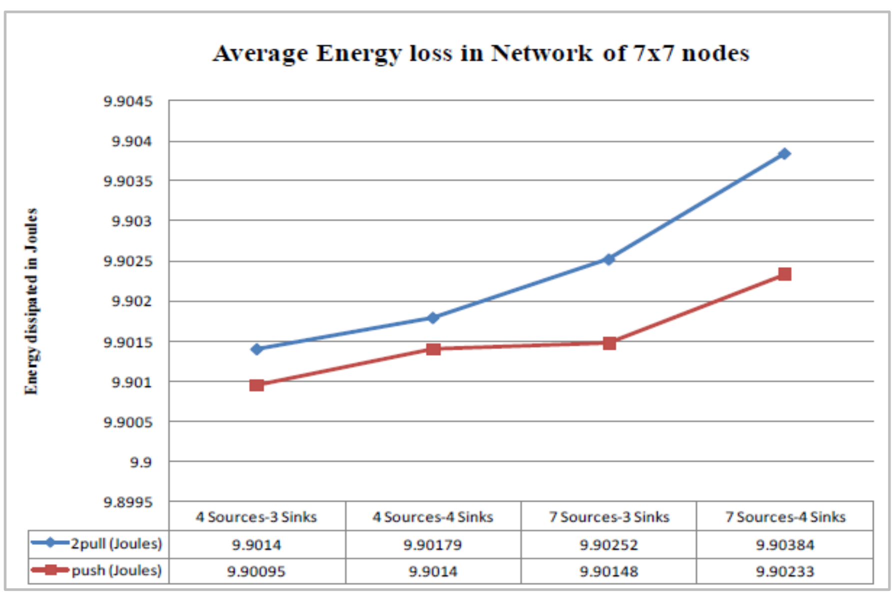


Figure 3-6: The average energy dissipation in 7x7 nodes network

Above figures, further illustrates the difference of energy in each network for both default directed diffusion (shown as 2-pull) and the modified one for the purpose of the applications of this paper (shown as push).

As demonstrated above, the dissipated energy in push scenario is lower than that in the 2-pull phase. Moreover, evidently as the number of sources and sinks increases, the difference between them increases.

The network was run for just 100 seconds. This explains why the energy dissipation difference between 2-pull phase and push is not significant. Such network however, is expected to work for several weeks and this could lead to a considerable energy saving over such a protracted time span. As the number of sources and sinks increases in each scenario, the difference between energy dissipation of 2- pull and push raise. This confirms our earlier evaluation of push and 2-pull for such an event-driven network, in which it was theoretically concluded that push method holds a comparative advantage for such networks. In other word, by using push technique in the even-driven networks, the bigger the size of the network, and the higher the number of sources and sinks, the more energy saving can be achieved.

This energy saving is therefore, the result of less interest dissemination and absence of an active link between each source and node in the network.

3.5.3 EVALUATION OF THE NETWORK LATENCY

Collective latency is the major parameter in QoS. Therefore, the performance of two networks in terms of collective latency, will now be assessed. The collective average latency of each network for different number of sources and sinks are demonstrated in below figures.

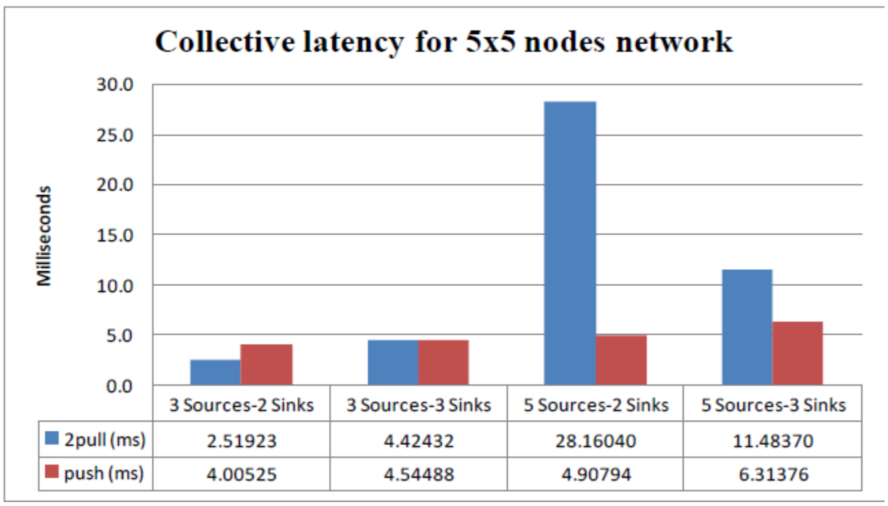


Figure 3-7: The collective latency in 5x5 nodes network

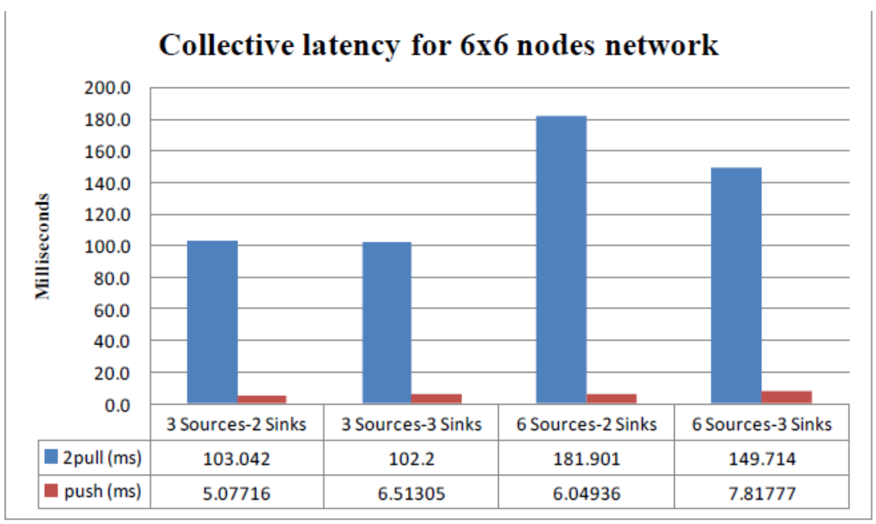


Figure 3-8: The Collective Latency in 6X6 nodes network

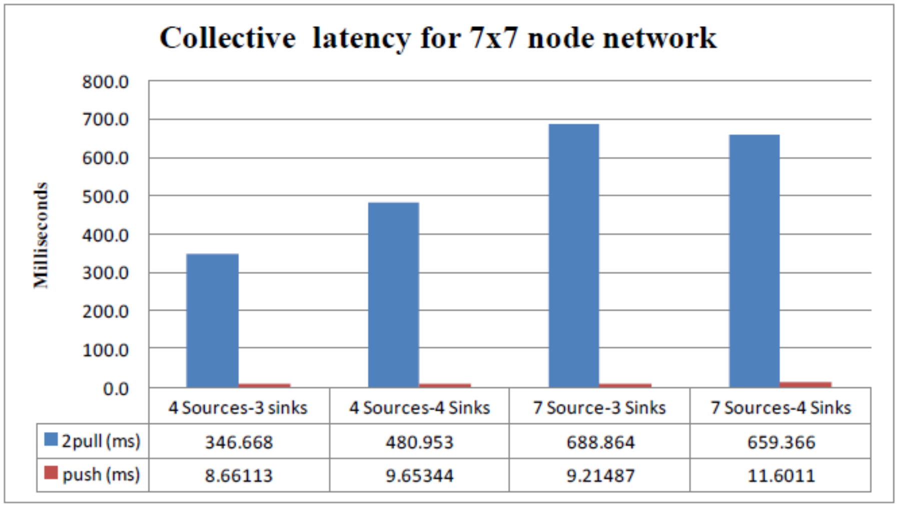


Figure 3-9: The collective latency in 7x7 nodes network

As illustrated in figures above, there is a significant difference in delay between 2-pull phase and push networks. As the number of nodes increases, this difference grows significantly. This is due to the number of active links between sources and sinks in the 2-pull which do not exist in push networks. In 2-pull phase when a data is desired, it should be requested by the corresponding sinks. This request should be propagated throughout the network until it reaches the appropriate source with the desired data is cashed in its cash table. This data should be then returned to the sinks. Consequently, a route is established between sources and sinks using reinforcement. Data then starts flowing though this route. In other word, the data should be pulled by the sinks. This imposes an extra overhead on the network, and as a result, the round trip travel of data, leads in excessive delay. The same data in push is propagated once it is detected, and the sinks which have already subscribed to that data will receive it as exploratory data. Reinforcement is then established and subsequently receives the actual data. In other words, the data is pushed by the source in push and this reduces the number of trips and reliefs the network from excessive overhead.

3.6 CLUSTER BASED DATA CENTRIC ROUTING PARADIGM

As discussed, push method proved to be a choice where the network is flat and without hierarchy; and hence is limited in terms of scalability. For those scenarios which necessitate such hierarchy and scalability, further methodologies such as clustering can be considered.

To this end, we propose an efficient method for grouping adjacent nodes into clusters, electing cluster heads; diffusing exploratory interests through cluster heads and finally receiving the data through the cluster heads. In this method, only the cluster heads will receive the broadcast messages therefore, significant energy previously consumed for communication and processing the broadcast messages can be saved and in addition, the process of diffusing the messages in the network would be faster hence less in network latency would be achieved.

In this process the following assumptions are made:

- All nodes are stationary
- Sink has access to the unlimited power source
- Sink is informed of the total number of nodes in the entire network
- Nodes can locate their geographical position
- Nodes have a unique identifier (e.g a MAC address or Bluetooth unique identifier)

We will then simulate a typical scenario and then compare the results of our proposed method against those of directed diffusion.

3.6.1 SCENARIO PROPOSAL

To evaluate the performance of proposed clustering method, the following scenario will be considered and then simulated in NS2 environment.

- Sensors are randomly placed within an area of 10,000sqm
- Number of nodes is set to 100
- Initial energy is set to 15J
- The communication range of nodes is set to 150m
- The energy threshold is set to 11.25W.
- The hard threshold is set to 0.75W.
- The transmission protocol is IEEE 802.11
- The transmitter circuitry dissipation is 50nJ/bit.

We have also assumed that the area is divided into 9 geographical areas and therefore, sink has selected 9 cluster heads within the entire network. In our scenario, all nodes are set as sources to ensure the concept of re-election based on energy level is evaluated.

The sink node diffused an interest message every 2 seconds targeted at one of the clusters in round robin manner. A node within the target cluster responded to the interest 2 seconds after receiving the interest. The responsive node was randomly selected. The simulation run time was experimentally increased to reach a point that the energy of all nodes were below the hard threshold. This was equal to approximately 10000 interest message transmission within 6 hours.

Directed diffusion was set over the same parameters and sink targeted the same geographical area for the data and a node randomly responded to the interest within the same time interval. The performance was evaluated based on two criteria: The average latency of the network from the time that an interest was diffused in the network until the respond was received by the sink (The source 2s waiting period is excluded from the result) and the number of alive nodes during the simulation.

3.6.2 EVALUATION OF ENERGY EFFICIENCY

As it is illustrated in figure 3-10 when directed diffusion is used as the routing paradigm nodes start failing after an hour whereas the proposed method %100 of nodes are alive for nearly 2 hours which is double the period. This trend stays true in the entire period of the evaluation. Finally, the network stays alive for nearly %10 longer. This is due to less involvement of nodes in activities such as data forwarding aggregation and better task distribution among the network.

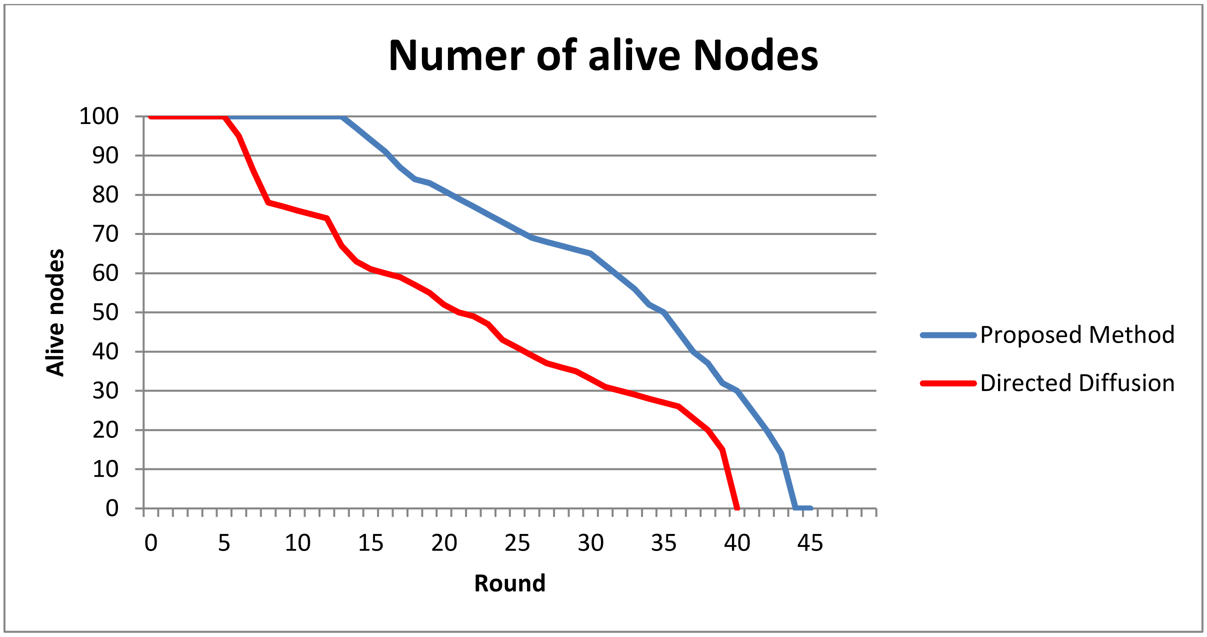


Figure 3-10: Number of Alive Nodes

3.6.3 EVALUATION OF NETWORK LATENCY

Figure 3-11 illustrates the network latency comparison between directed diffusion and the proposed method. The proposed method outperforms the directed diffusion due to targeted data dissemination. As explained in section 3 after initial phase the sink will only propagate the interests within cluster heads. This considerably reduces the network latency as the number of nodes that data must be diffused through is only almost %10 of the entire network.

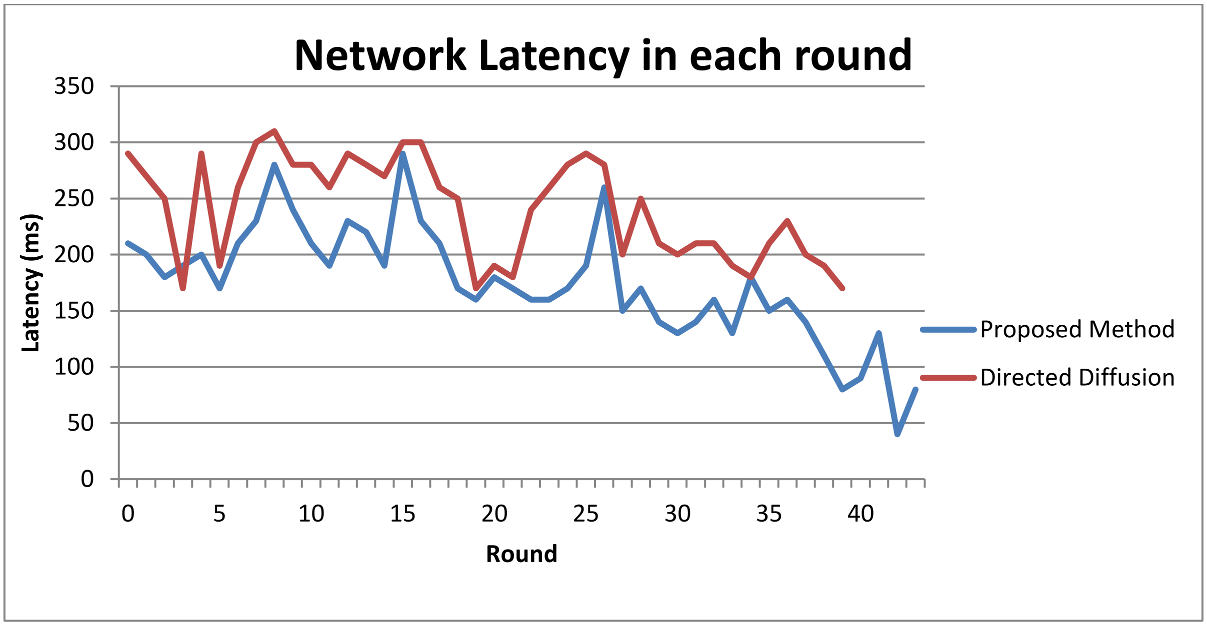


Figure 3-11: Network Latency

3.7 CONCLUSION

Based on the results of simulation and the theoretical evaluation as examined in our proposed Push Based paradigm, the push provides several advantages over 2-pull phase. However, as elaborated earlier, the outperformance of push is dependent to the application of the network, and although push is very effective for such event-driven networks (as defined in the scenarios of this project), it cannot be used in a query-driven network where sinks need to receive data on demand.

For instance, in case of mobile object tracking, sinks may need to define what kind of data they are interested in and depending on the attribute and value of data, diffuse this interest in network and task sinks to receive corresponding data. Obviously, push cannot be implemented in such scenario since sources do not know what data sinks are interested in, at any time. In other word, if the types of data which sinks are interested in are predefined for sensors then push can be implemented. However, if the requested data is arbitrary and its characteristics change over the time, then this characteristic should be defined by the sinks at the time of request.

In our proposed method of clustering, the formation of clusters and subsequently interest diffusion and data aggregation were examined. We conclude that grouping nodes into several clusters, electing one as the cluster head and responsible as interest receiver/data aggregator and router would save energy and reduce in network latency. It was demonstrated in evaluation results how the proposed method outperforms directed diffusion data centric routing paradigm.

Data centric routing paradigms are important methods of data routing in WSNs for several reasons, most importantly the application awareness of nodes at routing layer which result in effective in data aggregation and redundancy elimination and significantly less overhead on each data packet. Less overhead in data centric routing paradigms results in remarkable energy saving at network layer (Chang & Tassiulas, 2004). Another important feature of data centric routing paradigms is the possibility of tailoring the paradigm based on the network application. Such feature can result in more secure communication and proprietary routing paradigm that the exact routing and data structure would be only disclosed to the authorised people. This is an important advantage for high profile applications such as military based applications. We intend to evaluate the performance of the proposed method with other data centric and hierarchical routing protocols.

CHAPTER 4

4 ENERGY AWARE AND GLOBAL ADDRESS FREE CLUSTERING MODEL (EAAFC)

4.1 INTRODUCTION

In chapter 3, we elaborated the PUSH paradigm and by way of experimenting we demonstrated how eliminating the initial phase of query driven networks improve the network latency and the energy dissipation. Inspired by the paradigm and the clustering method described in chapter 3 where no global addressing mechanism is required and packets can be routed based on the application contents, we propose the design and implementation of an energy and QoS aware routing protocol for wireless sensor networks. To achieve this, we developed Energy Aware and Address Free Clustering (EAAFC), a mechanism for clustering that examines communication consumption for energy and effect of failures in the nodes on networks with various densities (Mehdi Toussi & Politis, 2013). Developed algorithm aims to group the nodes into groups with the minimum quantity of cluster heads. EAAFC does not need time synchronisation nor global addressing for performing. Addressing mechanism impose complications and overhead to networks. Assigning locally unique identifier to the nodes is one of the goals of this research. Later in evaluation we discuss how such approach helps to outperform other related paradigms. Similarly, we try to group the maximum number of nodes into each cluster hence electing the minimum number of cluster heads as cluster heads consume more energy compared to the other nodes. Another goal is to ensure with minimum number of cluster heads the entire network is covered. Coverage is a valuable QoS parameter in WSNs. In following subsection we will discuss some of the famous addressing mechanisms, The clustering methods as well as how other research works try to achieve coverage the maximum network coverage. We will see in this chapter Evaluation outcomes shows that EAAFC extends the lifetime of the network as well as enhances the coverage in the network. We evaluated EAAFC performance through NS2 simulator. This research implicates EAAFC to homogenous and static nodes and assumes the base station is fixed and far away from the network

4.2 OBJECTIVES

Below summarises the objective of EAAFC clustering model:

- To achieve energy conservation and coverage preservation
- To maximise the cluster size hence select minimum number of cluster heads
- To ensure every node belongs to a cluster
- To achieve a cluster in which each node is maximum 2 hops away from the cluster head
- To ensure nodes self-assign unique ID based on the local information

4.2.1.1 NODES STATES

Each node in network can be in one of following states:

- cluster head
- 1-hop member (one hop away from the cluster head)
- 2-hop member (two hops away from the cluster head)
- Un-cluster node

4.3 ADDRESS ASSIGNMENT

With the advent of WSNs in recent years several addressing protocols have been developed (Ali & Uzmi, 2004), (ELMoustapha, 2008), (Schurgers, et al., 2002), (Zhou, et al., 2005).

In (ELMoustapha, 2008), the authors propose an algorithm that assigns globally unique addresses by computing the size of the network. To this end, using a tree structure is proposed. The unique addresses are then assigned using the minimum number of bytes. On the downside, this protocol needs to use the temporary ID, the final ID and the information related to size of sub-trees. Processing such amount of data results in high communication cost. In most of the addressing and assignment protocols, IDs are locally unique within 2-hops so to distinguish a sensor from those in its vicinity (ELMoustapha, 2008). Authors in (Schurgers, et al., 2002) propose a pro-active conflict detection procedure for a general sensor network. When a node joins the network, it first gets a random physical address assigned to it, and then announces its

ID to all neighbouring nodes in periodic intervals by sending a hello message. Therefore, nodes which are 2 hops away will receive information that can resolve the ID conflicts.

The proposed approach in (Zhou, et al., 2005), is for the nodes to randomly choose an address that is likely to be unique within their 2-hop vicinity. In this method, no conflict resolution is performed until data communications are commenced.

Focusing on Cluster Based WSNs, (Ali & Uzmi, 2004) proposes a protocol to prevent the risk of collisions. The authors propose that the nodes within a cluster are assigned different local addresses. Global addresses are then obtained by putting together the local IDs and the Cluster Head (CH) IDs. The caveat is that in case of larger networks, this protocol consumes a significant amount of energy.

4.4 CLUSTERING

Clustering the sensor nodes is a method which is most commonly used to intensify network coverage and extend the duration of network lifetime (Abbasi, 2007).

Clustering is accepted as one of the efficient methods for WSNs. In a cluster based WSN, only a few sensors are being elected as cluster head. The main aim of this cluster head is to receive information collected by non-cluster heads and sent to the sink node. Sink node is a node that contains “infinite” energy and all the information are feedback to this certain node for processing, analysing or forwarding. This way problems such as bandwidth limit and limited available are eliminated. Cluster heads can also act as routers. Clustering in sensor networks is used to transfer processed data to base stations, hence reducing the total number of nodes which take place in long distance communication (Chang, et al., 2015) which otherwise if it was forwarded directly by nodes would result in inefficient energy dissipation of nodes. Other than sensor networks, clustering has been implemented in fields like VLSI-CAD and data mining. A classical analytic VLSI placer utilizes clustering for adequate standard cell placement. These problem instances used to have more applications in sensor networks, especially in both master node selection and energy management. Clustering protocols are used to enhance the network lifetime. EAAFC verifies a technique which is used for cluster heads election and improves a gateway concept for advance nodes to transmit the data load from cluster heads into their base station. To utilise and preserve the energy of the network further, a sleep state is being advised for some sensor nodes. The suggested protocol has two various types of the node, normal and advanced. The main objective of this cluster protocol is to effectively maintain the energy consumption and enhances the lifetime of the certain network.

4.5 NETWORK COVERAGE

Network coverage is a crucial problem to be addressed in WSNs as it directly correlates the network’s quality of service (Thai, et al., 2008), (Cardei & Wu, 2006).

The authors of (Bae & Yoon, 2005) introduce an autonomous clustering protocol using the coverage estimation self-pruning. The nodes which have the largest expected coverage will be elected as CHs (Bae & Yoon, 2005). This protocol minimizes the clustering overhead and provides lower variation in the number of CHs over time, hence pruning. On the downside, this protocol is unable to guarantee full coverage of the network.

With energy efficiency as their core objective, in (Cardei, et al., 2005) the authors attempt to tackle the problems with having full network coverage by dividing the nodes into disjointed “coverage sets” that become active one after the other. In each coverage set, a large number of nodes to cover the targets become active, whilst the rest of the nodes are in a low energy sleep mode. However, this method relies significantly on a centralised processing solution.

Focusing on geographical location, the works in (Liu, et al., 2007) provides for a flooding technique that uses just 1-hop neighbour information. This method guarantees total deliverability and attains a local optimum for the number of forwarding nodes.

Works in (Wang, et al., 2009) address the problem of energy efficiency optimisation for the network coverage. The authors propose models for coverage and energy efficiency based on which, stationary nodes are distributed into clusters by entropy clustering.

Authors of (Couqueur, et al., 2002) undertake a thorough analysis of the strategies for node distribution to attain adequate coverage for distributed detection.

4.6 NETWORK FEATURES AND DEPLOYMENT

In a network that EAFFC is utilised nodes are scattered randomly and there is no mobile node in use, all nodes are static. There is also no location detection mechanism such as GPS in use. All the nodes within the network must be homogenous and there is no global addressing mechanism in place. All the nodes are uniquely and locally ID assigned.

4.7 EAAFC ATTRIBUTES

EAAFC takes the topological location of the nodes into account and does not require any time synchronisation mechanism. Within an EAAFC network, nodes make independent decisions per their schedule. Regardless of the network size, clustering is performed within a fixed time. The fixed time clustering formation and reformation is an effective method to eliminate unnecessary in network delays. Cluster reformation based on nodes threshold energy ensures nodes save energy to participate in network sensing and data forwarding and prevent in network breakage which can lead to loss of communication between different sectins of the network. Each node in EEAFC, is assigned with a unique local ID. This approach reduces the communication energy expenditure and improves the network coverage in large scale networks. By the end of clustering or re-clustering in EAAFC, all nodes belong to a cluster and no node is left un-clustered. This protocol examines communication’s energy consumption and the trends of node failures within clusters that have various densities. One of the objectives of EAAFC is to cluster nodes with as few as possible number of cluster heads. EAAFC does not need global addressing or time synchronisation to perform. Evaluation results prove that EAAFC extends the duration of network's lifetime while improving their network coverage (Mehdi Toussi & Politis, 2013). EAAFC does not require any time synchronisation mechanism and there is no location detection mechanism such as GPS in place. In EEAFC it is assumed that all nodes are homogenous menaing all the nodes are identical in terms of communication; computation and energy resources. There is also no global addressing required for the protocol to perform.

4.7.1 ENERGY CONSUMPTION

The energy model adopted for EAAFC is that used by Zhou in Reactive ID Assignment for Sensor Networks (Zhou, et al., November, 2005). The consumption of energy to execute digital electronics, lE_{elec} represents modulation, coding and processing and for communication lE_c. This involves both multipath fading (d^4 power loss) and free space (d^2 power loss). This relies on distance (*s*) between receiver and transmitter.

For sending an *n*-bit message with distance s the radio consumes

$$\boldsymbol{E_{TX}(l.d) = \begin{cases} lE_{elec} + lE_{fs}d^2 & d < d_0 \\ lE_{elec} + lE_{mp}d^4 & d \geq d_0 \end{cases}} \qquad \textbf{\textit{4-1}}$$

To receive l bit data the below is true:

$$\boldsymbol{E_{RX}(l) = lE_{elec}} \qquad \textbf{\textit{4-2}}$$

Where:

- lE_{elec} represents energy expanded for digital modulation, coding, signal spreading and filtering
- E_{fs} represents amplifier factors for energy for channel of free space

- E_{mp} denotes amplifier factors for energy for multipath channel for fading
- d_0 denotes threshold distance between sender and receiver that relies on circumstance.

4.7.2 DEFINITIONS

EAAFC aims to assign the minimum number of cluster heads and at the same time achieve the full coverage of the area. Heads in the cluster consume notably higher quantity of energy because of processing the aggregated data and data forwarding to base station. Thus, minimum quantity of heads in the cluster when protecting the full coverage will outcome in more efficient network in terms of energy consumption. EAAFC aims to choose the heads in the cluster from more sparse areas as failure in nodes in intense areas have less effect on network performance due to data redundancy and overlapped coverage. Only Few nodes in more sparse areas and network edge are unable to send their data to cluster heads due to restricted range of communication. To tackle this problem EAAFC permits 1-hop nodes to forward the information from 2-hop nodes to heads in the cluster. If we assume node as $NodeD(N_v)$ as total quantity of node neighbours N_v:

$$\boldsymbol{NodeD}(\boldsymbol{N_v}) = \boldsymbol{Count}(\{\boldsymbol{N_u} | \boldsymbol{dist}(\boldsymbol{N_v}, \boldsymbol{N_u}) < \boldsymbol{N_T}, \boldsymbol{N_u} \in \boldsymbol{N}, \boldsymbol{N_u} \neq \boldsymbol{N_v}\}) \quad \textbf{4-3}$$

We do not adopt any mechanism for location awareness in EAAFC degree message, $NodeD$ is adopted to determine the density of the various network parts.

Prior to any cluster formation the following 4 messages are adopted to perform the clustering process:

- **Degree Message ($NodeD$)**: Each node sends a message to the neighbours to inform them of its own $NodeD$.
- **Un-clustered nodes (N_{un}):** In cluster migration phase N_{un} is transmitted to indicate the number of neighbours.
- **State message (S_M):** Every node transmits its S_M to its neighbors to indicate its status i.e. clustered or unclustered.
- **Join message:** Unclustered nodes transmit a join message request to the cluster head or 1-hop member to become a 1 hop or 2 hop members.
- **Opt out message:** Such message is transmitted by cluster heads to notify their resignation in the subsequent round election as a cluster head.

N	***Set of ordinary nodes in the network***
N_u , N_v	***Differentiated representative nodes in N***
CH	***Set of cluster heads***
CH_n	***Cluster head with sequence number n***
H_1	***Set of 1-hop members of a cluster***
H_2	***Set of 2-hop members of a cluster***
H_{1j}	***1-hop member node with sequence number j***
H_{2i}	***2-hop member node with sequence number i***
$M_{1-hop}(CH_n)$	***Set of all 1-hop members of*** CH_n
$M_{2-hop}(CH_n)$	***Set of all 2-hop members of*** CH_n
$UN_{1-hop}(N_n)$	***Set of all 1-hop un-clustered nodes around*** N_n
$UN_{2-hop}(N_n)$	***Set of all 2-hop un-clustered nodes around*** N_n
N_{UN}	***Set of un-clustered nodes around each node***
$dist(N_u, N_v)$	***Distance between*** N_u, N_v
$NodeD$	***Number of neighbours of each node***
$Count(M)$	***Number of elements in a finite set M***
N_T	***Node transmission range***

$\boldsymbol{N_s}$	***Node sense range***
$\boldsymbol{T_{N_u}}$	***Delay of a node***
$\boldsymbol{E_{th}}$	***Energy threshold of each cluster head***
$\boldsymbol{E_R}$	***Residual energy of each node***
$\boldsymbol{E_{DA}}$	***Energy of data aggregation***
$\boldsymbol{f}$	***Number of frames of data transfer per round***
BS	***Base Station***

Table 4-1: List of Notations

4.7.3 CLUSTER FORMATION

Upon receipt of an initialisation message from base station each node broadcast a HELLO message to notify its existence and presence. To reduce the message collisions such messages will be transmitted in a window period which ranges between 0 and T_i. T_i is determined and calculated based on the network size and circumstance. Nodes then transmit their $NodeD$ based on the number of HELLO messages they receive.

$$T_{N_u} = \propto e^{\frac{1}{NodeD(N_u)}} \quad \propto = \textit{Constant to satisfy } 0 < T_{N_u} < T_i \qquad \textbf{4-4}$$

Nodes await their delay time, T_{N_u}, before they can determine to announce themselves as the cluster head. Those nodes that do not receive degree message greater than their own by the end of their delay time, will chose a randomly generated 4-byte integer as their ID and declare and broadcast the cluster head. As equation 4.5 recommends T_{N_u} is a decreasing function of $NodeD$. This maximises the node chance with higher $NodeD$ which denotes nodes in more intense areas to become a cluster head. Cluster head transmits a State Message s to all nodes within their transmission range, N_T.

Those nodes that are not a member of any cluster and receive the State Message from the cluster head consequently choose a random 2 byte integer, concatenate this 2 byte with cluster head's 4 byte integer and transmit back a join message encompassing their identification number to the cluster head. This join message confirms the 1-hop membership. In an unlikely circumstance that more than one node chooses identical identification within a cluster, cluster head can resolve the issue by choosing a new identification for one or more nodes and send back. Another alternative is for the cluster head to send a decline message to nodes with identical IDs and request a new generated ID.

A non-clustered node upon receiving a State Message from a 1-hop member will choose any one of the below mentioned statuses:

- If a non-clustered node becomes aware of one or more nodes with a higher $NodeD$ than that of itself within its N_T it will choose a random 2 byte integer, concatenate it to the 1-hop member ID and declare and announce itself as a 2-hop member.
- If no $NodeD$ larger than that of itself is identified it will announce as the new cluster head when the delay time expires.

Nodes which do not join any cluster which tends to occur more in sparse areas as well as at the networks edges choose a random 4 byte digit and develop their own clusters by the close of their delay time. This way every node within the network will possess a locally different identification and they recognize to which group of cluster they belong.

4.7.4 ENERGY MODEL AND DISSIPATION PATTERN

After the clusters are formed, the 1-hop members (i.e. nodes which are one hop away) transmit a list of their members to the cluster head. The identical fist 4 bytes of the ID assures only members of the same cluster are registered by cluster head. At this stage cluster heads creates a Time Division Multiple Access (TDMA) in which schedule all 2 hop members send their data to 1 hop members. 1 hop members in turn aggregates such data and forward to cluster head.

Assuming distance among the nodes of a certain cluster is less than d_0 the consumption of energy will follow the free space model.

$$\boldsymbol{E_{H_{2i}} = l \times E_{elec} + l \times E_{fs} \times dist^2(H_{2i}, H_{1j})} \qquad \textbf{4-5}$$

$$\boldsymbol{E_{H_{1j}} = l \times E_{elec} \times count\left(M_{2-hop}(H_{1j})\right) + l \times E_{DA} \times \left(count\left(M_{2-hop}(H_{1j})\right) + 1\right) + l \times (E_{elec} + E_{fs} dist^2\left(H_{1j}, (CH_k)\right)} \qquad \textbf{4-6}$$

Where $H_{2i} \in M_{2-hop}\left(H_{1j}\right), H_{1j} \in M_{1-hop}(CH_k)$

Subsequently cluster head aggregates the data received from 1-hop nodes and pass the information to base station.

The following formula applies to transmitted data in greater distance than d_0

$$\boldsymbol{E_{CH_k} = l \times E_{elec} \times count(M_{1-hop}(CH_k)) + l \times E_{DA} \times (\, count(M_{1-hop}(CH_k)) + 1) + l \times (E_{elec} + E_{mp} dist^4(CH_k, BS))} \qquad \textbf{4-7}$$

It is essential to define an energy threshold level to ensure cluster heads are re- elected once hit this energy threshold. The following equation is suggested to determine such threshold:

$$E_{th}(CH_k) = E_{CH_K} \times f = l \times [(E_{elec} + E_{DA}) \times \left(count\left(M_{1-hop}(CH_k)\right) + 1\right)$$
$$+\boldsymbol{\varepsilon_{mp}} \times \boldsymbol{dist^4}(\boldsymbol{CH_k}, \boldsymbol{bs})] \times \boldsymbol{f} \qquad \textbf{4-8}$$

Where:

$E_{th}(CH_k)$ is the energy consumption of cluster head CH_k in the current round. E_{th} is decided based on the number of 1 hop members and their distance from the base station.

E_{DA} is the data aggregation dissipated energy. This is the minimum required energy to accomplish the round. Figure 4-1 shows the energy threshold of cluster heads in distance and number of 1 hop members 2 dimension coordination. Figure 4-1

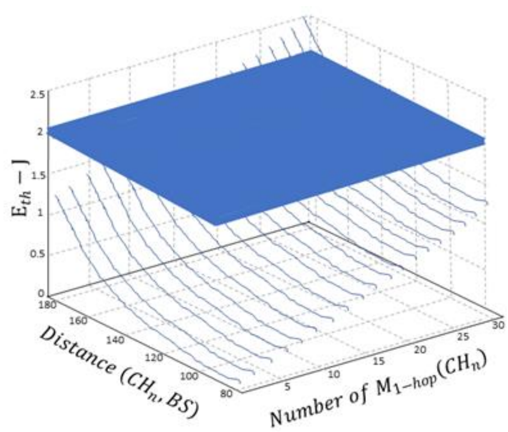


Figure 4-1 The energy threshold of cluster head

The pseudo code of cluster head formation and reformation is presented below:

$If\ \mathrm{E}_R(\mathrm{CH}_N) < \mathrm{E}_{th}(CH_N)\ do$

broadcast $Msg(ID$, E_{th}, OPTOUT-MSG, $M_{1-hop}(CH_n))$

$If\ H_{1j} \in M_{1-hop}(CH_n) and\ received$ OPTOUT − MSG $then$

forward $Msg(ID$, E_{th}, OPTOUT-MSG, $M_{2-hop}(CH_n))$

$end\ If$

$end\ If$

$If\ \forall\ N_n \mid N_n \cap (H_1 \cup H_2) \neq \phi\ \ do$

$wait\ T = 0$

$N_n\ broadcast\ Msg(ID$, E_{th}, STATE-MSG, $\mathrm{N}_T)$

forward $Msg(ID$, STATE-MSG, $\mathrm{N}_T)$‖ when a STATE-MSG is received

N_n puts all the receied messages into routing table

$N_{UN}(N_n) \leftarrow count\ \left(UN_{1-hop}(N_n) \cup UN_{2-hop}(N_n)\right)$

$T = T_{max}$

$end\ If$

$If\ \ \mathrm{E}_R(N_n) \geq \mathrm{E}_{th}(CH_N)$

$broadcast\ Msg(ID$, DEGREE-MSG, $\mathrm{N}_\mathrm{T})$

$If\ N_n\ has\ the\ maximum\ N_{UN}\ in\ the\ nodes\ broadcasting\ DEGREE -$
$MSG\ during\ \left(0, T_{N_n}\right)$

$become\ cluster\ head\ and\ broadcast\ Msg(ID$, DEGREE-MSG, $\mathrm{N}_T)$

end If

$end\ If$

4.8 CLUSTER HEAD REFORMATION

Once the cluster head's residual energy reaches the threshold level, it will send a resignation message to 1 hop node members which in return will be forwarded to 2 hop members. All members that receive the resignation message change their status to un-clustered.

At this stage node N_n broadcast a State Message within N_T and T_i. N_n also, forwards the received such messages to its neighbours. This forwarded message contains its own and the ID of the member from whom the message was received. Node N_n also forwards a degree message to all members within T_n. If N_n does not receive a degree message with N_{UN} larger than its own it will declare as the new cluster head.

$$\boldsymbol{UN_{1-hop}(N_n) = \{N_u | E_R(N_u) > 0 \ \& \ dist(N_n, N_u) < N_T,\ N_u \in (H_1 \cup H_2), N_u \neq N_n\}} \quad \textbf{\textit{4-9}}$$

$$\boldsymbol{UN_{2-hop}(N_n) = \{N_u | \overline{UN_{1-hop}(N_n)},\ N_u \in (H_1 \cup H_2)} \quad \textbf{\textit{4-10}}$$

Where $\overline{UN_{1-hop}(N_n)}$ defines of $UN_{1-hop}(N_n)$ compliment. Therefore, the total number of unclustered nodes around the N_n can be found by the following equation

$$\boldsymbol{N_{UN}(N_n) = count[UN_{1-hop}(N_n) \cup UN_{2-hop}(N_n)]} \quad \textbf{\textit{4-11}}$$

This clearly demonstrates that EAAFC takes the network density into account to achieve the local optimal outcome.

Clustering reformation happens within a constant time of $3 \times T_i$. In three cases are considered for each N_n regardless of the network size there are three possibilities for N_n:

First: N_n has the largest $NodeD$ and declares as the cluster head.

Second: N_n joins a network within the R_T by sending a join message to cluster head or a 1-hop member.

Third: N_n does not receive any state message within $2 \times T_i$. In this case N_n forms a cluster between $2 \times T_i$ and $3 \times T_i$. After cluster formation, each node can be in one of the three following states: cluster head, 1-hop member or 2-hop member. The cluster head chooses random 4-byte ID. So, the probability of two cluster heads to have identical ID is $\frac{1}{2^{4\times 8}}$. P_{CH} is the probability of two or more cluster heads having the same IDs in a network with $n < 2^{32}$ nodes

$$\boldsymbol{P_{CH} = 1 - \frac{2^{32}\times(2^{32}-1)\times(2^{32}-2)\times\ldots(2^{32}-n+1)}{2^{32\times n}}} \qquad \textbf{\textit{4-12}}$$

For a network with 100 nodes $P_{CH} = 2.33 \times 10^{-6}$. The ID length can be increased to reduce the P_{CH}. Figure 4-2 presents the algorithm flowchart.

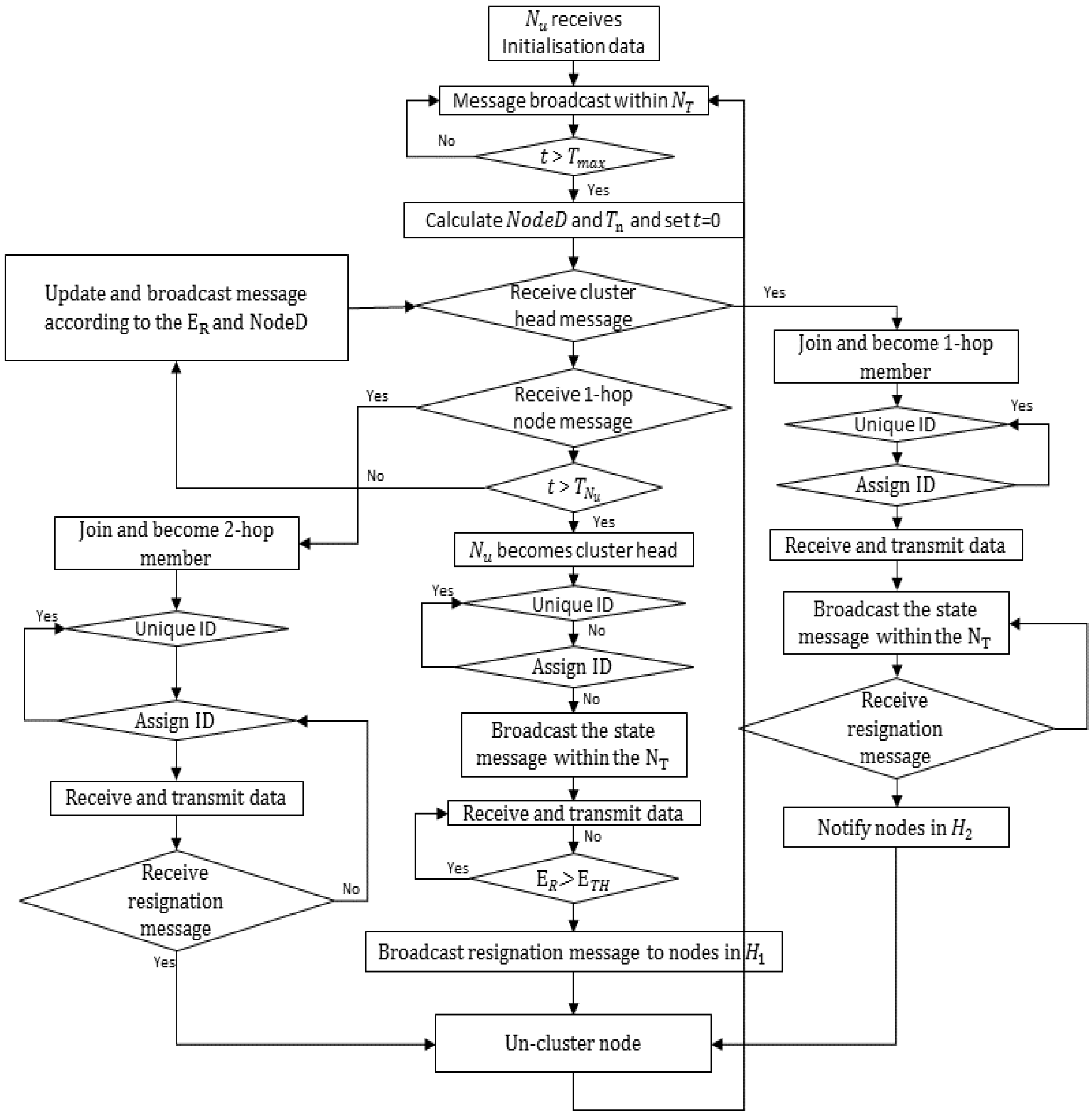


Figure 4-2 Flowchart of the EAAFC Algorithm

4.9 THE IMPLEMENTATION DESIGN OF EAAFC AND COMPARISON PROTOCOLS

In this section, we will demonstrate the design of EAAFC routing protocol in details including the objectives and implantation methodology followed by step by step instructions to execute the code and screenshots of the working code. At the same time, the performance of developed protocol is compared with EECF and LEACH routing protocols.

We evaluate the performance of EAAFC via NS2 simulator. The rationale behind using NS-2 is explained under introduction to NS2 section herewith.

We assume the base station is fixed and distanced from the network. We compare the EAAFC with LEACH (Heinzelman, 2002) and EECF. EECF has been selected as an algorithm that considers the residual energy of nodes and the node degrees. LEACH is also selected as another remarkable clustering algorithm in which nodes are randomly distributed. LEACH continuously sense the environment and sends the packets to the base station.

4.9.1 IMPLEMENTED ALGORITHMS

4.9.1.1 LEACH

It was pointed out by Chong and Kumar (Chong & Kumar, 2003), and Cardei (Cardei, et al., 2005), that conversation of energy is dealt with five unique levels are as follows:

i. Efficiently scheduling the states of sensor to alternate between active modes and sleep modes

ii. Efficiently controlling the power for transmission to assure that an optimal trade-off between connectivity and consumption of energy

iii. Compression of data that is source coding for reducing the amount of uselessly sent data

iv. Efficiently channel access and retransmission of packet protocols on the layer of data link

v. Energy-efficient clustering, routing and aggregation of data.

Yassein (Yassein, 2009) and Handy (Handy, et al., 2002), assert that LEACH is the first protocol in the network, which adopts hierarchical routing for sensor networks which is unfixed to maximise the network lifetime. Each network node organises into local clusters, with one node which acts as head for a cluster. All nodes in the non-cluster-head send their data to the head in the cluster, at the same time, the node in the cluster head obtain data from all members in the cluster, perform functions of signal processing on the data for example aggregation of data and send data to the remote station of a base. Thus, being a node in the cluster head is more intensive for energy than counterparts that are the node in non-cluster-head. When a node in the cluster-head dies all the nodes which related to cluster lose the ability for communication.

LEACH includes randomised rotation of position of the head in the cluster at high energy. In effect, LEACH rotates among sensors for avoiding draining the battery of any network sensor as reviewed in depth in works of Heinzelman, (Heinzelman, et al., 2000). In such manner, a load of energy linked with head in the cluster is evenly allocated among the nodes. Because a node in the cluster head knows all members of the cluster, it can generate a schedule of TDMA that informs every node accurately when to send its data. Additionally, using the schedule of TDMA for transfer of data prevents collisions among intra-cluster. LEACH operation is categorised into rounds. Every round starts with the phase of set-up when the clusters are planned, subsequently by a phase of steady-state where few data frames are sent from nodes to head in the cluster and on to the station for a base (Heinzelman, 2002).

The protocol of LEACH is a typically represent of protocols for hierarchical routing. It is self-organized and self-adaptive LEACH protocol adopts a round as a unit, every round contains steady-state stage and cluster set-up stage, for an intention of minimising unnecessary costs for energy, the steady-state stage which will be longer than the counterparts that are set-up stage.

During the stage of forming the cluster, a node aimlessly selects a number between 0 and 1, and then compares this number with the values for threshold *n(t)*. If the number is > *n(t)*, the node becomes head for the cluster in that round, otherwise it will turn to just a common node. *N(t)* that is threshold value is identified by the following:

$$n(t) = \{\frac{S}{S-1} * (p\ mode\ \frac{1}{p})\}\ if\ t\ belongs\ to\ R \quad \textbf{4-13}$$

$$n(t) = \{\frac{S}{S-0} *(p\ mode\ \frac{1}{p})\}\ if\ t\ does\ not\ belongs\ to\ R \qquad 4\text{-}14$$

Where *s* is the percentage of the head for cluster no nodes in each nodes, *R* is the nodes collection that was not nodes in the head in the first *1/s* round, and *p* is the number of the rounds. Using such value for threshold, all nodes can be nodes in the head after *1/s* rounds. Each node that became head for the cluster with possibility *s* when the round starts; the nodes were nodes in the head in next *1/s* rounds, since the number of nodes that have the potential of node in the head will minimize, thus for remaining nodes, possibility of being nodes in the heads must be maximised. After the *1/s-1* round, all nodes cannot be selected as head nodes, only nodes in the head with possibility 1 can be selected, when *1/s* rounds completed, all nodes will come to the same line on starting.

When forming the clusters, nodes begin to send the data for inspection. Heads in the cluster acquire data transmitted from other nodes, obtained data was transmitted to the gateway after fused and known as frame transmission of data. For reducing the unnecessary cost for energy, steady stage involves various frames, and the steady stage is higher than another one.

4.9.1.2 EECF

According to Chamam and Pierre (Chamam & Pierre, 2010), EECF protocol is completely distributed. It involves a numerous actions and exchanges of messages executed by every sensor, which result in choice of set of cluster heads and assures that every regular sensor (not cluster head) is linked to cluster head. Under a specific condition, any configuration given by EECF will display a spanning tree, which will connect all cluster heads provided that there is a route present between any pair of cluster heads. This makes the network for logical overlay formed by set of cluster heads efficient to data of route from any sensor toward the BS. EECF descriptions are as follows:

$$\boldsymbol{s(a) = a.\frac{d(a)}{(b+1)} + (1 - a).\frac{E(a)}{ES0}} \qquad \textbf{4-15}$$

Every sensor transmits to all its neighbours a message namely Score Advertisement Broadcast (SAB) which contains a function for score which express its ability to be endorsed cluster head. In EECF, the function for score advertised by every sensor with the help of SAB is a linear mixture of its residual energy and degree. It is denoted by:

- And then coefficient α will evaluate the significance of residual energy with specific reference to number of neighbours.
- After obtaining a SAB from all its neighbours, every node divide the neighbours set into two subsets: $b^+ (a) = \{c\ \varepsilon\ n\ (a)\ such\ that\ s(c) \geq s\ (a)\}$ and $b^- (a) = \{\ c\ \varepsilon\ n(a)$ such that

$$\boldsymbol{s(c) < s(a)\}.b + (a) = \{c\ \varepsilon\ n\ (a) such\ that\ s(c) \geq s(a)\} and\ b - (a) = \{\ c\ \varepsilon\ n(a) such\ that\ s(c) < S(a)\}.} \qquad \textbf{4-16}$$

The concept behind the division is that regular sensor seems to be linked with the cluster head which has a higher score and therefore is more appropriate to be the cluster head and thus belongs to $b^+ (a)$. Next to that, node a, computes, for every node $c\ \varepsilon\ b^+ (a)$, a function $R_a(c)$ represents the relative preference that sensor b has for sensor c as its capable cluster head. In deploying, $R_a(c)$ takes the probability function form for sensor *c* to be cluster head for sensor *a*, i.e. proportional to sensor rank *c* within $b^+ (a)$.

This is denoted as:

$$\boldsymbol{R_a(c) = [b + (a) + 1 - Rank\frac{c}{|b+(a)|} * (|b + (a)| + \frac{1}{2}} \qquad \textbf{\textit{4-17}}$$

- Where rank (c) is the sensor rank c within $b + (a) and\ (|b + (a)| * (|b + (a)| + \frac{1}{2}$

is the total of all probable ranks. Subsequently, sensor *b* transmits a message namely relative rank advertisement for cluster head which contain the values $R_a(c)$ of all neighbours $c\ \varepsilon\ b^+\ (a)$. Likewise, every sensor *a* receives a unique relative rank advertisement for cluster head from all its $b^-\ (c)$, neighbours which express its relative “significance” as a capable cluster head to each of them.

- After acquiring all relative advertisement for ranking the cluster head from its $b^-(a)$, neighbours, each sensor *a* computes a function *R(a)* represent its Relative Contribution to Network (RCN). *R(a)* denotes the possibility for node *a* to be elected as a cluster head, based on the information received from its $b^-\ (a)$ neighbours. Each sensor *a* receives from each of its $b^-\ (a)$, neighbours a relative advertisement for ranking the cluster head which represent sensor *a*’s possibility to be elected as a cluster head and thus all $b^-\ (a)$ neighbours have the same weight, it was denoted *R(a)* as follows:

$$\boldsymbol{R(a) = 1 - \pi\ c\ \varepsilon\ b -\ (a)\ (1 - Rc\ (b))} \qquad \textbf{\textit{4-18}}$$

- Afterwards, every sensor transmits a message namely contribution to the advertisement of the network. It was transmitted by sensor *a* will be acquired by all sensors in b^{-} *(a)* neighbours elects it as cluster head. Thus, if we assume that probabilities for election of a cluster head are independent, probability for a sensor of not being elected cluster head equals $\pi\ c\ \varepsilon\ b^{-}\ (a)\ (1\text{-}Rc\ (b))$ and thus *R(a)* denotes the probability of sensor a to be elected cluster head.
- After receiving all relative advertisement for ranking cluster head from b^{-} *(a)* neighbours, every node *a* takes its decision regarding the cluster head it will link to, if not it has been selected itself, cluster head by one of its b^{-} *(a)* neighbours. If $b^{-}\ (a) \neq \Theta$, sensor *a* must wait until all ranking advertisement for cluster head are obtained from its b^{+} *(a)* neighbour or until a predefined timeout has passed for making its decision. Then decision must be transmitted to all neighbours through message for election holding the identification of the sensor to designate the sensor a as its cluster head.
- When a sensor is selected as a cluster head, it transmits a message that contains its identification and its new and fresh state to its neighbours.

4.9.2 IMPLEMENTATION PARAMETERS

Performance of EAAFC was evaluated through NS2 simulator in this research. NS2 provides sufficient tools and modules to simulate such wireless environments. For further details regarding NS2 refer to chapter 2.

Parameters for simulation 100 runs of simulation are carried out with different topologies for network and the outcomes are average of 100 run.

Network Size	***100 sqm***
Number of nodes	***100***
Base station distance from nodes	***75m***
Initial energy of nodes	***2J***
Ns	***10m***
d0	***75m***
l	***4000 bits***
Ti	***500ms***
α	***0.18***
NT	***20m***
EDA	***5nj/bit***
Emp	***0.0013pj/bit/ m4***
Eelec	***50nj/bit***
Efs	***10pJ/bit/m2***

Table 4-2: Simulator parameters

4.9.3 IMPLEMENTATION OF PROPOSED METHOD

At first, the base station sends initialisation message to all neighbours. After receipts of this message, nodes send HELLO message to all neighbours. Each node then calculates the degree of message, based on the received hello message count. The degree message is calculated using below formula:

$$\tau_{N_u} = \propto e^{\frac{1}{NodeD(N_u)}} \quad \propto\text{=Constant to satisfy } 0 < \tau_{N_u} < T_i \qquad 4\text{-}4$$

This formula implicates that the larger the count node, the shorter the sending time. A node that receives degree message then joins the cluster head and all future received degree messages, this node acts as a member of this cluster. All data communication is performed by the cluster head. This is the main parameter to save energy and improve the network coverage.

To set up the sensor network in NS2 following must be designed and implemented:

- To configure a channel for phenomenon and data.
- To configure a MAC protocol for the phenomenon channel
- To configure nodes of phenomenon with the PHENOM protocol for routing
- To configure the pulse rate and type for phenomenon node
- To configure nodes for non-sensor like collecting the data gateways or points for the sensor network
- To attach sensor agents
- To attach a user datagram protocol agent and applications for the sensor to each node this is optional.

4.9.3.1 IMPLEMENTATION DETAILS

TwoRayGround propagation model is selected to represent the real environment. Topology is made as random and all nodes are static.

There are several states of node app. They are described following:

- INIT
- RECEIVE_INIT
- HELLO
- DEGREE
- JOIN

INIT

"INIT" is the initial state of all nodes.

RECEIVE_INIT

At first base nodes send "INIT" message. Nodes that receive this message are flagged as "RECEIVE_INIT" state.

HELLO

A node received "INIT" message sends HELLO message to "neighbours". Nodes are then flagged as "HELLO" state.

DEGREE

A node received "HELLO" message prepare to send "DEGREE" message based on the received "HELLO" message count. This is the "DEGREE" state.

JOIN

A node received "DEGREE" message send "JOIN" message to the cluster head. After planning this sending, the node is put on "JOIN" state.

4.9.3.2 TCL SCRIPT AND ENVIRONMENT SETTINGS

The following parameters are used to set attributes of simulation environment.

```
# Parameters: seed

set val(seed) [lindex $argv 0]

Mac/802_11 set CWMin_              15
Mac/802_11 set CWMax_              1023
Mac/802_11 set SlotTime_           0.000009
Mac/802_11 set SIFS_               0.000016
Mac/802_11 set ShortRetryLimit_    7
Mac/802_11 set LongRetryLimit_     4
Mac/802_11 set PreambleLength_     60
Mac/802_11 set PLCPHeaderLength_   60
Mac/802_11 set PLCPDataRate_       6.0e6
Mac/802_11 set RTSThreshold_       2000
Mac/802_11 set basicRate_          6.0e6
Mac/802_11 set dataRate_           6.0e6

Mac/802_11Ext set CWMin_           15
Mac/802_11Ext set CWMax_           1023
Mac/802_11Ext set SlotTime_        0.000009
Mac/802_11Ext set SIFS_            0.000016
Mac/802_11Ext set ShortRetryLimit_ 7
Mac/802_11Ext set LongRetryLimit_  4
Mac/802_11Ext set HeaderDuration_  0.000020
Mac/802_11Ext set SymbolDuration_  0.000004
Mac/802_11Ext set BasicModulationScheme_ 0
Mac/802_11Ext set use_802_11a_flag_ true
Mac/802_11Ext set RTSThreshold_    2000
Mac/802_11Ext set MAC_DBG          0

Phy/WirelessPhy set CSThresh_      6.30957e-12
Phy/WirelessPhy set Pt_            0.01
Phy/WirelessPhy set freq_          5.18e9
Phy/WirelessPhy set L_             1.0
Phy/WirelessPhy set RXThresh_      3.652e-10
Phy/WirelessPhy set bandwidth_     20e6
Phy/WirelessPhy set CPThresh_      10.0
```

```
Phy/WirelessPhyExt set CSThresh_           6.30957e-12
Phy/WirelessPhyExt set Pt_                 0.001
Phy/WirelessPhyExt set freq_               5.18e9
Phy/WirelessPhyExt set noise_floor_        2.51189e-13
Phy/WirelessPhyExt set L_                  1.0
Phy/WirelessPhyExt set PowerMonitorThresh_ 2.10319e-12
Phy/WirelessPhyExt set HeaderDuration_     0.000020
Phy/WirelessPhyExt set BasicModulationScheme_ 0
Phy/WirelessPhyExt set PreambleCaptureSwitch_ 1
Phy/WirelessPhyExt set DataCaptureSwitch_  0
Phy/WirelessPhyExt set SINR_PreambleCapture_ 2.5118
Phy/WirelessPhyExt set SINR_DataCapture_   100.0
Phy/WirelessPhyExt set trace_dist_         1e6
Phy/WirelessPhyExt set PHY_DBG_            0
Phy/WirelessPhyExt set CPThresh_           0 ;# not used at the moment
Phy/WirelessPhyExt set RXThresh_           0 ;# not used at the moment

#======================================================================

#configure RF model parameters
Antenna/OmniAntenna set Gt_ 1.0
Antenna/OmniAntenna set Gr_ 1.0

Propagation/Nakagami set use_nakagami_dist_ false
Propagation/Nakagami set gamma0_ 2.0
Propagation/Nakagami set gamma1_ 2.0
Propagation/Nakagami set gamma2_ 2.0

Propagation/Nakagami set d0_gamma_ 200
Propagation/Nakagami set d1_gamma_ 500

Propagation/Nakagami set m0_  1.0
Propagation/Nakagami set m1_  1.0
Propagation/Nakagami set m2_  1.0

Propagation/Nakagami set d0_m_ 80
Propagation/Nakagami set d1_m_ 200

#========================================================================
```

```
set val(chan)       Channel/WirelessChannel
set val(prop)       Propagation/TwoRayGround

set val(netif)      Phy/WirelessPhyExt
set val(mac)        Mac/802_11Ext
set val(ifq)        Queue/DropTail/PriQueue
set val(ll)         LL
set val(ant)        Antenna/OmniAntenna
set val(x)          768         ;# X dimension of the topography
set val(y)          768         ;# Y dimension of the topography
set val(ifqlen)     20           ;# max packet in ifq
set val(nn)         124         ;# how many nodes are simulated
set val(rtg)        DumbAgent
set val(stop)       124         ;# simulation time
set val(nam)        smile.nam
set val(tr)         smile.tr

# =====================================================================
# Main Program
# ======================================================================
```

4.9.3.3 CREATING TOPOLOGY FILE

This topology is created using third party "topology creating tool" with following parameters. Motion information is not required in this simulation.

```
#
# nodes: 124, pause: 0.00, max speed: 0.00, max x: 768.00, max y: 768.00
#
$node_(0) set X_ 693.644046281921
$node_(0) set Y_ 485.309078771688
$node_(0) set Z_ 0.000000000000
$node_(1) set X_ 628.475096084834
$node_(1) set Y_ 346.657637158592
$node_(1) set Z_ 0.000000000000
$node_(2) set X_ 262.238202635559
$node_(2) set Y_ 65.160663780155
$node_(2) set Z_ 0.000000000000
$node_(3) set X_ 681.812869845209
$node_(3) set Y_ 610.857747573967
$node_(3) set Z_ 0.000000000000
$node_(4) set X_ 74.045251617537
$node_(4) set Y_ 281.968832975607
$node_(4) set Z_ 0.000000000000
$node_(5) set X_ 26.640531459178
$node_(5) set Y_ 389.840240940165
$node_(5) set Z_ 0.000000000000
$node_(6) set X_ 204.478012808465
$node_(6) set Y_ 300.738225361693
$node_(6) set Z_ 0.000000000000
$node_(7) set X_ 630.392071318243
$node_(7) set Y_ 579.439898180659
$node_(7) set Z_ 0.000000000000
$node_(8) set X_ 751.386973053331
$node_(8) set Y_ 553.732990974668
$node_(8) set Z_ 0.000000000000
$node_(9) set X_ 396.286628066473
$node_(9) set Y_ 174.285496688304
$node_(9) set Z_ 0.000000000000
```

Figure 4-3 is the capture of topology. At this simulation node 54 is selected as base station node.

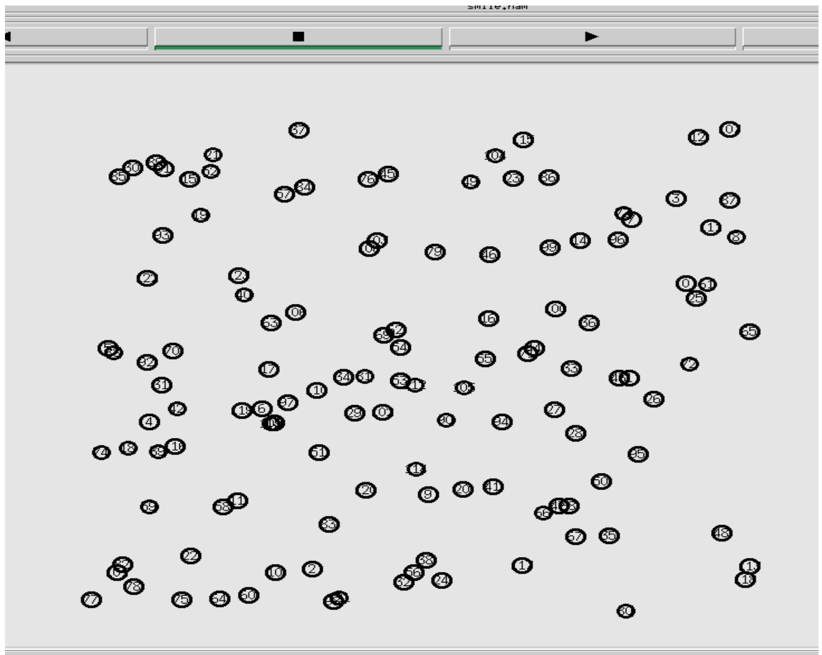


Figure 4-3: The simulation network

4.9.3.4 MODELS

The main logic is described in Agent/PBC application. In addition to origin members and properties, there must be following parameters:

```
    // written by smile
public:
    int receiveHellowCount;
    string state;
    string ID;
    string headID;
    bool isHead;
    int base;

    double uniform();
    string gen4ID();
    string gen2ID();
    string get4ID(string org);
    string get2ID(string org);
    list<string> IDs;
};

#endif // ns_pbc_h
```

This simulation is experimented several times per round count.

4.9.4 EVALUATION

4.9.5 END TO END DELAY AND NETWORK RATIO

We evaluate the end to end delay by measuring the average number of hops from a member node to the cluster head. Figure 4-4 shows that the average number of hops is below 1.4 for the entire network life. Since the 2-hop members are only in the sparse areas in a large network small proportion of nodes which are the 2-hop members, will not remarkably increase the delay. As more nodes fail, data load and subsequently the delay in network drops.

$$Ratio(CH) = \frac{count(\{Nu \mid Ere(Nu) > 0, Nu \in N\})}{count\ (CH)} \quad 4\text{-}19$$

The lower the cluster ratio the more efficient the algorithm is considered in terms of required number of cluster heads to cluster the network. The EAAFC, LEACH and EECF Ratio (Chin various rounds is depicted in Figure 4-4 it is evident that EAAFC Ratio(CH) is significantly higher than that of LEACH and EECF. This is expected as EAAFC is programmed to choose the fewest number of cluster heads for the network coverage also EAAFC reduces the redundant clusters among the network. Excellent data fusion of EAAFC is owed to small overlap and large cluster size.

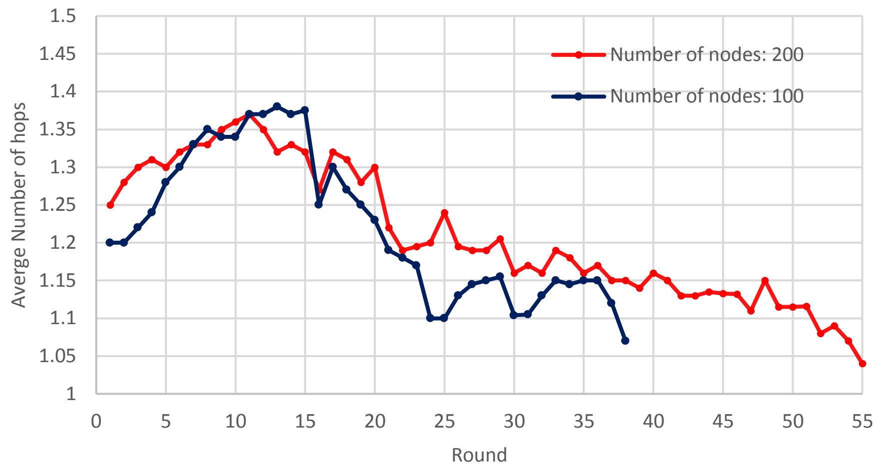


Figure 4-4: Average delay from node to cluster head per round.

4.9.6 CLUSTER SIZE

Figure 4-5 compares the EAAFC cluster size with LEACH and EECF. EAAFC cluster size is significantly larger than the other two protocols in all rounds which means the minimum number of cluster heads have been selected. This helps to decrease the delay while preserve the dissipated nodes energy.

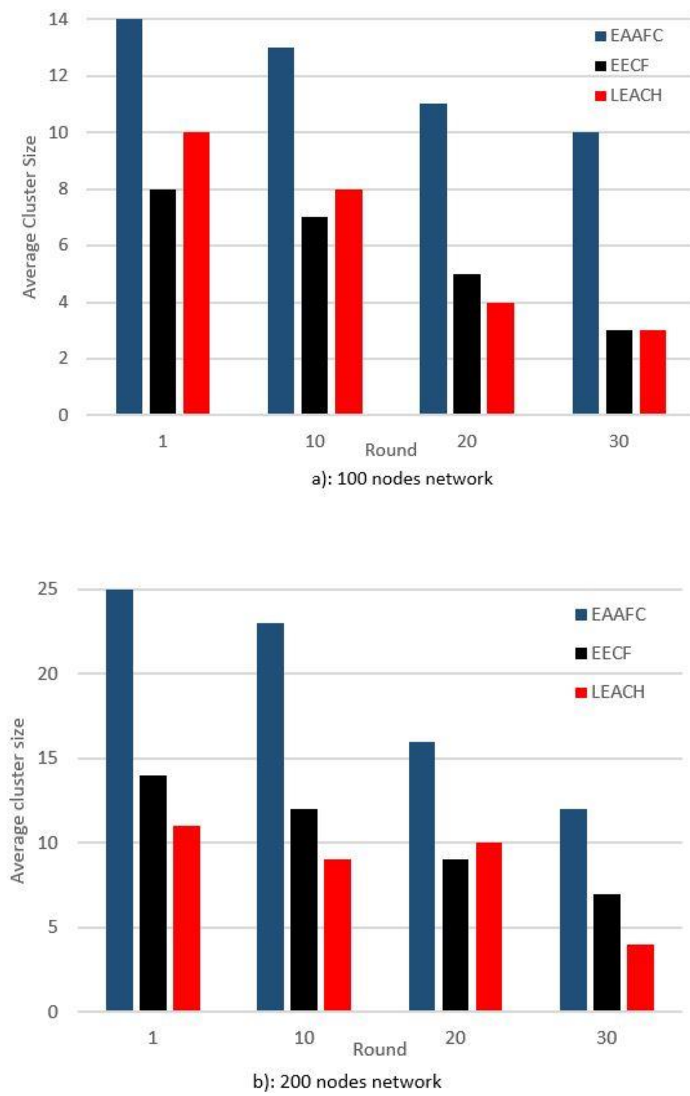
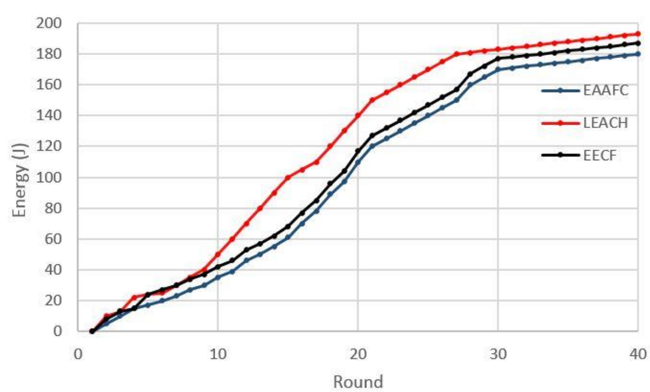


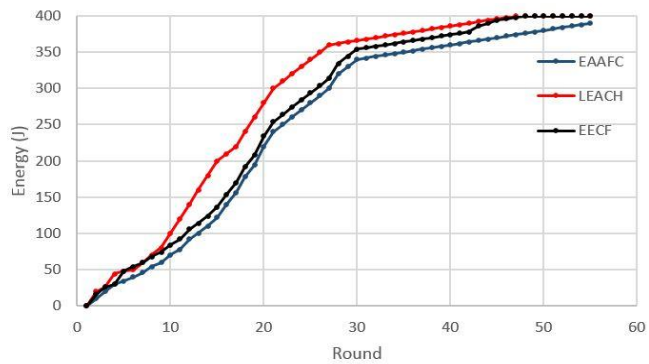
Figure 4-5: Average cluster sizes comparison for EAAFC, EECF, LEACH and highest-Degree

4.9.7 ENERGY EFFICIENCY

Figure 4-6 exhibits that the dissipated energy in EAAFC is lower than other two protocols. This energy consumption variance among three protocols gets smaller as the simulation progress. The reason is that towards the end of simulation, the number of the nodes that remained alive in EAAFC is significantly higher than the other two protocols. This results in more energy dissipation. The simulation outcome confirms that node's consumed energy in EAAFC is dramatically less than that of the other two algorithms. This is more apparent during the early stages. As the simulation approaches the end dissipated energy of EAAFC and EECF gets closer. The reason why is that as more rounds are passed EAAFC retains more alive nodes compared to the other two algorithms. EAAFC outperforms the other two protocols due to Since LEACH selects the cluster heads randomly, there might be a long distance to transmit the data between a node and the cluster head and this can result in large energy dissipation while data is being transmitted.



a): 100 nodes network



b): 200 nodes network

Figure 4-6: The total amount of dissipated energy in the Network

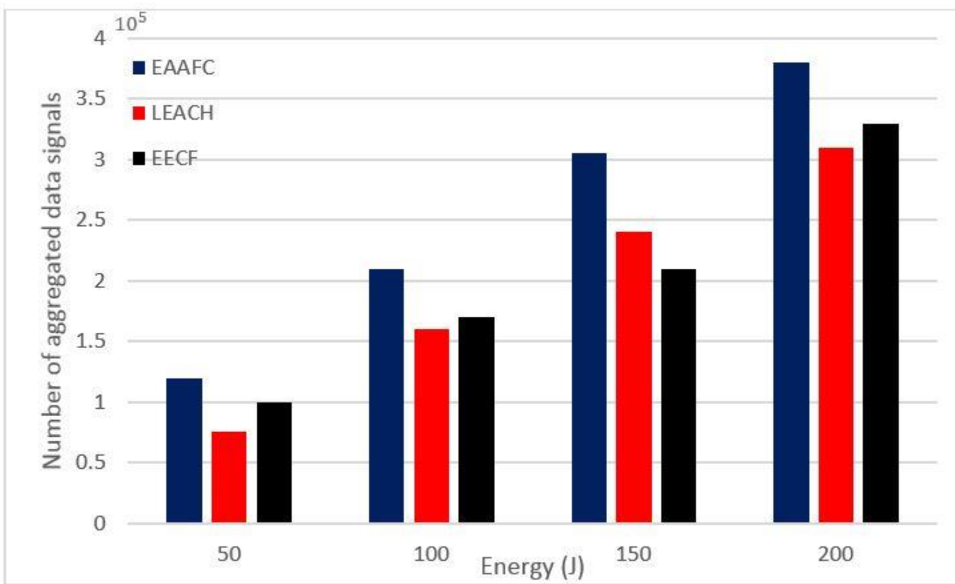
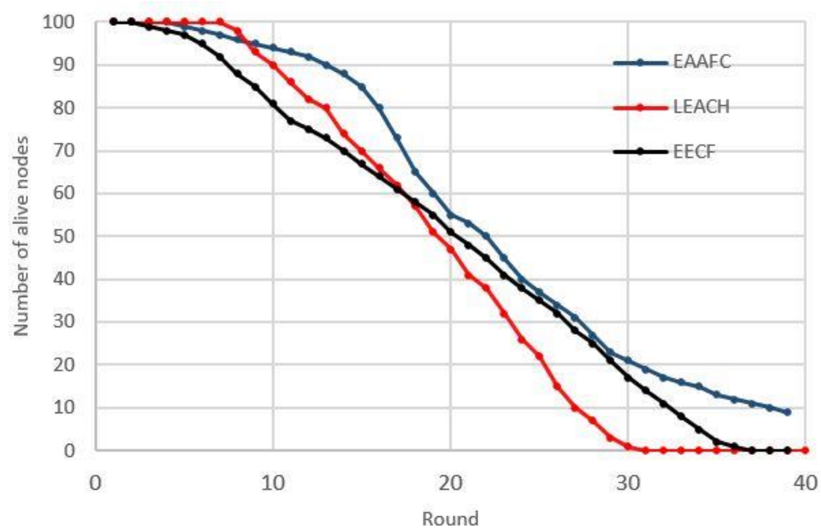


Figure 4-7 The total number of data signals aggregated at the cluster head per given amount of energy

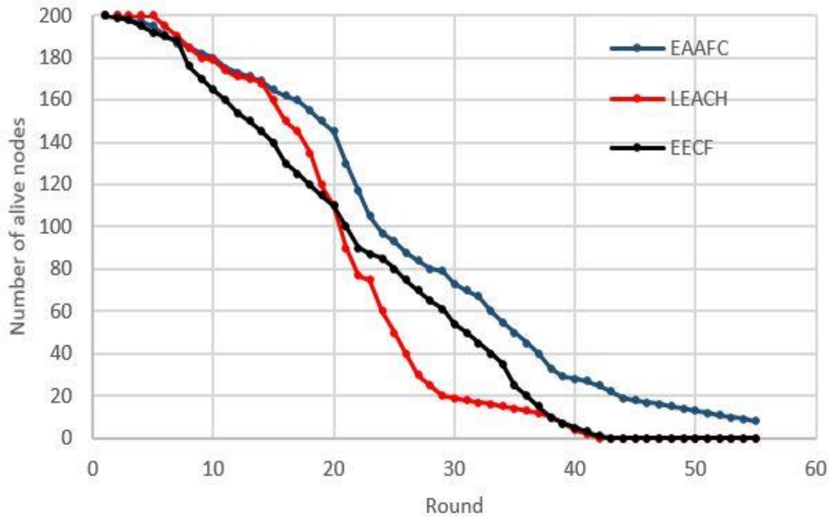
4.9.8 NUMBER OF REMAINED ALIVE NODES

The number of nodes that remained alive is plotted in Figure 4-8. It is evident that EAAFC retains more alive nodes compared to LEACH and EECF as more rounds are passed. This is because EAAFC selects nodes that have higher E_R during cluster head re-election. This mechanism ensures energy node's energy balance and lowers the chance of cluster head loss.

Once no node remains to perform the cluster head role the clustering process is terminated. In EECF a node is dead when it cannot communicate with any cluster head within the network. LEACH, on the other hand, selects the cluster heads randomly. This means no energy level is considered EAAFC maintains the alive nodes due to the fair cluster election by taking into account the residual energy of nodes during cluster reformation which balances the energy dissipation within the network.



a): 100 nodes network



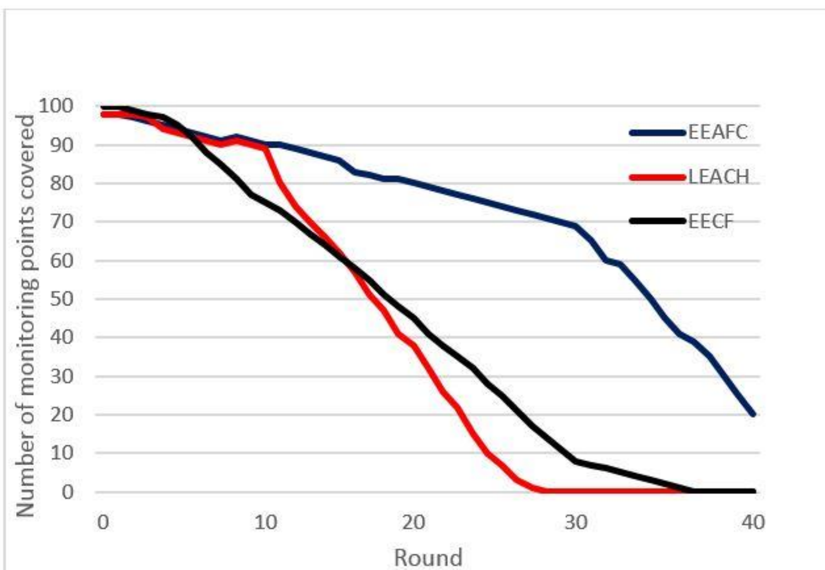
b): 200 nodes network

Figure 4-8: Number of remained alive node

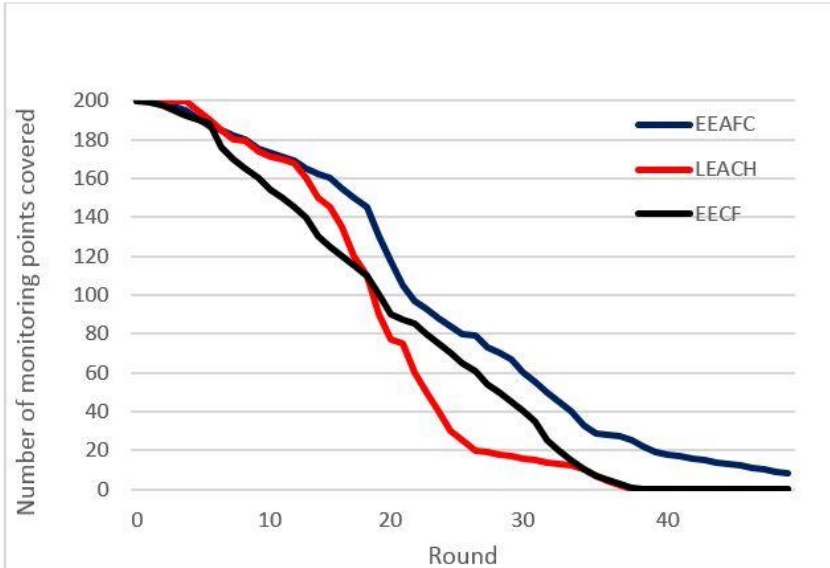
4.9.9 NETWORK COVERAGE

In this simulation, we have utilized 100 and 200 nodes to cover 100 and 200 randomly distributed points in the 100 sqm area. As expected not all nodes equally participate in coverage.

Nodes failure in less dense areas has more impact on coverage than those dense areas. Results as illustrated in the Figure 4-9 prove that EAAFC has a better coverage compared to EECF and LEACH. This is due to the awareness of nodes residual energy and the number of cluster head neighbours in EAAFC. From our data analysis, we observed that EEAFC can still cover nearly 20% of the network when %40 of nodes have failed. This is while the other two protocols have completely lost the network coverage. We also measured the number of running rounds for which a different coverage metric is preserved. Since nodes are randomly distributed the full coverage of the network cannot be guaranteed. When there are 100 nodes in the network, as Figure 4-7 depicts, the number of running rounds of EAAFC for providing %100 coverage increases by 33%, and 50% when compared to EECF and LEACH. When the network coverage decreases to 70% EAAFC improves the coverage per rounds by 35% to 55% compared to other two algorithms. Overall EAAFC provides more coverage compared to other two algorithms.



a): 100 nodes network



b): 200 nodes network

Figure 4-9: Network Coverage per round

As the number of failed nodes increases the covered area decreases and this can be evidenced in Figure 4-10. As the number of failed nodes reach 120, EAAFC still deliver 80% coverage.

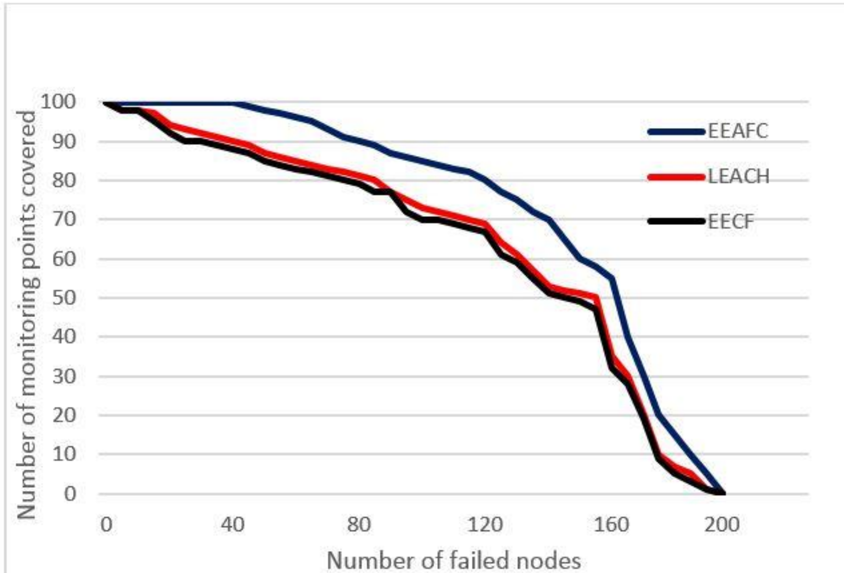


Figure 4-10 Network coverage with several dead nodes

Figure 4-11 compares the network coverage in different rounds in sparse and dense networks. The result shows that EAAFC outperforms EECF and LEACH by 25% and 15% respectively in dense network (200 nodes). With 70% network coverage EAAFC still outperforms the other two algorithms by an average of 45%. In a sparse network of 100 nodes, EAAFC coverage is 33%, which is 50% better than EECF and LEACH. Therefore, it is evident that EAAFC provides better coverage compared to the other two algorithms.

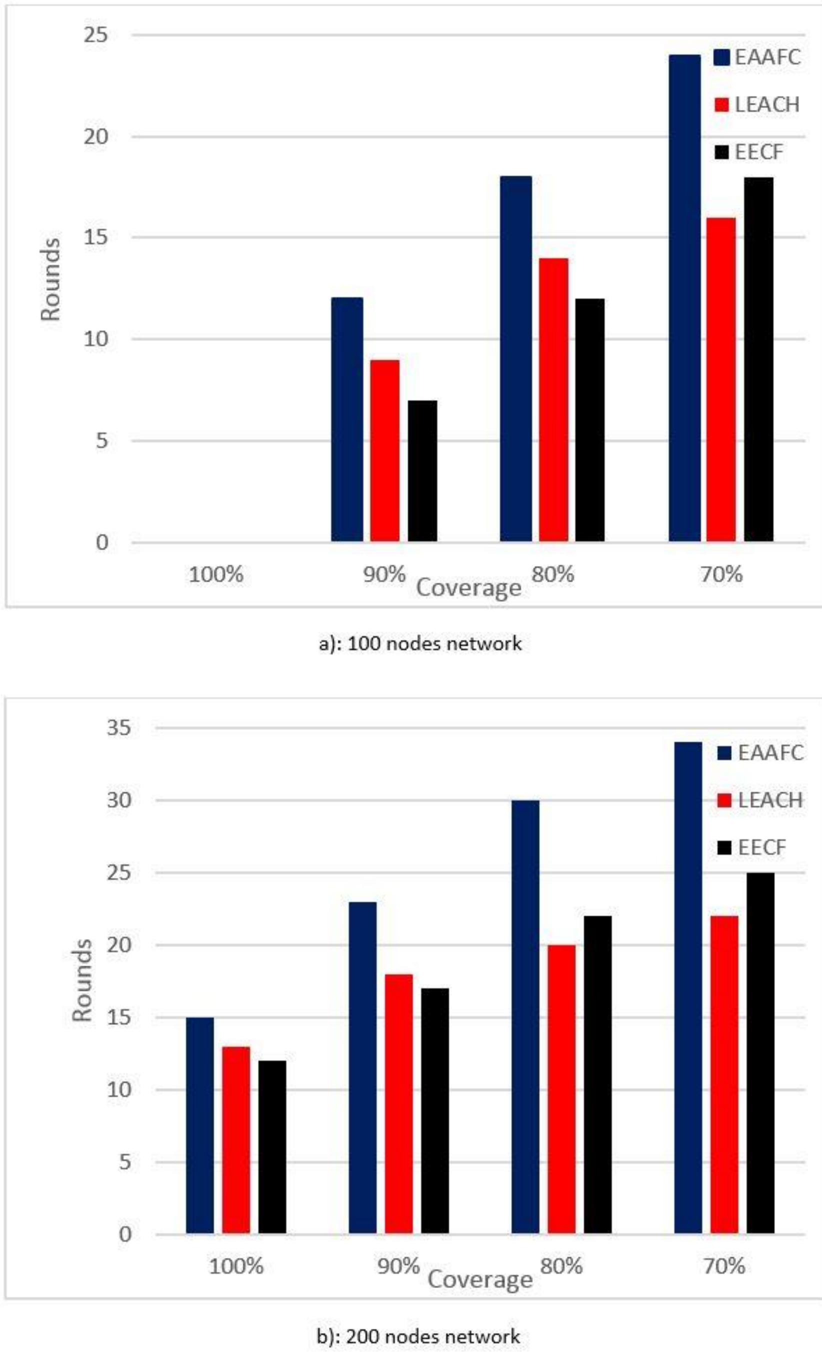


Figure 4-11 Comparison of the different clustering algorithms in terms of coverage-rounds

CHAPTER 5

5 CONCLUSION AND FUTURE WORKS

This chapter will conclude the works that have been presented in previous chapters. We will present the achievements that fulfilled the research objectives as discussed in Chapter 1. We will then follow discussion by presenting the possibilities of future work in clustering routing protocols for WSNs when nodes are not homogenous and not necessarily static. We further include a list of our publications related to our works in the broader field of energy and QoS aware routing for WSNs.

5.1 MAJOR ACHEIVEMENTS

This thesis has achieved two major goals: proposing a new paradigm for energy and QoS awareness; which in turns inspired us to develop a whole new routing protocol known as Energy Aware and Address Free Clustering (EAAFC) (Toussi, et al., 2010); (Toussi, 2013).

5.1.1 PUSH (EVENT DRIVEN) PARADIGM: DELAY AND ENERGY EFFICIENCY PERFORMANCE

We have modelled the average energy loss and collective latency characteristics of WSNs routing approaches of Directed Diffusion routing protocol for 2 pull and push models over IEEE 802.11 interfaces with Distributed coordination. This implementation proved that Push paradigm (event driven) significantly outperforms the 2-pull paradigm (query driven) in terms of energy dissipation and collective network latency where network application allows. This method resulted in a routing paradigm where the energy and the end to end delay are enhanced for flat and unclustered networks. Based on the outcomes of such approach the research was guided towards the concept of clustering, and benefits of such networks over flat networks was exploited.

5.1.2 CLUSTER BASED DATA CENTRIC ROUTING PARADIGM

Mindful of limitations we discovered in Push based paradigm, we endeavoured to further optimise our paradigm. To this end, we proposed a cluster based data centric routing paradigm, then implemented it in the simulator environment to prove its outperformance against direct diffusion. The results were proving significant betterment in terms of network latency and also energy efficiency.

This experiment paved the road for us to further develop a new cluster based routing protocol which was elaborated in the subsequent chapter.

5.2 ENERGY AWARE AND ADDRESS FREE CLUSTERING (EAAFC): A ROUTING PROTOCOL

Grouping the sensor nodes into clusters is a common approach which is being used to satisfy the scalability characteristic of WSNs, to achieve energy efficiency, and to improve network lifetime in large scale WSNs. Grouping nodes into clusters, further allow hierarchical data aggregation and routing which allows organising large scale networks. In clustered networks, each network has leader (CH) which performs data fusion and aggregation. There are also several ordinary nodes (N) as members. Cluster formation creates two-level hierarchy where the CH nodes and the ordinary nodes form the higher lower level respectively. The ordinary nodes transmit their data to their corresponding CH and CH in turn send their data to the base stations. Considering that Clustering is an efficient method in large scale network for above reason and based on the research results of chapter 3 we designed Energy Aware and Address Free Clustering (EAAFC) paradigm. We demonstrated in details in chapter 4 that EAAFC endeavours to select the minimum number of clusters and those with largest number of neighbours to improve the network coverage. In addition, EAAFC utilises the local information of nodes to assign the local unique IDs and to decide the new clustering election to enhance the network energy efficiency. We elaborated on how EAAFC performs without requiring any pre-assigned addressing, nor any time synchronization, nor even any geographical location of nodes. We then demonstrated that EAAFC outperforms both EECF and LEACH, two of the most vastly used cluster based routing protocols. This outperformance was in terms of nodes life span, energy dissipation, network delay and coverage.

5.3 FUTURE WORKS

Currently our proposed EAAFC routing protocol has its own limitations. EAAFC as proposed in this thesis, works based on static nodes. Moreover, it works only when nodes are homogenic. With expansion of WSN applications, it would be essential to extend EAAFC to mobile and heterogeneous nodes, hence the future works need to be focused on mobility and heterogeneity of the node.

The EAAFC clustering model must be integrated to a nominated routing protocol where such nominated protocol can be enhanced and benefits from characteristics of EAAFC model. To achieve above, further study on relevant routing protocols must be carried and the most suitable protocols must be identified. Such routing protocol must be put in to test in comparison with the original routing protocol as well as other similar approaches to evaluate its performance. In short EAAFC can be most useful when it is used in conjunction with a WSN routing protocol.

5.4 LIST OF OUR PUBLICATIONS

- Mehdi Toussi, Ahora and Politis, Christos (2013) Energy conservative and coverage preservative clustering for wireless sensor networks. In: IEEE PIMRC'13 Conference; 8-11 Sep 2013, London, U.K.. ISSN (print) 2166-9570
- Toussi, Ahora M. and Politis, Christos (2013) A cluster based data centric routing paradigm for wireless sensor networks. *In: Wireless World Research Forum Meeting 30;* 23-25 April 2013, Oulu, Finland.
- Mehdi Toussi, A.M., Ramrekha, T.A. and Politis, C. (2010) Energy efficiency and QoS in wireless sensor networks. *In: 25th Wireless World Research Forum (WWRF) meeting ;* 16 Nov - 18 Nov 2010, London, UK

5.5 SUBMITTED

Journals

- Mehdi Toussi, Ahora and Politis, Christos, An Energy Aware and Address Free Cluster Based Routing Protocol for Wireless Sensor Netowrks (EAAFC), IEEE Transactions on Mobile Computing- Submitted in Feb 2017
- Mehdi Toussi, Ahora and Politis, Christos, Cluster based framework for full network coverage in homogenous static Wireless Sensor Networks, IEEE Sensor Journals – Submitted in June 2017

References

Abbasi, A. a. Y. M., 2007. A Survey on clustering algorithms for wireless sensor networks. *Computer communications,* 30(14), pp. 2826-2841.

Abolhasani, S. M., Meybod, M. R. & Esnaashari, M., 2007. *"LABER: A Learning Automata Based Energy-aware Routing Protocol for Sensor Networks".* Iran, Third Information and Knowledge Technology conference, Ferdowsi University, Iran, pp. 27-29.

Ahvar, E., Pourmoslemi, A. & Piran, M., 2011. Fear: A Fuzzy-based Energy-aware Routing Protocol for Wireless Sensor Networks. *arXiv preprint arXiv:1108.2777.*.

Akkaya, K. a. Y. M., 2003. A Survey on Routing Protocols for Wireless on Distributed Computing Systems. pp. 19-22.

Akkaya, K. a. Y. M., 2005. Energy and QoS aware routing in wireless sensor networks. *Cluster computing,* 2(3), pp. 179-188.

Akkaya, K. & Younis, M., 2003. *An energy-aware QoS routing protocol for wireless sensor networks.* s.l., 23rd International Conference on Distributed Computing Systems Workshops, IEEE, pp. 710-715.

Akkaya, K. & Younis, M., 2005. A Survey on Routing Protocols for Wireless Sensor Networks. *Ad hoc networks,* 3(3), p. 325–349.

Akyildiz, I. F. & Vuran, M. C., 2010. *Wireless Sensor Networks.* UK: John Wiley & Sons.

Akyildiz, I., Pompili, D. & Melodia, T., 2005. Underwater Acoustic Sensor Networks: Research Challenges. *Ad Hoc Networks 3,* Volume 3, p. 257–279.

Akyildiz, I., Su, W., Sankarasubramaniam, Y. & Cayirci, E., 2002. A Survey on Sensor Network. *IEEE Communication Magazine,* 40(8), pp. 102-114.

Alemdar, A. & Ibnkahla, M., 2007. *Wireless Sensor Networks: Applications and Challenges.* Sharjah, 9th International Symposium on Signal Processing and Its Applications, pp. 1-7.

Ali, M. & Uzmi, Z., 2004. *An Energy Efficient Node Address Naming Scheme for Wireless Sensor Networks.* s.l., s.n.

Al-Karaki, J. a. K. A., 2004. Routing techniques in wireless sensor networks: a survey. *IEEE wireless communications,* 11(6), pp. 6-28.

Alwan, H. & Agarwal, A., 2009. *A Survey on Fault Tolerant Routing Techniques in Wireless Sensor Networks.* Athens, 3th International Conference on Sensor Technologies and Applications (Senosrcomm '09), p. 366–371.

Alwan, H. & Agarwal, A., 2013. MQoSR A Multiobjective QoS Routing Protocol for Wireless Sensor Networks. *ISRN Sensor Networks,* Volume vol. 2013.

Ammari, H. M., 2013. *The Art of Wireless Sensor Networks: Volume 1: Fundamentals.* London: Springer Science & Business Media.

Annie, U. & Kasmir, S., 2012. QOS routing in wireless sensor networks. *Journal ACM Computing Surveys*, Volume 4.

Anon., n.d. *The Network Simulator – ns – 2.*[Online] Available at: http://www.isi.edu/nsnam/ns/[1 October 2016].

Arampatzis, T., Lygeros, J. & Manesis, S., 2005. *A Survey of Applications of Wireless Sensors and Wireless Sensor Networks.* Limassol, Cyprus, Proceedings of the 13th Mediterranean Conference on Control and Automation .

Backhyun, K. & Iksoo, K., 2006. Energy Aware Routing Protocol in Wireless Sensor Networks. *International Journal of Computer Science and Network Security*, Volume 6.

Bae, K. & Yoon, H., 2005. Autonomous Clustering Scheme for Wireless Sensor Networks Using Coverage Estimation Self-Pruning. *IEICE Transactions on Communications,* E88(B3), pp. 973-980.

Bagula, A. & Mazandu, K., 2008. *Energy Constrained Multipath Routing in Wireless Sensor Networks.* Heidelberg, International Conference on Ubiquitous Intelligence and Computing, pp. 453-467.

Banner, R. & Orda, A., 2007. Multipath routing algorithms for congestion minimization. *IEEE/ACM Transactions on Networking (TON),* 15(2), pp. 413-424.

Barua, S., Sunbeam Islam, F., Ahmed A.U., G. P. & Sandrasegaran, K., 2014. COMPARATIVE STUDY ON PRIORITY BASED QOS AWARE MAC PROTOCOLS FOR WSN. *International Journal of Wireless & Mobile Networks (IJWMN),* October.6(5).

Basma & al., e., 2011. An Optimized Energy-aware Routing Protocol for Wireless Sensor Network. *Egyptian Informatics Journal,* Volume 12.

Bhaskar, B. et al., 2010. Quality of Service (QoS) Provisions in Wireless Sensor Networks and Related Challenges. *Scientific Research Journal,* Volume 2.

Biradar, R. V., Patil, V. C., Sawant, S. R. & Mudholkar, R. R., 2004. Classification and comparison of routing protocols in wireless sensor networks.Special Issue on Ubiquitous Computing Security Systems. *Ubiquitous Computing and Communication Journal,* 4(2), pp. 704-711.

Boukerche, A., Nakamura. & Loureiro, A. .., 2009. *Algorithms for Wirelss Sensor Networks. In Algorithms and Protocols for Wireless Sensor Networks; Boukerche, A.,.* NJ(Hoboken): Ed John Wiley & Sons.

Braginsky, D. & Estrin, D., September 2002. *Rumor Routing Algorithm for Sensor Networks.* Atlanta, GA, In Proceedings of the First ACM International Workshop on Wireless Sensor Networks and Applications(WSNA), p. 22–31.

Callaway, E. et al., 2002. Home Networking with IEEE 802.15.4: A Developing Standard for Low-Rate Wireless Personal Area Networks. *IEEE Communications Magazine,* pp. 70-77.

Cardei, M. & Du, D., 2005. Improving Wireless Sensor Network Lifetime Through Power Aware Organization. *ACM Wireless Networks* , 11(3), pp. 333-340.

Cardei, M., Thai, M., Li, Y. & Wu, W., 2005. *Energy-efficient target coverage in wireless sensor networks.* s.l., In Proceedings of 24th annual joint conference of the IEEE computer and communications societies (INFOCOM), p. 1976–84.

Cardei, M. & Wu, J., 2006. Energy-efficient coverage problems in wireless ad hoc sensor networks. *Computer Communications Journal,* 29(4), p. 413–420.

Carpenter, B. E. & Nichols, K., 2002. *Differentiated services in the Internet.* s.l., In Proceedings of the IEEE.

Chamam, A. & Pierre, S., 2010. A Distributed Energy-Efficient Clustering Protocol for WSN,. *Computers and Electrical Engineering,* March, 36(2), pp. 303-312.

Chang, J. & Tassiulas, L., 2004. Maximum lifetime routing in wireless sensor networks. *IEEE/ACM Transactions on Networking (TON),* 12(4), p. 609–619.

Chang, L., Xiaofeng, G., Fan, W. & Guihai, C., 2015. *Energy- Aware Clustering and Routing Scheme in Wireless Sensor Network.* s.l.:Springer.

Chen, D. & Varshney, P., 2004. *QoS Support in Wireless Sensor Networks: A Survey.* s.l., In the proceedings of the International conference on wireless networks (ICWN), pp. 227-233.

Chen, Y. & Nasser, N., 2006. *Energy-balancing multipath routing protocol for wireless sensor networks.* s.l., 3rd international conference on Quality of service in heterogeneous wired/wireless networks, p. 21.

Chilamkurti, N., Zeadally, S. & and Chaouchi, H., 2013. *Next-Generation Wireless Technologies: 4G and Beyond.* London: Springer Science & Business Media.

Chong, C. & and Kumar, S., n.d. *Sensor networks: evolution, opportunities, and challenges.* s.l., Proceedings of the IEEE, pp. 1247-1256.

Chong, C.-Y. & Kumar, S., 2003. Sensor networks: Evolution, opportunities, and challenges. *IEEE.*

Chopra, H. & and Rastogi, R., 2014. Performance of QoS Aware Routing Protocol in WSAN. *Software Engineering and Technology,* 6(7), pp. 189-192.

Couqueur, T., Phipatanasuphorn, V., Ramanathan, P. & K.K., S., 2002. *Sensor Deployment Strategy for Target Detection.* s.l., s.n.

Couto, D. S., Aguayo, D., Bicket, J. & Morris, R., 2005. A high-throughput path metric for multi-hop wireless routing. *Wireless Networks*, 11(4), pp. 419-434.

Culler, D. E. & Hong, W., 2004. Wireless Sensor Networks. *Communication of the ACM,* 47(6), pp. 30-33.

Derogarian, F., Ferreira, J. & and Tavares, V., 2011. *A routing protocol for WSN based on the implementation of source routing for minimum cost forwarding method,* s.l.: In Proceedings of the 5th International Conference on Sensor Technologies and Applications (SENSORCOMM'2011).

Eiko, Y. A. B. J., 2005. *Wireless sensor network technologies: research trends and middleware's role,* Cambridge: Computer Laboratory, University of Cambridge.

ELMoustapha, O., 2008. Distributed unique global ID assignment for sensor networks. *Ad Hoc Networks,* 7(6), p. 2051–2055.

Fardin, D. & Joao, C., 2011. *A Ruting Protocol for WSN baseon on the implementation of Source Routing for Minimum Cost Forwarding Method.* s.l., The fifth International Conferences on Sensor Technologies and Applications, Sensorcomm.

Felemban, E., Lee, C. G. & Ekici, E., 2006. MMSPEED Multipath Multi-SPEED Protocol for QoS Guarantee of Reliability and Timeliness in WSNs. *IEEE TMC,* Volume 5, pp. 738-754.

Feng, J., Koushanfar, F. & and potkonjak, M., 2002. *System-architectures for sensor networks issues, alternatives, and directions in Computer Design: VLSI in Computers and Processors.* s.l., IEEE International Conference, pp. 226-231.

Fonseca, C. N., 2010. *Multipath Routing for Wireless Mesh Networks,* s.l.: Doctoral dissertation, Ph. D. Dissertation.

George, C. & and Kumar, M., February 2013. *Cluster based location privacy in wireless sensor networks against a universal adversary.* s.l., International Conference in Information Communication and Embedded Systems (ICICES). IEEE, pp. 288-293.

Gopi, P., 2014. Multipath Routing in Wireless Sensor Networks: A Survey and Analysis. *IOSR Journal of Computer Engineering (IOSR-JCE),* 16(4), pp. 27-34.

Guibas, L. & Zhao, F., 2004. *Wireless Sensor Networks: An Information Processing Approach*, San Francisco: Morgan Kaufman Publishers.

Hancke, G. & and Leuschner, C., 2007. SEER: a Simple Energy Efficient Routing protocol for wireless sensor networks. *SACJ,* Issue 39, pp. 17-24.

Handy, M. J., Haase, M. & Timmermann, D., 2002. Low Energy Adaptive Clustering Hierarchy with Deterministic Cluster-Head Selection. *IEEE MWCN.*

Haseeb, Z. et al., 2012. QoS-aware Multipath Routing Scheme for Mobile Ad Hoc Networks. *International Journal of Communication Networks and Information Security,* Volume 4.

Heikalabad, S., Rasouli, H., Nematy, F. & Rahmani, N., 2011. QEMPAR: QoS and energy aware multi-path routing algorithm for real-time applications in wireless sensor networks.. *arXiv preprint arXiv:1104.1031..*

Heinzelman, W. B., Chandrakasan, A. & Balakrishnan, H., 2000. *Energy-Efficient Communication Protocol for Wireless Micro sensor Networks.* Hawaii, Hawaii International Conference on System Sciences .

Heinzelman, W. C. A. a. B. H., 2002. An application-specific protocol architecture for wireless microsensor networks. *IEEE Transactions on wireless communications,* 1(4), pp. 660-670.

Heinzelman, W., Chandrakasan, A. & and Balakrishnan, H., 2002. An application specific protocol architecture for wireless microsensor networks. *J IEEE Trans Wire Commun,* 1(4), pp. 660-670.

He, T. & et al., 2003. *SPEED: A stateless protocol for real-time communication in sensor networks.* s.l., in the Procedings of the Internation Conference on Distributed Computing Systems.

Hill, J. et al., 2000. *System architecture directions for networked sensors.* s.l., ACM SIGOPS operating systems review, pp. 93-104.

Himali, C., 2014. Performance of QoS Aware Routing Protocol in WSAN. *Matrix Academic International Online Journal of ENgineering and Technology,* Volume 2.

Huang, X. & and Fang, Y., 2008. Multiconstrained QoS multipath routing in wireless sensor networks. *Wireless Networks,* 14(4), pp. 465-478.

Intanagonwiwat, C., Govindan, R. & and Estrin, D., 2000. *Directed diffusion: a scalable and robust communication paradigm for sensor networks.* s.l., In Proceedings of the 6th annual international conference on Mobile computing and networking. ACM., pp. 56-67.

Issariyakul, T. & al., e., 2008. *Introduction to NS2,* US: Springer.

Jin, Z. et al., 2009. A survey on position-based routing algorithms in wireless sensor networks. *Algorithms,* 2(1), p. 158–182.

Junyoung, H., Jiman, H. & Yookun, C., 2009. EARQ: Energy Aware Routing for Real-Time and Reliable Communication in Wireless Industrial Sensor Networks. *IEEE,* Volume 5.

Kadiyala, P., 2008. *Non-uniform Grid-based Coordinated Routing in Wireless Sensor Networks, ProQuest, Ann Arbor.* Ann Arbor: ProQuest.

Kang, J., Zhang, Y. & Nath, B., 2004. *End-to-End Channel Capacity Measurement for Congestion Control in Sensor Networks.* Boston, MA, 2nd International Workshop on Sensor and Actor Network Protocols and Applications (SANPA '04).

Karl, H. & Willig, A., Oct 2007. *Protocols and architectures for wireless sensor networks.* West Sussex: John Wiley & Sons.

Khanke, K. & Sarde, M., 2015. An Energy Efficient and QoS Aware Routing Protocol for Wireless Sensor Network. *International Journal of Advanced Research in Computer and Communication Engineering,* 4(7), pp. 355-358.

Kim, J.-H.et al., 2008. *PRODUCE: a probability-driven unequal clustering mechanism for wireless sensor networks.* Okinawa, 22nd international conference on advanced information networking and applications—workshops, pp. 928-33.

Kiran, M., Kamal, K. & Nitin, G., 2011. Application based Study on Wireless Sensor Network. *International Journal of Computer Applications,* Volume 21.

Krishnamachari B, E. D. W. S., 2002, June. *Modelling data-centric routing in wireless sensor networks.* New York, s.n.

Krishnamachari, B., Murphy, A. & Trigoni, N., 2014. *Wireless Sensor Networks.* UK: Springer.

Krishnaveni, P. & Sujatha, J., 2012. Analysis of routing protocols for wireless sensor networks. *International Journal of Advanced Engineering,* Volume 2.

Kulik, J., Heinzelman, W. & Balakrishnan, H., 2002. Negotiation-based protocols for disseminating information in wireless sensor networks. *Wireless networks,* 2(3), pp. 169-185.

Lee, S., Koh, J. & Jung, C., 2014. An energy-efficient QoS-aware routing algorithm for wireless multimedia sensor networks. *International Journal of Multimedia and Ubiquitous Engineering,* 9(2), pp. 245-252.

Lin, J., Liu, Y. & Ni, L., 2007. SIDA: self-organized ID assignment in wireless sensor networks.. *IEEE International Conference on Mobile Adhoc and Sensor Systems,* pp. 1-8.

Liu, H. J. X., Wan, P., Liu, X. & Yao, F., 2007. A Distributed and Efficient Flooding Scheme Using 1-hop Information in Mobile Ad-Hoc Networks. *IEEE Transactions on Parallel and Distributed Systems* , 18(5), pp. 1-14.

Liu, M., Cao, J., Chen, G. & Wang, X., 2009. An energy-aware routing protocol in wireless sensor networks. *Sensors,* 9(1), pp. 445-462.

Lotf, J., Bonab, M. & Khorsandi, S., 2008. *A novel cluster based routing protocol with extending lifetime for wireless sensor networks.* s.l., In Proceedings of the 5th IFIP international conference on wireless and optical communications networks, pp. 1-5.

Lou, W. & Kwon, Y., 2006. H-SPREAD A Hybrid Multhipath Scheme for Secure and reliable Data Collection in Wireless Sensor Networks. *IEEE Transactions on Vehicular Technology,* Volume 55, pp. 132-1330.

Lou, W., Liu, W. & Zhang, Y., 2006. Performance Optimization Using Multipath Routing in Mobile Ad Hoc and Wireless Sensor Networks. *Combinatorial optimization in communication networks,* Volume 2, pp. 117-146.

Malfa, S. L., 2010. *Wireless ireless Sensor Networks.* [Online] Available at: http://www.dees.unict.it/users/bando/files/wsn.pdf

Manjeshwar, A. & Agarwal, D. P., 2001. *TEEN: a routing protocol for enhanced efficiency in wireless sensor networks.* s.l., in Proceedings of the 15th International parallel and distributed processing symposium, pp. 2009-2015.

Manjeshwar, A. & Agarwal, D. P., 2002. *APTEEN: a hybrid protocol for efficient routing and comprehensive information retrieval in wireless sensor networks.* s.l., in Proceedings of the 16th International parallel and distributed processing symposium, pp. 195-202.

Maraiya, K., Kant, K. & Gupta, N., 2011. Application based study on wireless sensor network. *International Journal of Computer Applications,* Volume 21, pp. 9-15.

Martirosyan, A., Boukerche, A., Werner, N. & Pazzi, R., 2008. Energy-aware and quality of service-based routing in wireless sensor networks and vehicular ad hoc networks.. *Annales des Telecommunications,* 63(11-12), pp. 669-681.

Mavromoustakis, C. X., Pallis, E. & Mastorakis, G., 2014. Resource Management in Mobile Computing Environments. *Springer,* p. 443.

Mazaheri, M., Homayounfar, B. & Mazinani, S., 2012. QoS based and energy aware multi-path hierarchical routing algorithm in WSNs. *Wireless Sensor Network,* 4(2), p. 31.

Meeneghan, P. & Delaney, D., April 2004. *An Introduction to NS, Nam and OTcl,* Maynooth: National University of Ireland, Maynooth.

Meeneghan, P. & Delaney, D., April 2004. *An Introduction to NS, Nam and OTcl,* Maynooth: National University of Ireland, Maynooth.

Mehdi Toussi, A. & Politis, C., 2013. *Energy conservative and coverage preservative clustering for wireless sensor networks, Personal Indoor and Mobile Communications (PIMRC).* London, IEEE Publisher.

Miao, Y., 2005 . *Applications Of Sensor Networks.* Numberg , Seminar on Wireless Self-Organization Networks Friedrich-Alexander-University Erlangen-Numberg.

Mueller, S., Tsang, R. & Ghosal, D., 2004. *Multipath Routing in Mobile Ad Hoc Networks: Issues and Challenges,* s.l.: Lect. Note. Comput. Sci.

Narottam, C., 2012. Cooperative Data Caching in WSN. *World Academy of Science, Engineering and Technology,* Volume 63.

Nazir, B. & Hasbullah, H., 2013. Energy efficient and QoS aware routing protocol for clustered wireless sensor network. *Computers & Electrical Engineering,* 38(9), pp. 2425-2441.

Nikoletseas, S. & Spirakis, P., 2009. Probabilistic Distributed Algorithms for Energy Efficient Routing and Tracking in Wireless Sensor Networks. *Algorithms,* Volume 2, p. 121–157.

Prasanna, S. & Rao, S., 2012. An overview of wireless sensor networks applications and security. *International Journal of Soft Computing and Engineering (IJSCE),* Issue 2 ISSN: 2231-2307.

Puccinelli, D. & Haenggi, M., 2005, 3rd Quarter. Wireless Sensor Networks: Applications and Challenges of Ubiquitous Sensing. *IEEE Circuits And Systems Magazine.*

Radi, M., Dezfouli, B., Bakar, K. A. & & Lee, M., 2012. Multipath routing in wireless sensor networks: survey and research challenges. *Sensors*, 12(1), pp. 650-685.

Rakesh, K., 2012. Clustering Based Efficient Data Aggregation Protocol for Wireless Sensor Networks. *International Journal of Engineering Research and Development*, 3(6), pp. 51-67.

Rao, A. et al., 2003, Sept. . *Geographic Routing without Location Information.* San Diego, CA, USA, Ninth Annual International Conference on Mobile Computing and Networking (MOBICOM), p. 96–108.

Sadagopan, N., Krishnamachari, B. & Helmy, A., May, 2003. *The ACQUIRE Mechanism for Efficient Querying in Sensor Networks.* Anchorage, AK, First IEEE International Workshop on Sensor Network Protocols and Applications (SNPA), p. 149–155.

Sangho, Y., Junyoung, H., Yookun, C. & Jiman, H., 2007. PEACH: power-efficient and adaptive clustering hierarchy protocol for wireless sensor networks. *Computer Communications,* 30(14-15), p. 2842–2852.

Santhi, G. & Alamelu, N., 2010. A Survey of QOS Routing Protocols For Mobile Ad Hoc Networks. *International Journal of Computer Science and Information Technology,* Volume 2.

Sarma, H. K. D., Rai, P. & Borah, S., 2014. *Communication, Cloud and Big Data*. England, ACCB Publishing, p. 91.

Schurgers, C., Kullkarni, G. & Srivastava, M., 2002. Distributed On-Demand Address Assignment in Wireless Sensor Networks. *IEEE Transactoins on Parallel and Distributed Systems,* 13(10), pp. 1056-1065.

Shafiullah, G. M., Gyasi-Agyei, A. & Wolfs, P. J., 2008. A survey of energy-efficient and QoS-aware routing protocols for wireless sensor networks. In: T. Sobh, K. Elleithy, A. Mahmood & M. A. Karim, eds. *Novel algorithms and techniques in telecommunications, automation and industrial electronics.* Dordrecht: Springer, pp. 352-357.

Shan, G., 2006. *Quality of Service Aware Routing Protocols for Mobile Ad Hoc Networks,* s.l.: Aalto University, Department of Electrical and Communications Engineering Sähkö- ja tietoliikennetekniikan osasto.

Sharifi, M., Taleghan, M. A. & Taherkordi, A., 2006. *A Middleware Layer for QoS Support in Wireless Sensor Networks.* Mauritius, Networking, International Conference on Systems and International Conference on Mobile Communications and Learning Technologies.

Sharma, P., Tyagi, D. & Pawan, B., 2010. A study on prolong the lifetime of wireless sensor network by congestion avoidance techniques. *International Journal of Engineering and Technology,* Volume 2.

Shigang, C., 2000. A QoS-Aware Multicast Routing Protocol. *IEEE Journal on Selected Areas in Communications,* Volume 18.

Singh, S. K., Singh, M. P. & Singh, D. K., 2010 . A survey of Energy-Efficient Hierarchical Cluster-based Routing in Wireless Sensor Networks. *International Journal of Advanced Networking and Application (IJANA),* 02(Sept–Oct), p. 570–580.

Soheil, G., Ankur, S., Xiaojian, Y. & Majid, S., 2002. Optimal Energy Aware Clustering in Sensor Networks. *Sensors,* Volume 2, pp. 258-269.

Sohrabi, K. & Pottie, J., 2000. Protocols for self-organization of a wirless sensor network. *IEEE Personal Communications,* 7(5), pp. 16-27.

Sohraby, K., Daniel, M. & Znati, T., 2007. *Wireless sensor networks, technology, protocols and applications.* New Jersey: John Wiley & Sons, Inc..

Son, D., Krishnamachari, B. & Heidemann, J., 2006. *Experimental Study of Concurrent Transmission in Wireless Sensor Networks.* Boulder, CO, USA, 4th International Conference on Embedded Networked Sensor Systems (SenSys ’06), p. 237–250.

Sriporamanont, T. & Liming, G., 2006. *Wireless Sensor Network Simulator,* s.l.: Halmstad University.

Sundani, H. L. H. D. V. A. M. a. B. P., 2011. Wireless sensor network simulators a survey and comparisons. *International Journal of Computer Networks,* 2(5), pp. 249-265.

Surender, K., Sumeet, K. & Bharat, B., 2014. Energy Aware Clustering Protocol for Heterogeneous WSNs. *International Journal of Computer Networks and Communications,* Volume 6.

Tarique, M., Tepe, K., Adibi, S. & Erfani, S., 2009. Survey of Multipath Routing Protocols for Mobile Ad Hoc Networks. *The Journal of Network and Computer Applications,* Volume 32, p. 1125–1143.

Tavares, J., Velez, F. J. & Ferro, J. M., 2008. Application of Wireless Sensor Networks to Automobiles. *MEASUREMENT SCIENCE REVIEW,* 8(3).

Thai, M., Wang, F. & Du, D., 2008. Coverage problems in wireless sensor networks design and analysis. *International Journal of Sensor Networks,* 3(3), p. 191–200.

Thai, T. V., Viet D., N. & Hien M., N., 2013. An energy aware routing protocol for wireless sensor network based on K-means clustering. In: I. Zelinka, V. H. Duy & J. Cha, eds. *AETA 2013: Recent Advances in Electrical Engineering and Related Sciences.* s.l.:Springer, pp. 297-306.

Tilak, S., Abu-Ghazaleh, N. & Heinzelman, W. A., 2002. Taxonomy of Wireless Micro-Sensor Network Models. *Mobile Computing and Communications,* 6(2), pp. 28-36.

Toussi, A., 2013. *Energy conservative and coverage preservative clustering for wireless sensor networks, Personal Indoor and Mobile Communications (PIMRC).* London , IEEE Publisher.

Toussi, A. M., Ramrekha, T. & Politis, C., 2010. *Energy efficiney and QoS in wireless sensor netwroks.* London, Wireless World Research Forum (WWRF).

Toussi, A. M., Ramrekha, T. & Politis, C., 2013. *A Cluster based data centric routing paradigm for wireless sensor networks.* Oulu, Finland, Wireless World Research Forum (WWRF).

Tsai, J. & Moors, T., 2006. *A review of multipath routing protocols: From wireless ad hoc to mesh networks.* s.l., ACoRN early career researcher workshop on wireless multihop networking.

Verdone, R., 2008. *Wireless Sensor Networks.* Bologna, Italy, 5th European Conference, Bologna.

Verdone, R., Dardari, D., Mazzini, G. & Conti, A., 2008. *Wireless Sensor and Actuator Networks: Technologies, Analysis and Design.* London, UK: Elsevier.

Villalba, L. J. G., Orozco, A. L. S., Cabrera, A. T. & Abbas, C. J. B., 2009. Routing Protocol in Wireless Sensor Networks. *Sensors*, Volume 9, pp. 8399- 8421.

Wang, X., Ma, J. & Wang, S., 2009. Parallel Energy-Efficient Coverage Optimization with Maximum Entropy Cluestering in WIreless Sensor Networks. *Journal of Parallel and Distributed Computing*, Volume 69, pp. 838-847.

Woo, A., Tong, T. & Culler, D., 2012. *Taming the Underlying Challenges of Reliable Multihop Routing in Sensor Networks.* Los Angeles, CA, USA, 1st International Conference on Embedded Networked Sensor Systems 5–7 November 2003, p. 14–27.

Yahui, L. & al., e., 2010. Secure Message Distribution Scheme with Configurable Privacy in Heterogeneous Wireless Sensor Networks. *IEICE Transactions on Information and Systems,* Volume E93-D.

Yahya, B. & Ben-Othman, J., 2009. *An energy efficient and QoS aware multipath routing protocol for wireless sensor networks.* s.l., IEEE 34th Conference on Local Computer Networks , pp. 93-100.

Yao, Y. & Gehrke, J., 2002. The Cougar Approach to In-Network Query Processing in Sensor Networks. *SIGMOD Record,* 31(3), p. 9–18.

Yassein, M. K. Y. a. M. W., 2009. Improvement on LEACH protocol of wireless sensor network (VLEACH). *International Journal of Digital Content Technology and its Applications,* 3(2).

Ye, F., Chen, A. & Lu, S., 2001. *A Scalable Solution to Minimum Cost Forwarding in Large Sensor Networks.* Scottsdale, AZ, USA, 10th International Conference on Communications and Networks, p. 304–309.

Ye, M., Li, C., Chen, G. & Wu, J., 2005. *EECS: an energy efficient clustering scheme in wireless sensor networks.* Los Alamitos, IEEE Computer Society Press, p. 535–540.

Yick, J., Mukherjee, B. & Ghosal, D., 2008. Wireless Sensor Network Survey. *Computer networks*, 52(12), pp. 2292-2330.

Younis, O. & Fahmy, S., 2004. HEED: a hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks. *IEEE Transactions on Mobile Computing*, 3(4), p. 366–379.

Zamalloa, M. & Krishnamachari, B., 2007. An Analysis of Unreliability and Asymmetry in Low-Power Wireless Links. 3(7).

Zanaj, E., Baldi, M. & Chiaraluce, F., 2007. *Efficiency of the Gossip Algorithm for Wireless Sensor Networks.* Split–Dubrovnik, Croatia, 15th International Conference on Software, Telecommunications and Computer Networks (SoftCOM).

Zhang, Q. & Zhand, Y. Q., 2008. *Cross layer Design for QoS Support in Multihop Wireless Networks.* s.l., IEEE, pp. 64-76.

Zheng, J. & Jamalipour, A., 2009. *Wireless Sensor Networks: A Networking Perspective.* s.l.:A John & Sons, Inc, and IEEEE.

Zhou, H., Mutka, M. & Ni, L., 2005. *Reactive ID Assignment for Sensor Networks.* s.l., 2nd IEEE International Conference on Mobile Ad-hoc and Sensor Systems (MASS).

Zhou, H., Mutka, M. & Ni, L., November, 2005. *Reactive ID Assignment for Sensor Networks.* Washington, DC, USA, 2nd IEEE International Conference on Mobile Ad-hoc and Sensor Systems (MASS).

Declaration

I herewith declare that I have produced this thesis without the prohibited assistance of third parties and without making use of aids other than those specified; notions taken over directly or indirectly from other sources have been identified as such. This thesis has not previously been presented in identical or similar form to any other UK or foreign examination board.

The thesis work was conducted from SEP 2010 to Feb 2017 under the supervision of Dr. Christos Politis at Kingston University.

Kingston-upon-Thames,