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BALANCED INTRA-CLUSTER MULTI-HOP ROUTING ALGORITHM BASED ON FORWARDING RESTRICTION ANGLE (B-IMRA) IN WIRELESS SENSOR NETWORKS

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ABSTRACT

Wireless Sensor Network (WSN) is evolving as a leading technology in the next generation of wireless communication systems. Energy optimization in WSN is an important requirement to be fulfilled since these sensors in most situations are battery-powered. This study is mainly focus on resolving an ideal routing technique to support intra-cluster communications which address energy constraint and load balancing within a cluster. Hence, a routing technique which is to extend the first forwarding scheme of existing Intra-Cluster Multi-Hop Routing Algorithm Based on Forwarding Restriction Angle (IMRA_1) is proposed and developed. Apart from satisfying IMRA_1's restriction conditions to limit the scope while forwarding a data packet to the Cluster Head, the proposed technique will calculate the Multi-hop Over Direct-hop (MOD) ratio and compare with a predefined Threshold Value (TV) to consider the most beneficial routing path to be elected. The key idea is to balance between energy consumption minimization and workload handled by each sensor nodes. The performance of this new approach is evaluated and compared with IMRA_1 routing protocol through sets of simulation. All the three research objectives defined at the beginning of this study have been achieved.

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CHAPTER ONE

INTRODUCTION

1.1 Background

The wireless communication nowadays has been revolutionized in improving the degree of human-computer interaction and making integrated networks a reality. Compared to wired solution, wireless network is typically lower in cost, instantaneous and practical to implement within infrastructure or power limitations. Due to this, wireless solution offers the alternative in which in some applications, we can merge wireless approach with the existing wired solution to yield a better outcome. One of the emerging technologies in wireless communication is Wireless Sensor Network (WSN).

The origin of WSN has started around 1998 and has received tremendous interest from the research community (Wang & Balasingham, 2010). WSN is particularly applicable for applications demanding low cost, low power, limited memory, limited computation and capable to be deployed on harsh environmental condition with unattended operation. Nowadays, WSN forms an important niche in wireless technology arena. There are many ranges of applications which are ideal for WSN including environmental sensing, industrial monitoring, agriculture, area monitoring and structural monitoring.

Since the past few years, intensive research in WSN is particularly emphasized in routing protocols. Routing in WSN is very challenging due to the unique features of these sensor nodes. They are energy and bandwidth constrained. Thus, innovative routing protocol that able to optimize the power consumption and efficiently exploit the limited bandwidth usage is deemed necessary.

There are many ways of categorizing the routing protocols in WSN today. One of the most popular is based on the network organization which consists of flat-based network routing, hierarchical-based network routing and location-based network routing. Among these, hierarchical-based network routing which employed clustering scheme has been extensively studied since it offers the potential for substantial performance improvements in WSN operations particularly in energy consumption.

Clustering in WSN context can be defined as a way of organizing a set of sensor nodes with its main objective is to prolong the lifetime of these sensors and increased network scalability by optimizing the energy consumption (Katiyar, Chand, & Soni, 2011; Younis, Youssef, & Arisha, 2003). Some of the major benefits derived from the implementation of clustering approach in WSN are briefly explain as below:

1. Implementation of Cluster Head (CH) in clustering approach, managed to extend the battery life span of individual sensor nodes through several management strategies which can lengthen the network lifetime (Younis, et al., 2003).
2. Clustering is able to conserve communication bandwidth through limiting the inter-cluster communication range and preventing the redundant message exchanges between sensor nodes (Younis, et al., 2003).

3. Clustering minimized the memory required to store routing table at individual nodes by localizing the routing within the cluster (Akkaya & Younis, 2005).
4. Clustering enhanced network scalability especially for network with large number of sensor nodes (Katiyar, et al., 2011).
5. Only aggregated data is transmitted to the sink node via CH, thus reducing the number of redundant packets and sensor nodes involved in each transmission (Dasgupta, Kalpakis, & Namjoshi, 2003).
6. Clustering can reduced the communication overhead as each sensor node is only required to communicate with their CH (Hou, Y.Shi, & Sherali, 2005).

Most routing protocols which employed clustering scheme primarily emphasized on the cluster formation process and communication between CH to the Base Station (BS). In this study however, the focus is only on the communication process within a cluster, on how efficient a sensor node is able to send data to its CH.

Research interest in WSN routing protocol mainly concentrate on minimization of energy consumption as a critical measure to achieve maximum WSN lifetime. However, apart from energy efficiency, routing protocol designs should also consider the reliability of the data transmitted as well as manage the load balancing throughout the whole network.

In that direction, this study will introduce an ideal routing technique to support intra-cluster communications which address energy constraint and load balancing within a cluster. The key idea is to balance between energy consumption minimization and workload handled by each sensor nodes.

1.2 Motivation

1. The energy scarcity has become the most important constraint in WSN. The amount of energy consumed in WSN is critically measured due to its basic features such as lightweight size, low battery powered and limited computation capability. Even though there are situations where alternatives to battery operated are available such as solar power recharge or battery replacement; but quite a number of applications which are impractical to do so. This includes critical and real-time applications such as military surveillance, hazardous application and remote monitoring. Therefore, this study will consider this kind of WSN application, where energy management is vital.
2. Clustering is highly adopted where most of hierarchical routing employed this technique. Within clustering scheme, only minimum number of research which addressed the intra-cluster communication was found. Majority highlighted the CH selection process and routing towards Base Station. Thus, since intra-cluster communication directly contributes to the whole of clustering scheme in maximizing network lifetime, this study is in the right direction.
3. Most study especially for large network focus on applying multi-hop solution as to conserve the battery lifetime, without considering the higher workload which need to be carry out by some nodes nearer to the CH; which also lead to higher energy consumption. This study will contemplate whether using the shortest route through multi-hop routing can reduce the total energy

consumption or by balancing between efficient routing path taken and workload will lead to a better solution.

4. Useful for researchers or network admin to consider the methods and apply in the network design if the network lifetime and energy consumption is a critical issue.

1.3 Problem Statement

Within cluster formation process, three important considerations should be focus in which are:

1. Cluster Head Selection
2. Intra-cluster communication
3. Inter-cluster communication

Among the three above, there are lack of studies that discuss on intra-cluster communication if compared to cluster head selection and inter-cluster communication. Intra-cluster communication as the internal routing method inside a cluster is deemed required being as efficient as it can before the external routing between clusters take place. The traditional intra-cluster communications make use of either single-hop routing or multi-hop routing.

When considering a large size of cluster, the existing IMRA_1 (Yang, Yin, & Yang, 2008) method which acts as the intra-cluster routing may emerge a new problem. IMRA_1 method is totally focused on reducing the energy usage, hence choosing an optimal routing path with least energy dissipation is preferred. Most of the time, multi-hop routing will be adopted. This will result with some sensor nodes especially those which frequently chosen as next hop nodes or the cluster member nodes which have the closest connection to CH will get exhausted very quickly because of the high workload that they need to accomplish. In addition, considering the transmission delay over the long hop prior reaching the CH will periodically require more energy usage. Thus, a load-balancing strategy is required to address the problem.

1.4 Research Objectives

Realizing the demand to minimize overall energy consumption within the cluster, there should be some mechanism to address the problem of unbalanced work load among sensor nodes. One possible implementation is to extend the first forwarding scheme of existing Intra-Cluster Multi-Hop Routing Algorithm Based on Forwarding Restriction Angle (IMRA_1), by calculating the Multi-hop Over Direct-hop (MOD) ratio to consider the most beneficial routing path to be elected. A name has been given to the proposed method, and it is called as Balanced Intra-Cluster Multi-Hop Routing Algorithm Based on Forwarding Restriction Angle (B-IMRA).

This optimal intra-cluster routing must be adopted to maximize the life span of the sensor nodes. Thus, the followings are the list of objectives for this research:

1. To enhance the existing route selection criteria and implement the original IMRA_1 protocol and the newly proposed method, B-IMRA protocol using simulation experiment.
2. To determine the ideal weight of Threshold Value (TV) for consideration during route selection process using simulation experiment of the newly proposed method, B-IMRA protocol.
3. To analyze and compare the performance of the existing IMRA_1 protocol with the newly proposed method, B-IMRA protocol in term of overall energy consumption and load balancing.

1.5 Scope of The Study

The scope of this research is as follows:

1. The study will focus on the improvement of the existing method, IMRA_1 specifically on load balancing within a cluster but at the same time maintain the efficiency of energy conservation.
2. The sensor nodes are defined to be homogenous with a standard transmitting power
3. All sensor nodes are considered as battery-operated, without the alternatives of battery replacement or solar power recharge
4. Initial energy of all nodes including CH are equally same
5. CH and cluster members are considered stationary as there is no mobility involved in this study

6. Static Clustering method is adopted, as CH will be maintained throughout the simulation testing
7. Sensor nodes and clusters are designed as distributed to consume better reliability

1.6 Organization of The Report

The report is presented in the following format. The first chapter focuses on the introduction of the topic in general. This includes background of the WSN, motivation of the study, the problem statement, objectives of the study and the scope covered on the proposed technique.

The second chapter discusses on the literature review which provide a critical analysis of the relevant literature. In this chapter, the author argues, evaluates and relates the previous works which are closely related to this study. It starts with general overview of wireless sensor network, followed by hierarchical-based routing which adopt clustering scheme. The literature continued with some intra-cluster routing and focusing specifically on IMRA_1 technique followed by a brief assessment on WSN simulation approach. This chapter concludes with discussion on overall literature studies.

The third chapter provides the research methodologies employed in this study. This includes the quantitative methods used, the research framework overview, the details of the existing and proposed method for the current study and the experimental methodology employed.

The following fourth chapter will explain about the simulation results and findings of this study. Results from simulation of both protocols with different parameters will be presented and compared accordingly.

The final fifth chapter discusses the conclusion and contribution of this study. The limitation of the study is also been highlighted. Both protocols involved in this study will be evaluated in term of its energy efficiency and load balancing. At the end of this chapter, some recommendations for future work will be proposed.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

A vast number of WSN routing algorithms has been presented since the past decade. There exist several surveys (Akkaya & Younis, 2005; Akyildiz, Su, Sankarasubramaniam, & Cayirci, 2002; Al-Karaki & Kamal, 2004; Dargie & Poellabauer, 2010; Le-Trung & Nguyen, 2011) that aimed to classify and categorize the various routing protocols according to either network organization, protocol operation, route discovery or type of application. Figure 2.1 below presents the classical categories of routing protocols from (Al-Karaki & Kamal, 2004).

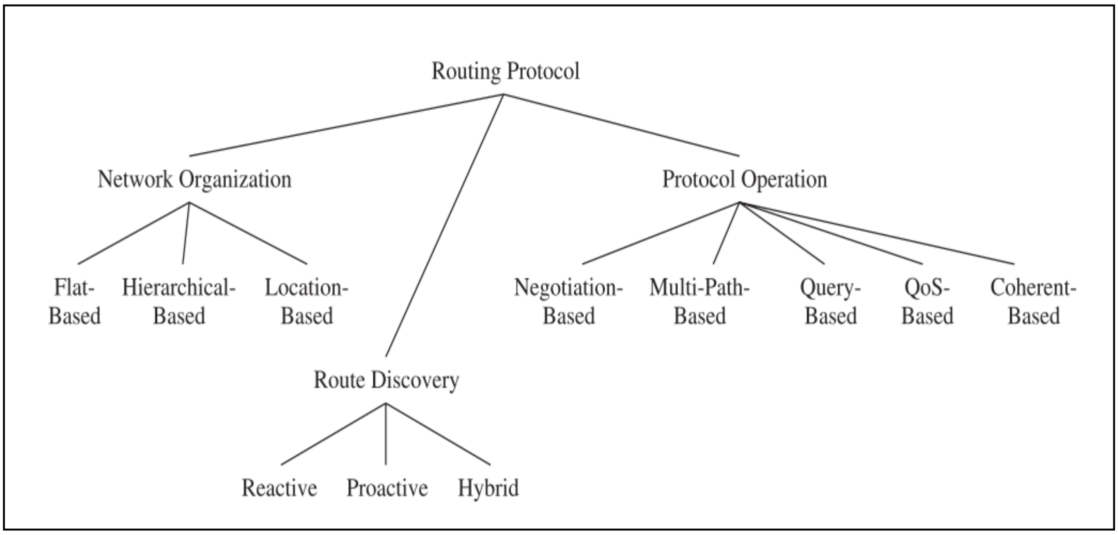

Figure 2.1: Categories of Routing Protocols in WSN
Source: Al-Karaki & Kamal, 2004

In WSN, energy usage can be classified into three major domain namely sensing, communication and data computation. Among the three domains, energy is mostly consumed during data communication process for transmitting own data or relaying neighbor’s data (Akyildiz et al., 2002).

A common WSN include a large number of tiny sensors with limited in power supply, computational capacities and memory (Al-Karaki & Kamal, 2004); but are designed to constantly sense and transmit the data. In order to improve the productivity of these sensors, clustering scheme is widely used.

Clustering approach is employed in hierarchical routing protocols as to address some limitation which faced by flat routing protocols particularly in efficiency and scalability (Dargie & Poellabauer, 2010). In hierarchical routing topology, two types of routings are relevant to the environment namely intra-cluster routing and inter-cluster routing. Intra-cluster routing involved communications that happen inside a cluster, whereas inter-cluster routing managed the communications between each CH to the BS.

2.2 Clustering Techniques

Clustering is an important research topic in WSN which offer various types of approaches on different performance metrics. There exist two variation of clustering approach, as been depicted in the Figure 2.2 as below.

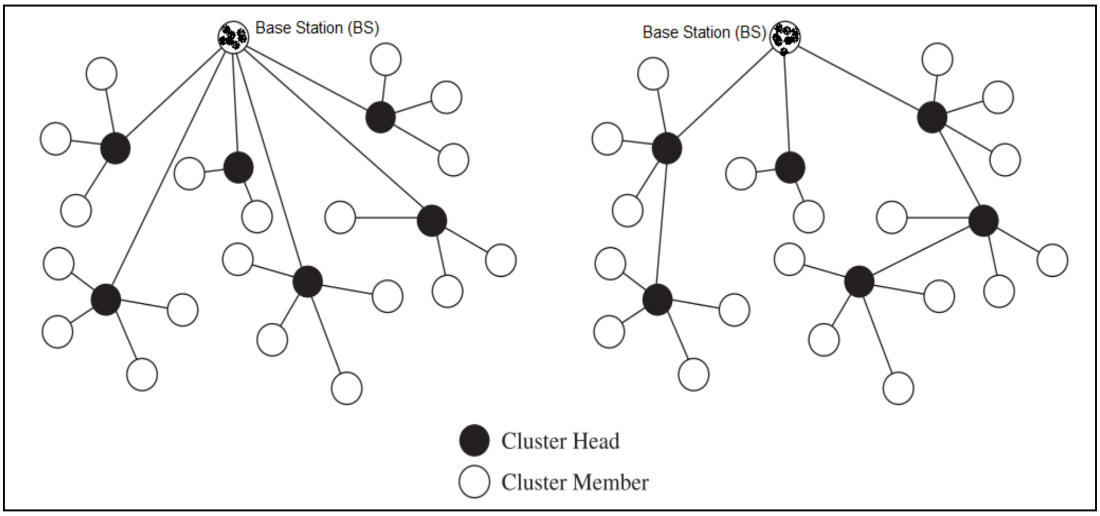

Figure 2.2: Clustering with single-hop connection to the BS (left) and clustering with multi-hop connections to the BS (right)
Source: Dargie & Poellabauer, 2010

Clustering with single-hop routing connection require CH which responsible for data aggregation to have a direct connection to the BS. This kind of topology minimized the routing challenges but may not be appropriate for a large network as more energy is needed to connect a very distant CH to the BS.

While multi-hop routing is adopted, the sensor nodes act as both data sender and data router. Thus, the role of these sensor nodes are very critical as any malfunctioning of some sensor nodes can cause packet loss, rerouting of data packets as well as jeopardized data accuracy. The malfunction of sensor nodes is typically due to power failure; hence the demand to sustain the power usage at an optimum level in WSN is indispensable.

Among the earliest and most popular hierarchical routing for WSN was developed by Heinzelman, Chandrakasan, and Balakrishman (2000) called LEACH (Low Energy Adaptive Clustering Hierarchy). The operation of LEACH is divided into rounds, where each round begins with a setup phase followed by a steady state phase. The formation of clusters is catered in the setup phase, whereas the steady state phase covered the data transmission to the base station. Formation of clusters are based on the signal strength of the broadcast message that received by each node. Each node will choose the strongest signal and join the cluster. In LEACH, the CH is selected randomly and the role rotates for every node in order to balance the energy used throughout the network. The CH will then broadcast to its cluster, a Time Division Multiple Access (TDMA) schedule which must be used by the cluster members for sending data to CH. From LEACH analysis, the total CH is about 5% from the total sensor nodes in the network. LEACH has structured the steady state phase much longer compared to setup phase in order to minimize the overhead (Patel & Singh, 2012). During steady state phase, data transmission can begin once the TDMA schedule is broadcast to the cluster members by the CH. Each node will only send their data to CH on the allocated TDMA schedule and they can be in sleep mode for the rest of the time to save energy. Apart of this novel algorithm, one of LEACH limitation is the random selection for CH. By using random concept, there can be possibility that the CH formations are not balanced throughout the network. There might be one part of the network are full of CHs while the other part contain none, thus resulting of network unreachable for the none-CH area. Today, most of the present clustering-based algorithms are adaptation of LEACH.

The enhancement of LEACH approach known as LEACH-C addressed the cluster formation process by using centralized cluster formation algorithm (Heinzelman, Chandrakasan, & Balakrishnan, 2002). This algorithm begins from the BS, where BS will receive all information on sensor nodes including location and energy level of the nodes. Then, BS will carry out the cluster formation process and CH are been selected. In this approach, the CH selection is maintained as randomized and the number of CH is also limited. Among the advancement made is BS will ensure that sensor nodes with less energy will not be chosen as CH. However, LEACH-C is not viable for bigger networks as the distant nodes will struggle to reach BS. This is getting worse when the CH keeps changing due to rotation and directly leads to high latency and delay.

On the other hand, LEACH–F by Heinzelman et al. (2002) designed to have fixed clusters and CH rotation only been carry out within the cluster itself. The strength of this idea are basically in energy saving and improving throughput, but it limits the network from scale. Thus, scalability is an issue for LEACH-F approach.

Said and Abdellah (2010) suggested an Improved and Balanced LEACH which is called IB-LEACH. IB-LEACH used randomization approach for uniformly distribute the energy load among sensor nodes. Some nodes with higher energy are called NCG nodes (Normal/Cluster-Head/Gateway) which will be chosen as CH to perform data aggregation within its cluster and data transmission towards the BS. The goal of IB-LEACH is typically to reduce the energy consumed and probability of malfunction nodes. Once cluster formation is established, each CH will create schedule for the nodes within a cluster which enables these nodes to be in sleep mode at all times except for data transmission activities. Therefore, the energy consume for each sensor nodes is minimized.

Earlier on, Manjeshwar and Agrawal (2001) introduced TEEN (Threshold sensitive Energy Efficient sensor Network protocol) which designed purposely for reactive networks to be used in time critical sensing applications. Data sensing is done continuously in this approach, whereas data transmission is on user demand. The CH employed two threshold values, which are soft threshold and hard threshold. Soft threshold denote the minor change of sense attribute which trigger the data transmission if the soft threshold value is satisfied, hence reducing the number of data communication. On the other hand, hard threshold hold the least value which initiate the data transmission from nodes to CH. The major benefit of this approach is it appropriates for time-critical applications and substantially decreases the number of communications. By varying the value of the threshold, user can have high control in accuracy of the attribute value collected.

APTEEN is an improvement of TEEN by Manjeshwar and Agrawal (2002) which is designed to address both periodic and time critical data aggregation. In this approach, CH broadcast four message types to its cluster members. In term of energy consumption, TEEN and APTEEN outperform LEACH. But overall performance shows TEEN is better compared to the rest. One of the main weakness of TEEN and APTEEN is their complexity and high overhead due to their multilevel clustering approach.

Additionally, Distributed Energy Efficient Clustering Algorithm (DEEC) was proposed by Li, Qingxin, and Mingwen (2006) which is also based on LEACH. Both DEEC and LEACH rotate the CH role, but DEEC first consider the two levels of heterogeneous nodes to be the CH before deploying the general election as LEACH. The key criteria in order to be elect as CH is based on ratio between node's residual energy and the average energy of the network. In term of intra-cluster routing, DEEC practice single hop routing.

A refined algorithm of DEEC is known as Stochastic DEEC (SDEEC) was designed by Elbhiri, Saadane, and Aboutajdine (2009). This technique maintained the CH selection in overall network but the improvement was in intra-cluster routing where the transmission is reduced. Non-CH can switch to sleep mode for energy conservation purpose, but this lead to another issue where these nodes are unaware of the next round of CH selection. However, SDEEC denote better in prolonging network lifetime rather than SEP and DEEC as shown in the simulation results.

More on energy-focus clustering approach is the scheme designed for heterogeneous WSN called TDEEC (Threshold Distributed Energy Efficient Clustering) protocol developed by Saini and Sharma (2010). The scope of the algorithm is including random deployment of location-unaware heterogeneous sensor nodes, which have similar computation and communication abilities. However, the heterogeneity of nodes is distinct in term of energy level. TDEEC introduced a threshold value for CH selection, based on ratio of residual energy and average energy in the current round to decide the number of CH. For heterogeneous environment of WSN, TDEEC produces better simulation outcome when compared to DEEC and SEP.

Kumar, Aseri, and Patel (2009) anticipated an Energy Efficient Heterogeneous Clustered scheme (EEHC) for selecting CH in a distributed fashion in hierarchical WSN. The CH is selected based on the residual energy of a node compared to other nodes in the network. The algorithm is LEACH-based but involved nodes heterogeneity. When compared to LEACH in simulation experiments, results show that EEHC performance is more effective in extending the network lifetime.

Another technique which aims to get a balanced network while minimizing the energy consumption is as proposed by Li Li and Xiang-ming (2006). The authors anticipated an Energy Efficient Clustering Routing (EECR) that form clusters and select CH base on weight value.

In 2006, Israr and Awan (2006) had presented a new multi-hop routing algorithm for inter cluster communication which address both energy consumption and load balancing issues by exploiting redundancy properties of WSN. The algorithm randomly chooses a small portion of the total sensor nodes and designates them as temporary CH. Nevertheless, the random concept applied in this algorithm did not guaranteed that all potential areas been covered.

Thus, Israr and Awan (2007) initiated an improved version of multi-hop routing algorithm called Multi-hop Clustering Algorithm for Load-Balancing (MCLB) which developed based on the principle of divide and conquer algorithm. MCLB enhanced the random technique used previously with a more specific technique in choosing the temporary CH. A neighbor node, B will become a temporary CH of sensor node A if B also covers the coverage area of sensor node A. With this concept, communication is performed in two layers which are bottom layer and top layer. Sensor nodes transmit data towards the temporary CH on the bottom layer, whereas this temporary CH will deliver the data to the BS using multi-hop routing in the top layer. When compared to LEACH, this MCLB technique yield better result in term of balancing the energy consumption load which lead to network lifetime continuity. Figure 2.3 below shows the general operation of this algorithm.

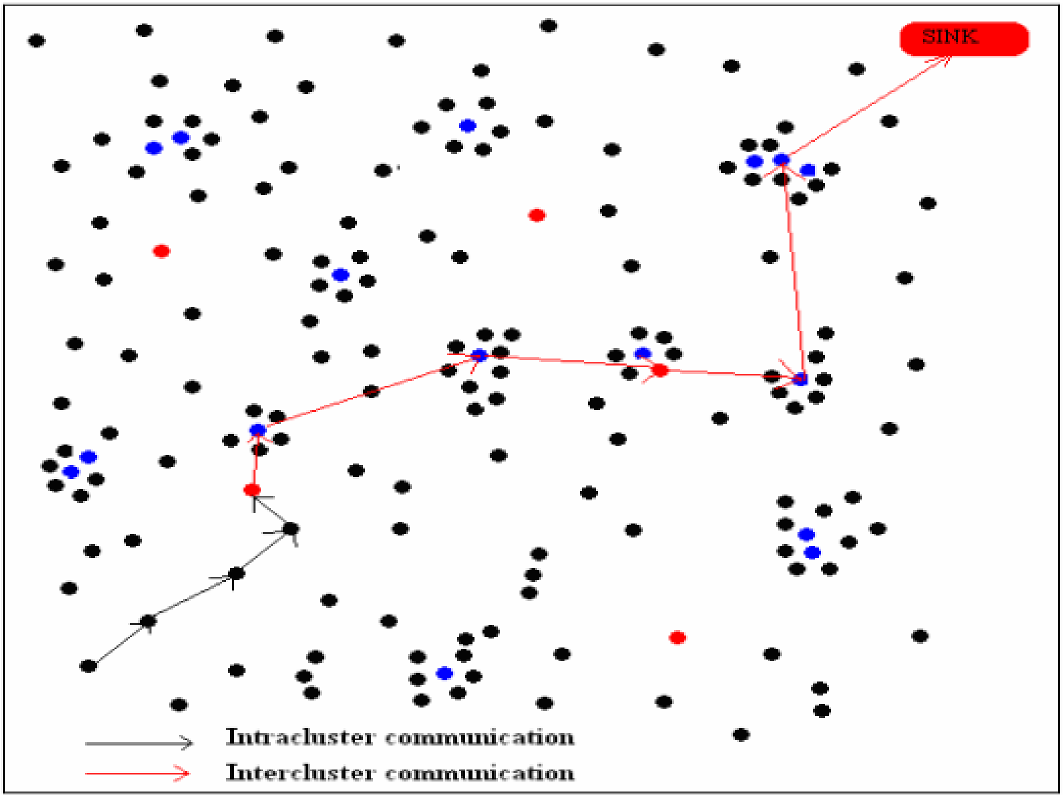

Figure 2.3: General Operation of the MCLB Algorithm
Source: Nauman & Israr, 2006

Marin-Perianu, Scholten, Havinga, and Hartel (2008) also focused on energy efficient heterogeneous WSN protocol known as Energy Efficient Service Discovery Protocol (C4SD). This protocol grounded on clustering structure which provides distributed storage of service descriptions. Each sensor node is associated with a unique weight and hardware identifier. The higher the weight reflects the capability level of CH suitability. The CH act as distribute directory for service registration within the cluster. With this design, construction and maintenance of overhead is minimized, hence adaptation to any topological changes will be quicker. Any service lookup will concentrate on the directory nodes only, thus reduce discovery cost. C4SD is been compared to Distributed Mobility Adaptive Clustering (DMAC) and yield better performance.

Bandyopadhyay and Coyle (2003) introduced another randomized and distributed clustering algorithm which is presented as a technique of dividing the network into clusters. The approach focus in avoiding unnecessary advertisements by limiting CH advertisement into some predefined hops, k. The main idea is basically to save energy.

The protocol by Gupta and Younis (2003) presented a multi-gateway architecture which satisfies multiple requirements without compromising the protocol efficiency. This algorithm balances the load of each cluster and resulting a uniform cluster formation. Two types of sensor nodes are been used. They are energy constrained sensor node and gateway node with less energy constrained. Communication between sensor nodes and CH is utilizing TDMA based MAC. The limitation of this approach is network connectivity will slowly decreased due to the nodes closer to CH will get exhausted quickly in the event of stationary CH and fixed topology. Nevertheless, if random deployment is employed, there is probability that the CH distribution will be unbalanced.

2.3 Intra-Cluster Communication

Both papers by Akhtar, Minhas, and Jabbar (2009); and Jardosh and Ranjan (2007) addressed on the importance of intra-cluster routing topology in WSN despite of the critical CH selection in every cluster formation. As covered in detail by Akhtar, et al. (2009), sensor nodes lifetime can be increased by deciding whether to use direct routing or multi hop routing for communication with their CH. Initially, prior to transmit the first data towards the CH, the sensor node must determine the best intra-cluster routing to be applied. Some predefined range of distance between CH and its cluster members is set. If the distance exceeds the limit, the sensor nodes are required to use multi hop routing to send data to CH, otherwise direct routing is engaged. This approach is simple to implement, yet it yields positive result where energy consumption is reduced and prolong the life span of the sensor node. However, the approach is only significant for large number of sensor nodes in a cluster because small network will typically used direct routing.

As mentioned by Mamalis, Damianos, and G.Pantziou (2009), among the key parameters for clustering measures are Cluster Count, Cluster Overlap, Cluster-head Selection, Node Mobility and Time Complexity. However these parameters are varies typically according to the type of application and the size of the network.

On the other hand, Jardosh and Ranjan (2007) employed Voronoi Tessellation algorithm in cluster region for CHs to established and announced on their existence. This technique will enable the remaining cluster members to identify their nearest CH and join the appropriate cluster. This technique applies leveling method to place the sensor nodes in the network in order to utilized level-based intra-cluster communication. In this approach, hop count and common communication range are used as the parameter in the leveling messages between CH and its members. From the simulation results, it is shown that this approach is better from the tree-based approach and it can be a good choice for network scalability. Figure 2.4 below shows the Voronoi Tessellation topology.

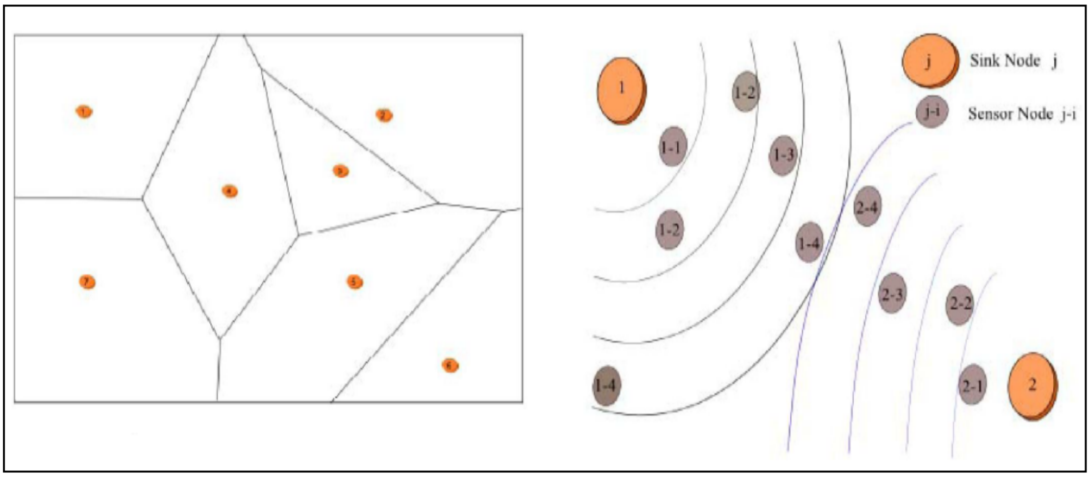

Figure 2.4: Voronoi Tessellation of WSN (left) and Intra-cluster leveling topology (right)
Source: Jardosh & Ranjan, 2007

Another cluster formation technique which utilizing grid-based topology is presented by Bhakare, Krishna, and Bhakare (2012) called as Grid Based Clustering. This technique gains its popularity due to its simplicity and scalability regardless of the number of nodes in the network. Besides, energy consumption can be reduced by determining the optimal grid size which contributes to the overall network lifetime in WSN. Several grid algorithms were introduced previously, and most of them calculated the energy usage by the average distance within a grid or between neighbor grids. Nevertheless, this average distance method is less accurate and will not depict the actual value. Thus, in this technique, cluster formation depends on the nodes interest. With regards to intra-cluster routing, drop-tail type of queue is been applied since it present in all nodes. In general, Grid Based Clustering is simple to implement and highly applicable for real-time applications.

Goyeneche, Villadangos, Astrain, Prieto, and C´ordoba (2006) had introduced a novel data aggregation method in a cluster network where CH is not been elect at the initial stage. Any node can transmit its data packet to the neighbors via multi-hop routing, but the last node that able to send such data to the BS will be selected as CH.

Derived from Ahmed, M.Peng, and Wang (2007) is one of adaptive algorithm manipulating on Cluster ID, known as Cluster ID based Routing in Sensor Networks (CIDRSN). This technique forms cluster once and maintain throughout the process, thus eliminate excessive energy usage for cluster formation. Apart from it, this technique addresses Cluster ID as the next hop in routing table rather than CH-ID.

The following section will particularly reviewed on the novel intra-cluster multi-hop algorithm which employ forwarding restriction angle. This method will be used in this study as the basis of intra-cluster communication for the newly proposed method.

2.3.1 Intra-Cluster Multi-Hop Algorithm Based On Forwarding Restriction Angle in WSNs (IMRA)

The paper presented by Yang et al. (2008) is made as the primary reference for this study. The main objectives of the paper are typically to reduce the energy consumption for internal environment of a cluster. The problem addressed is considering a high-density sensor network utilizing multi-hop routing protocol to transmit data from cluster member nodes to the CH. Transmission delay and maintenance of the lengthy multi-hop routes are believed to consume more energy. There is a single routing algorithm with two types of forwarding schemes had been introduced by Yang et al. (2008). The routing technique, Intra-Cluster Multi-Hop Routing Algorithm (IMRA) was explained as an undirected graph problem with every edge has a weight value representing communication energy consumption. During data transmission, some precondition which determine the actual route to be taken must be satisfied. The route selection process is shown as illustrated in Figure 2.5 below:

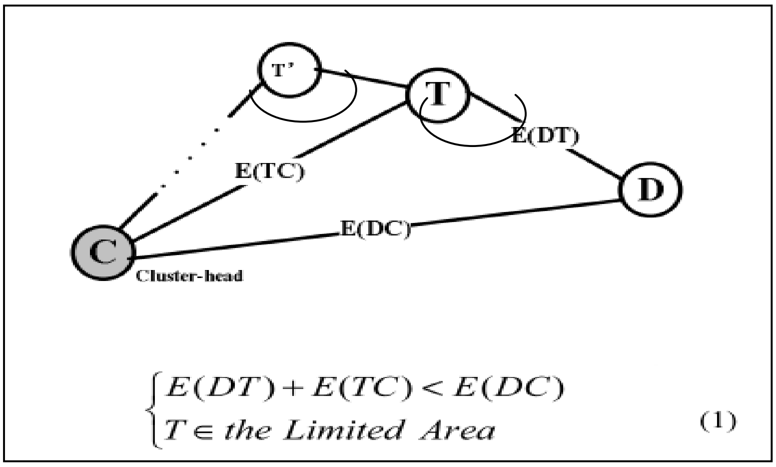

Figure 2.5: Route Selection Process in IMRA
Source: Yang et al., 2008

This algorithm proposed two approach of forwarding restriction schemes. The first scheme known as IMRA_1 as illustrate in the Figure 2.6 (left) below, is utilized the triangle formula to calculate the angle between edge DT and TC, also known as ∠DTC. At any point of data transmission, if ∠DTC is greater than the predefined forwarding restriction angle, therefore T is belongs to the limited area. Thus, D can forward the data to T. If ∠DTC is smaller than the predefined forwarding restriction angle, D will need to find other intermediate nodes which able to satisfy the condition required.

The second forwarding scheme named as IMRA_2 is based on idea of Static Angle Area (SAA). As shown in Figure 2.6 (right) below, two limited circles are built for CH node C and CH node D with their radius are R_C and R_D, where $R_C > R_D$. Then, common tangents of the two circles are constructed at the point M and N where both points intersect at point O. Therefore, the restrict area is the area between these two intersection of ON and OM.

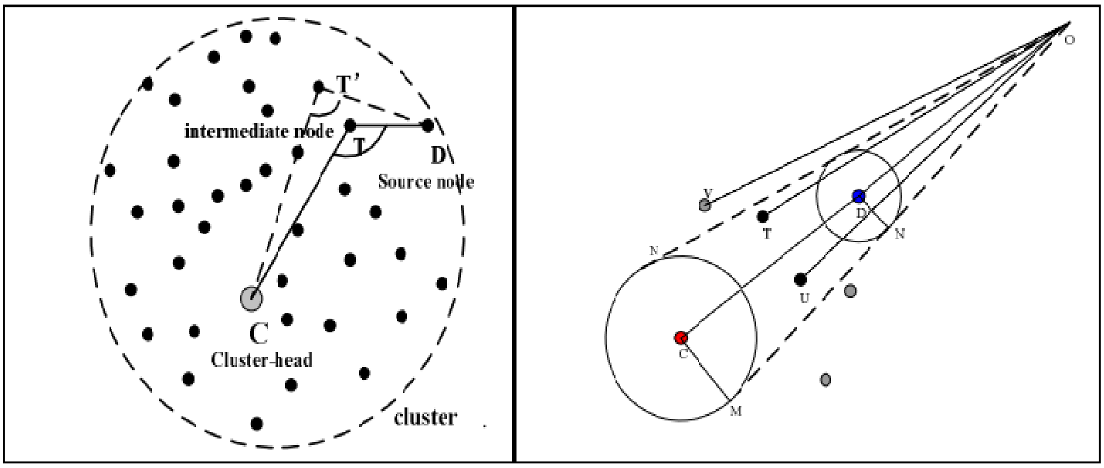

Figure 2.6: First forwarding scheme IMRA_1 (left) and second forwarding scheme IMRA_2 (right)
Source: Yang et al., 2008

The IMRA_1 technique has highlighted its limitation and the most-obvious one is the unbalanced situation whereby some nodes which always act as next hop towards the CH will die off very soon compared to the rest. Therefore, the authors addressed this condition by setting up a new criterion while choosing a next-hop. A next-hop to be chosen must satisfy the remaining energy threshold which has been set earlier. As a result, a chosen next-hop will always abide to certain energy level in order to carry out the data transmission.

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