YAŞAR UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MASTER THESIS

A PROPOSAL OF CONGESTION CONTROL MECHANISMS FOR WIRELESS SENSOR NETWORKS

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ABSTRACT

A PROPOSAL OF CONGESTION CONTROL MECHANISMS FOR WIRELESS SENSOR NETWORKS

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Congestion control is one of the critical issues in Wireless Sensor Networks (WSNs). It occurs due to high data generation rate and limited capacities of sensor nodes. Congestion in a network causes performance degradation because of packet drop, low delivery rate and high-energy dissipation. This study presents a new approach to control congestion in WSNs by using Vice Cluster Head (VCH). It is proposed for cluster-based networks and its significant role is to present an alternate solution when there is a congestion or energy dissipation in the Cluster Heads (CHs). It works in two phases; setup phase and transmission phase. Setup phase includes; making of clusters by dividing the network into grids, selecting CHs and VCHs for each grid, while the transmission phase includes; data transmission between member nodes to the CHs and from CHs to the Base Station (BS). The proposed protocol is simulated in MATLAB and the results show a significant increase in the performance of delivery rate, energy consumption and network lifetime in comparison to LEACH and MODLEACH.

Key Words: wireless sensor network, congestion control, cluster head, vice cluster head, centrality, congestion detection, buffer occupancy.

ÖZ

KABLOSUZ ALGILAYICI AĞLAR İÇİN BİR TIKANIKLIK KONTROL MEKANİZMASI ÖNERİSİ

Asim, Muhammad
Yüksek Lisans, Bilgisayar Mühendisliği
Danışman: Yrd.Doç. Dr.Tuncay Ercan
Ocak 2018

Tıkanıklık kontrolü, Kablosuz Algılayıcı Ağlardaki (KAA) önemli konulardan biridir. Bunun nedeni de herbir sensor cihazının sınırlı kapasitede olması ve ağ ortamındaki hızlı veri üretimidir. Ağ ortamındaki tıkanıklık paket kaybından, düşük iletim hızından ve yüksek enerji harcamasından kaynaklanan bir performans azalmasına neden olur. Bu çalışma, KAA.lardaki tıkanıklık sorununu yardımcı bir yığın başı kullanarak çözmeye yönelik yeni bir yaklaşım sunmaktadır. Yığın temelli ağlar için kullanılacak bu yaklaşımın temel rolü yığın başlarında oluşacak enerji azalmasına veya tıkanıklığa alternatif bir çözüm sunmaktır. Bu çözümün iki farklı safhası vardır: Kuruluş ve İletim safhası. Kuruluş safhasında ağ ortamı gridlere bölünerek yığınlar oluşturulur ve yığın başı ile yardımcı yığın başı seçilir. İletim safhası ise normal sensör birimlerinden yığın başlarına ve yığın başlarından baz istasyonuna olan veri iletişimini içerir. Önerilen protokol, MATLAB ortamında benzetilmiş ve verinin teslim hızında, enerji tüketiminde ve ağın yaşam süresine ilişkin performans ölçümlerinde LEACH ve MODLEACH protokolleriyle karşılaştırıldığında dikkat çekici sonuçlara ulaşılmıştır.

Anahtar Kelimeler: kablosuz algılayıcı ağ, tıkanıklık kontrolü, yığın başı, yardımcı yığın başı, merkeziyet, tıkanıklık tespiti, hafıza doluluğu.

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I would like to express my enduring love to my parents, who are always supportive, loving and caring to me in every possible way in my life.

Muhammad Asim

İzmir, 2018

TEXT OF OATH

I declare and honestly confirm that my study, titled "A PROPOSAL OF CONGESTION CONTROL MECHANISMS FOR WIRELESS SENSOR NETWORKS" and presented as a Master's Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Muhammad Asim

Signature

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January 08, 2018

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SYMBOLS AND ABBREVIATIONS

ABBREVIATIONS:

WSN	Wireless Sensor Network
CH	Cluster Head
VCH	Vice Cluster Head
FLS	Fuzzy Logic System
ADC	Analog to Digital Converter
CSMA	Carrier Sense Multiple Access
TDMA	Time Division Multiple Access
PDR	Packet Delivery Ratio
QoS	Quality of Service

SYMBOLS:

R	Transmission range of sensor nodes.
L	Length of one side of square grid.
D	Distance between two sensor nodes.

CHAPTER 1
INTRODUCTION

Wireless Sensor Network (WSN) is a collection of identical sensor nodes, which work collectively for a common task. They sense and gather information from environment and forward them to a sink, where a user can easily manipulate them (Uthra and Raja, 2012). Besides having resource constraints like computational power, memory and energy resources, sensors have to work and deliver accurate results.

In a wireless network environment, all the nodes work as a source and an intermediate node to forward data coming from their neighbor nodes. When a number of nodes attempt to send their sensed data simultaneously, or their data generation rate is higher than the computing capacity of a node, then this will cause a congestion in intermediate nodes or in the network. Congestion is one of the biggest challenges in sensor networks; it causes packet drops and energy dissipation due to retransmission of the lost packets.

The main reasons for congestion in WSN are as follows:

- Increased traffic flow in the network because of too many source nodes
- Concurrent transmissions
- Many to one nature of traffic flow

Congestion also occurs when a node receives more packets from its neighbors than it can handle, which results in buffer overflow and packet drop. Following the same route every time can also cause congestion and energy drain for the nodes on that route (Chakravarthi and Gomathy, 2010; Uthra and Raja, 2012; Ghanavati, Abawajy, and Izadi, 2013; Rana and Kamboj, 2016). That is why picking the right nodes as relay, play an important role to avoid network from getting into a congestion state, which results in network lifetime extension and helps to maintain fairness. Therefore, there has to be a control mechanism, which can avoid congestion and distribute traffic in different paths by employing nodes with greater energy.

There have been many protocols proposed to control congestion, which work when network gets congested, and that is a difficult state to recover the network from, by conserving all data. The best way is to predict and inform the nodes about the upcoming congestion situation and propose an efficient way to deal with it. Networks of critical and sensitive data for example, medical sector cannot afford any packet loss and cannot even get rid of a performance fall. A congestion prediction and avoidance mechanism need to be there before network goes to a worse state.

The reduction in the transmission rate (congestion window) of the source nodes is one of the methods used to mitigate congestion, as employed by Sharma, Singh, and Patel (2010), Patil and Dhage (2012), Hatamian and Barati (2015), Kadam and Chatur (2016). Another way to elevate congestion from network is to drop packets in an intelligent way, as adopted by Chakravarthi and Gomathy (2010), and Halim, Yaakob, and Isa (2016). However, in some applications all the data generated from an event holds importance and reducing their transmission rate or dropping some of the packets will effect overall network performance. On the other hand, another approach to control congestion is resource control, which allows the traffic generated from an event to flow by utilizing additional network resources, as adopted by Kang, Zhang, and Nath (2007), Sergiou, Vassiliou, and Pitsillides (2007), Heikalabad, Ghaffari, and Abolga (2011), Banimelhem and Khasawneh (2012), and Sergiou, Vassiliou, and Paphitis (2014). This method assures to deliver all generated data packets to the sink.

1.1. Thesis Objectives

This study discusses congestion occurrence in WSNs and the problems faced in the network due to congestion. Different approaches in the literature have been presented to mitigate congestion, they are analyzed in this paper and finally a new approach is presented to elevate congestion from the network. This approach is specifically designed for grid-based networks, where each grid is considered as a cluster.

The main objective of this proposal is to deliver all the generated data packets from source nodes to the sink by employing alternate nodes when congestion occurs in any part of the network. In cluster-based networks, the Cluster Heads (CHs) are the nodes where congestion is more likely to happen, so an alternate for CH is introduced in each cluster, i.e. Vice Cluster Head (VCH), which takes over CH’s functions when it suffers from congestion.

The VCH is selected by CH according to its rank and the ranks are calculated by using Fuzzy Logic System (FLS) from two input parameters; residual energy and centrality. CH in a cluster will be the node having highest residual energy and centrality, while VCH will be the node having second highest residual energy and centrality.

1.2. Order of Thesis

There are six main chapters in this thesis and they are briefly overviewed in this section. The first chapter begins with an introduction about the WSNs and congestion problems in such networks. Followed by the overview of the contribution of this thesis. For better understanding of the wireless sensor networks, the architecture and working methods of sensors are presented. The congestion occurrence in WSN is discussed in the last.

Chapter two gives details about congestion in WSNs and its controlling methods from the literature. Three main procedures for congestion are discussed and these are; congestion detection, congestion avoidance and congestion control. The control protocols are further divided into three mechanisms; traffic control, resource control and packet drop.

The working of the proposed method is explained step by step with supporting references from literature in chapter three. The main parts of the chapter are; selecting CH in grid based networks with fuzzy logic, selection and employing criteria for VCH and finally congestion detection parameters are discussed.

Chapter four explains the proposed method in details. It offers a way to divide network into grids and deals each grid as a cluster, then a method for CH and VCH selection is presented from two parameters; residual energy and centrality with the help of FLS. It further gives the radio energy consumption for communication and the calculations for congestion detection. Finally, it tells about the conditions where VCH replaces the CH.

The algorithm for proposed method is analyzed by using MATLAB in chapter five. The results are then compared with LEACH and MODLEACH. Through the graphs it is shown that the proposed algorithm gives significantly better results than the other two protocols in terms of energy consumption, packet delivery ratio and network lifetime extension.

Finally, the last chapter concludes the thesis with the future directions.

1.3. Sensors and Their Architecture

A sensor can be defined as "a device that produces measurable responses to the changes in a physical or chemical condition" (Torres, 2006). These responses are processed and transmitted by the sensors to the destinations where they are analyzed by an end user. The transmission is done according to the range of the sensor's radio coverage area. The sensors are made up of five basic components; sensing unit, processing unit, memory unit, transceiver and power capabilities (see Figure 1.1). They are explained as follows;

<u>Sensing Unit:</u> The part of sensor that senses and collects readings from the environmental changes. The sensors generate analog signals from a detected event and then it is converted into a digital signal with an analog-to-digital convertor (ADC), before it is transmitted any further.

<u>Processing Unit:</u> It plays an important role to handle the sensed data as a digital signal from the sensing part. A microcontroller in the processing unit performs some simple computations on the sensed data instead just transmitting it in raw form. Though there are nodes in the network responsible for fusing and aggregating the received data but it is also done locally in every node.

<u>Memory:</u> There are two types of memories found in a sensor node with their different usage. Microcontroller has a memory where it stores the system's software. Another type of memory is flash memory; it is used to store the applications and data.

<u>Transceiver:</u> The transceiver unit can be divide into four operational states; transmit, receive, idle and sleep. The sensors consume most part of their energy in communication processes. Most energy consumable states are transmission and receiving, and it can further increase with the longer distances. In WSN, nodes are densely deployed and they have short distances in between, so they use multi-hop approach, which is more energy efficient than the traditional way of single hop communication.

<u>Power Unit:</u> It is one of the most important parts of a sensor because the lifetime of a sensor depends completely on its power capabilities. Batteries are used as power sources and they can be categorized into two types; rechargeable and non-rechargeable. Mostly the nodes working in remote and harsh environments have non-rechargeable batteries and it is very challenging to replace them in case of their termination. This

requires to design energy efficient protocols in order to extend network life duration as long as possible.

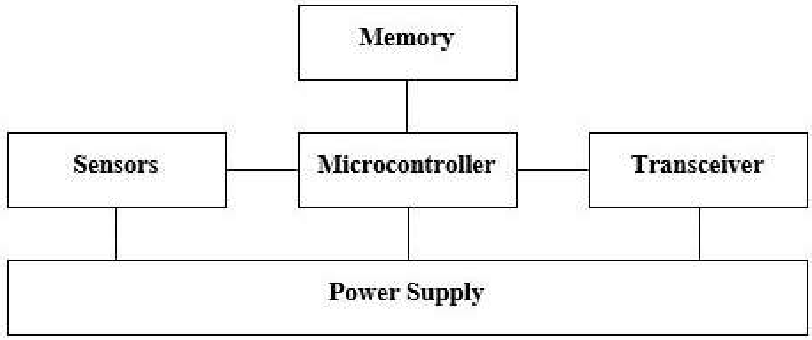

Figure 1.1. Architecture of Sensor Nodes

1.4. Wireless Sensor Networks

Wireless sensor networks (WSNs) comprise a large number of sensor nodes, spatially distributed in an area to gather information in a collaborative way. They monitor and report to the physical and environmental changes such as; temperature, pressure, light, motion, sound and vibration, where air is the communication medium between them. When sensor networks are built in remote areas, the sensor nodes need to self-organize themselves without having any knowledge about network topology (He, Blum, Stankovic, and Abdelzaher, 2004). This process makes it a challenging issue to discover the other nodes in the network initially and then to find ways to the destination. The sensor nodes sense and collect their observations and report them to the sink. Because of the limitations of their radio ranges and the location of the sink, the communication between the nodes and the sink cannot be direct in most of the cases, so they follow a multi-hop routing approach with the help of other intermediate nodes to reach the sink.

The routing protocols in WSNs are application specific, data centric, capable of data aggregation and can optimize energy consumption (Hussain, Singh, and Singh, 2013). The nodes do not have to send their data directly to the sink for long-range distances, they can route them through intermediate nodes that reduces energy consumption for transmission. Data aggregation is done in every intermediate node, which saves energy by reducing the size of transmitting data. In cluster-based networks, the CHs are used as intermediate nodes. They route data toward the destination and perform data aggregation tasks, which reduces energy usage.

In WSNs, the sink can be fixed or a mobile node, which has greater capabilities than the normal nodes. It makes the sensor network accessible to the communication infrastructures or to the internet where a user can access the collected data (Uthra and Raja, 2012) (see Figure 1.2). The sensor networks have many military and civil applications. They are being used for environmental monitoring, home automation and smart buildings (Lai , Fan, and Lin, 2012).

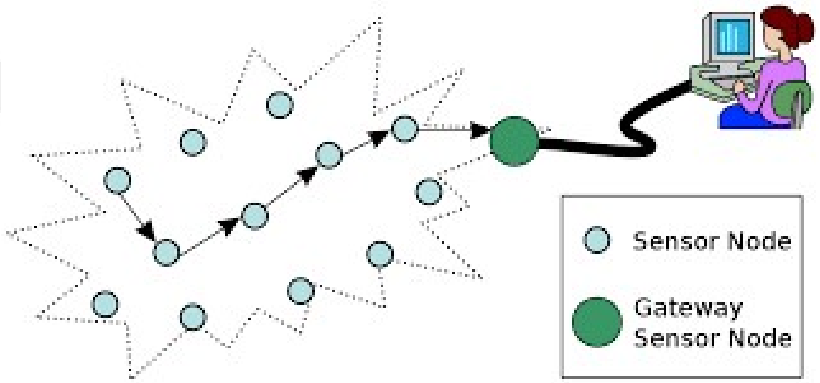

Figure 1.2. Wireless Sensor Network (n.d.)

1.5. Congestion in WSN

The sensor nodes are capable of sensing environmental changes, processing the sensed information, and transmitting the processed data. They operate easily under light load and low traffic flow until something happens beyond their capabilities. For example, a sudden increase in traffic flow due to an event detection causes excessive data packets in the buffer and if there is no control mechanism then it will result in a packet drop.

Sensors not only transmit data sensed by themselves but also work as routers for other nodes that are far from the sink. Routing the data for other nodes and working as a source node at the same time increases the load on these sensors, and because of the constraints in energy, memory and processing units, congestion is more likely to happen. The nodes that route maximum number of data are those that are located in between or near the sink. They work as relays for the nodes that are distant from the sink and it also affect their energy utilization.

A node cannot just route the receiving packets instantly while working as a relay, it initially stores it in the buffer and take some time to process it before transmitting any further. When the processing time becomes greater than the incoming rate of data packets, congestion will occur. The main drawbacks of congestion are; packet drop, delay, energy drain and low throughput. The sensor networks are data centric so they cannot stand for any data loss or packet delay (Uthra and Raja, 2012).

CHAPTER 2

CONGESTION AND LITERATURE BACKGROUND

Congestion is one of the main issues faced in WSNs. It is an unwanted condition where data packets cannot reach the base station. They are either dropped or delivered with so much delay that they become unrelated anymore at the output. This state usually happens when traffic flow increases suddenly because of occurrence of an event. As a normal reaction to this event, sensor nodes start to create more data packets, which increases the traffic flow in the network. Another cause of congestion in WSNs is its "many to one" traffic pattern, where all nodes send their data to a single destination so the upstream nodes in the network experience more congestion because they have to function as routers for their neighbor nodes which cannot reach the base station directly.

Heikalabad et al. (2011), and Patil and Dhage (2012) distinguish traffic flow in WSN in two different types; upstream traffic and downstream traffic. In order to give a better understanding about designing an effective method to cope with congestion in the network, they are explained below.

Upstream Traffic: The data flow from nodes towards the sink is called upstream traffic. It is convergent and many to one in nature (see Figure 2.1). It is where the congestion mostly occurs. The nodes having greater number of children suffer the most; especially the nodes near to the sink are most prone to congestion.

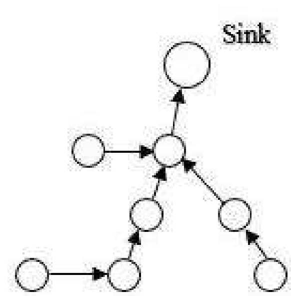

Figure 2.1. Upstream Traffic

Downstream Traffic: The data flow from sink towards the nodes is called downstream. It is one to many in nature and data can flow easily with this pattern (see Figure 2.2).

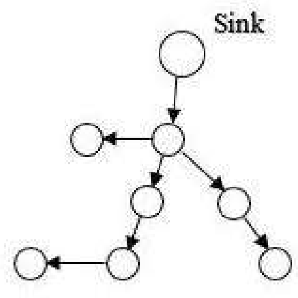

Figure 2.2. Downstream Traffic

2.1. Causes of Congestion

One of the causes for congestion is channel contention, which occurs in MAC layer when a number of sensor nodes try to access the channel at the same time and lack of an appropriate mechanism leads to packet collision. Carrier Sense Multiple Access (CSMA) is one of the most commonly used protocols in MAC layer, as employed by Heinzelman, Chandrakasan, and Balakrishnan (2000), and Heikalabad et al. (2011) to avoid packet collision. However, in cluster-based networks, CSMA is not feasible. It can still experience collision when there are multiple active sources and they try to access the channel simultaneously causing link level congestion and it also experience hidden terminal problem (Rhee, Warrier, Aia, Min, and Sichitiu, 2008; Sharma et al., 2010; Heikalabad et al., 2011). That is why Time Division Multiple Access (TDMA) is used for intra cluster communications, where each node gets a specific time slot for their data transmission and they wait for their turns. It is a time-synchronized protocol and in a cluster, CH is responsible for allotting time slots to the member nodes. Though TDMA performs better than CSMA but there are still chances of congestion to occur in the CHs. The reason for that is the increased rate of incoming data packets, which cannot be processed easily due to the limited processing capabilities of sensor nodes. CH working as intermediate node and relying data for neighbor CHs can also suffer from congestion.

Number of sensor nodes in the network have a direct effect on congestion. The network with greater number of nodes has more probability to get into a congestion state. Chitlange and Deshpande (2015) analyze network performance by varying density of nodes. The network performs well with a certain number of nodes, which make it easier for nodes to find their neighbors and increase routing performance by creating different alternate routes to the base station. Therefore, it results in enhanced Packet Delivery Ratio (PDR) and throughput. As the number of nodes are increased congestion is seen to happen more likely. Because the more number of nodes are, the higher reporting rate will be. The intermediate nodes in this situation will suffer the most from congestion, which reduces packet delivery to the sink and results in lower PDR. The highly dense network also faces jitter, because of high traffic flow; packets are routed using different paths, which increases the delay between consecutive packets. When these packets are received at the destination, they become unrelated and result to a bad throughput.

Each sensor node has a small buffer memory where the incoming data packets from the neighbor nodes are stored and processed before forwarding them to the base station. The buffer has a fixed size and when it becomes full, the last coming packets are dropped. Dropping the packets effects the throughput and causes energy loss for the nodes that are participating in the routing of that packet. That is why buffer needs to be monitored. Buffer occupancy is calculated by observing the queue length, and the queue length increases when packets inter arrival time becomes greater than packet inter service time (Chakravarthi and Gomathy, 2010). The packet inter arrival time is defined as the time between two consecutive data packets when they arrive to a node, while packet inter service time is the time taken by a node to process a packet.

2.2. Effects of Congestion

The congestion affects some main parameters for Quality of Service (QoS) in the network, which leads to a bad performance. These parameters include PDR, energy consumption, delay and throughput. Therefore, it impels to adopt some mechanisms to cope with congestion to maintain a good QoS in the network (Patil and Dhage, 2012; Chitlange and Deshpande, 2015).

Congestion causes energy drain when retransmission takes place, especially the nodes that contributed in gathering and transmitting these dropped packets suffer the most (it also include the intermediate nodes). By analyzing energy consumption model for sensors (see Table 2.1), it is observed that most of the energy is consumed in communication processes. As energy resources are limited in sensors, so their unnecessary usage of energy makes network lifetime shorter.

Table 2.1. Energy Consumption Model (Heinzelman et al., 2000; Torres, 2006)

Radio Mode	Energy Consumption
Transmitter electronics ($E_{Tx-elec}$) Receiver electronics ($E_{Rx-elec}$) ($E_{Tx-elec} = E_{Rx-elec} = E_{elec}$)	50 nJ / bit
Transmit amplifier (ε_{mp})	100 pJ / bit / m^2
Idle (E_{idle})	40 nJ / bit
Sleep	0

2.3. Communication Patterns in WSN

In WSNs, base stations collect data from network through different communication patterns. The upstream traffic can be divided into four types; event based, continuous, query based and hybrid. They are explained as follows.

Event Based: Event based traffic flow has grabbed large attention because of its nature, which flows in bursts when an event is detected. It suddenly raises reporting rate and traffic flow in the network. So a robust mechanism is needed to manage the data because the information collected from that event is of vital importance and need to be delivered to the base station. Since the traffic flow in event based method is sudden and high, so it increases the chances of congestion to occur in the network. Patil and Dhage (2012) propose a prioritize mechanism and regulate data flow to control congestion when an event is detected, while Sergiou et al. (2007) proposal adopts alternate routes to deliver data created from an event to the sink.

Continuous: In continuous communication pattern, sensor nodes detect and report the sink periodically. Heikalabad et al. (2011) present a method to control congestion in a network where data is reported to the sink continuously.

Hybrid and Query Based: In query based communication pattern, sensor nodes transmit their sensed data when they are asked for, and hybrid is a combination of other three methods, i.e. event based, continuous and query based (Chakravarthi and Gomathy, 2010; Patil and Dhage, 2012; Ghanavati et al., 2013).

2.4. Types of Congestion

Congestion in WSNs can be divided into two types; node level congestion and link level congestion.

2.4.1. Node Level Congestion

It occurs when a node receives more packet than it can handle from its neighbors. In this state, packet inter arrival time becomes greater than packet inter service time and that results to buffer overflow and packet drop. Mostly the upstream nodes suffer from node level congestion because of their locations. It causes packet loss and energy drain for nodes, which ultimately reduces the network lifetime (Heikalabad et al., 2011; Ghanavati et al., 2013; Hashemzehi, Nourmandipour, and Koroupi, 2013; Ghaffari, 2015) (see Figure 2.3).

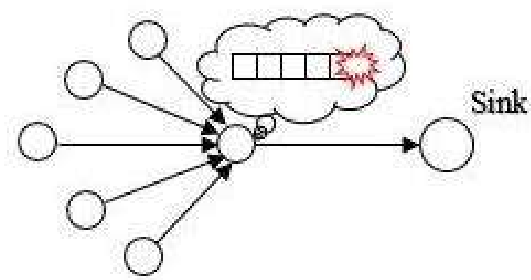

Figure 2.3. Node Level Congestion

2.4.2. Link Level Congestion

This type of congestion occurs when more than a certain number of nodes share a channel. When they attempt to access the channel at the same time, packet collision occurs and that decreases link utilization and affects the overall throughput (Heikalabad et al., 2011; Ghanavati et al., 2013; Hashemzehi et al., 2013; Ghaffari, 2015) (see Figure 2.4).

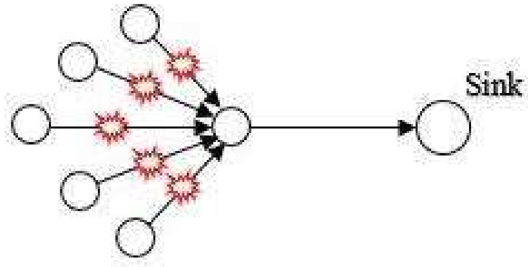

Figure 2.4. Link Level Congestion

2.5. Congestion Mitigation

To solve the congestion problem many techniques have been proposed. Some of them prevent network to enter into congestion state, while others offer solutions when congestion occurs. The techniques to handle congestion and mitigate it from a network can be divided into three main parts; congestion detection, congestion avoidance and congestion control. They are explained as follows.

2.5.1. Congestion Detection

Congestion detection uses some parameters throughout the network and observe them continuously or periodically to detect the presence of congestion. To mitigate congestion from a network first, an effective mechanism is required for its detection, so that the system gets information about the presence and severeness of congestion. Later a proper method is applied to prevent the network from this condition. Some commonly used parameters for congestion detection are; source node, channel load, buffer occupancy, number of participants, sending rate and receiving rate. They are adopted by Zawodniok and Jagannathan (2007), Chakravarthi and Gomathy (2010), Ghanavati et al. (2013), Jaiswal and Yadav (2013).

Buffer occupancy is one of the most frequently used parameter to detect congestion. Its calculation is based on packet inter arrival time and packet inter service time (Chakravarthi and Gomathy, 2010; Patil and Dhage, 2012). Sensor nodes have the capability to monitor their buffer occupancy level and react accordingly. However in some centralized protocols where sink is controlling all the behaviors of network because of its unlimited resources, also monitors the buffer occupancy of sensor nodes and calculates their congestion state. For example, in the proposed method of Paek and

Govindan (2010), sink decides whether there is a congestion in the network or not by observing the packet loss and recovery dynamics. Other protocols set a threshold value in the buffer and notify congestion occurrence when threshold limit is reached. Uthra, Raja, Jeyasekar, and Lattanze (2014) employ a threshold limit for congestion detection as well as an adaptive threshold value to predict congestion before its occurrence. It predicts congestion when buffer is half of its way to the full size. Jaiswal and Yadav (2013) use fuzzy system to detect congestion from three parameters; buffer occupancy, participants and traffic rate. Some other protocols, by Zawodniok and Jagannathan (2007) and Ghanavati et al. (2013), use buffer occupancy as a parameter to detect congestion.

2.5.2. Congestion Avoidance

Congestion avoidance proposes different (pre-designed) techniques to isolate the network from getting into a congestion state. Avoiding the network from congestion is probably the best way to follow, and get rid of all the unwanted and critical results that are caused by it. This method usually involves; pre allocated paths, maintaining transmission rate under a certain limit, multipath routing, etc. However, WSNs have many constraints about their range, computational capabilities and power resources, so it does not always end up with desired results.

Kadam and Chatur (2016) propose an efficient and fast way of data delivery, especially designed for health sector. It follows the shortest path for data transmission to the sink, and for congestion avoidance, it uses a bandwidth threshold (BW). The BW is compared with transmission control rate, when transmission rate reaches the threshold then it is reduced and reset to zero and again increased with a constant value. Hence, keeping the transmission rate under a limit saves the network from getting into congestion state.

Banimelhem and Khasawneh (2012) proposed a grid based multipath routing protocol, where each grid has a master node, which is responsible for collecting and delivering data from its fellow nodes to the sink. The master node finds multiple diagonal paths to the sink and stores them in the routing table. Once congestion is detected in any of the nodes on the diagonal path, an alternate route is adopted to reach the sink without interfering data flow.

2.5.3. Congestion Control

Congestion control provides various ways to cope with congestion, once it is detected. For example, reducing the transmission rate, prioritizing the data packets, dropping packets according to the priority etc. Congestion follows when buffer of a node overflows and forwarding any additional packet to that node will result in packet drop. To get rid of this state, the node that is suffering from congestion, notifies its previous nodes by using a backpressure method, the source node will come up with a predefined solution. The notification can be of two types (Ghaffari, 2015).

2.5.3.1. Explicit Congestion Notification

This method employs an extra control packet to notify about its congestion state to the upstream nodes. Since the network in congestion state already suffers from high traffic overhead, in such scenario an extra packet transmission will cause more problem.

2.5.3.2. Implicit Congestion Notification

This is the most commonly used notification method, which unlike explicit notification method does not increase traffic load. It simply piggybacks the congestion information of a node to the header of data packet.

After getting notification messages, the source nodes react in various ways to control congestion. The simple way to solve this problem is to minimize data transmission rate for that node or not to send any packet at all and let the buffer of node gets evacuated to make some rooms for more packets. Many mechanisms have been proposed to address this issue in different ways. Most of them fall into two major categories; traffic control and resource control, as discussed by Ghaffari (2015). Other possible solutions can be prioritizing data packets during transmission (Chakravarthi and Gomathy, 2010) or dropping them according to priority or size (Halim et al., 2016).

2.6. Controlling Techniques

2.6.4. Traffic Control

In traffic control based mechanism, the rate of data flow from the source nodes is reduced when it reaches to the limit of network resources where congestion is detected. Traffic control follows either reducing data packet creation of source nodes by increasing time interval between two consecutive packets transmission or by simply reducing the number of participating source nodes (Sharma et al., 2010).

Hop by Hop Congestion Control (HHCC), proposed by Sharma et al. (2010), regulates traffic flow according to the feedback messages from congested area. When a node transmitting a packet towards the sink, it will calculate its Node Rank (NR). NR is based on buffer size, hop count, channel busy ratio (time interval of transmission/total time) and MAC overhead. When NR crosses a threshold value, it will set Congestion Bit (CB) in every packet it forwards. The receiving node will check the CB in these packets. If the CB is not set then it will compute its NR, add it to the previous one, and forward the packet to the next node. In the other case, if CB is set then, based on the rank, the node will calculate Rate Adjustment Feedback (RAF) and send it towards the source node, the source will change its transmission rate according to that.

Priority-based Congestion Control Protocol (PCCP) proposed by Patil and Dhage (2012), detects congestion from congestion score, which is the ratio between packet service time and packet inter arrival time. It adopts transmission rate reduction when congestion occurs. In addition, this protocol also prioritizes sensor nodes in the form of a table and share this table with other nodes. In case of congestion, the sensed information of these nodes are given more importance than the others.

Hatamian and Barati (2015) propose Fuzzy Rate Adjustment Inference System (FRAIS), which uses Fuzzy Logic (FL) to reduce transmission rate when congestion is detected in the network. Fuzzy system decision is based on two input values; congestion score and buffer occupancy. It can also introduce a queuing method to identify local and transient data and place them in two different queues. As transient data comes through many intermediate nodes, it is given more priority than locally generated data packets, because it consumes more energy. Queue for transient data has a threshold limit, when it reaches to the limit; both queues are used for transient data while locally generated packets are dropped. This process continues until the node comes out of congestion state.

2.6.5. Resource Control

In resource control method, the extra resources of network are used to deliver the sensed information to the sink rather than reducing transmission rate. As in some cases data packets created from an event are considered to be important, so this technique assures to deliver all packets to the destination. It is achieved by distributing traffic among other nodes by creating different routing paths to the sink rather than just employing few nodes. This method balances the traffic load in the network by exploiting the node's resources and balancing the load among all the network (Rana and Kamboj, 2016).

Sergiou et al. (2007) propose Hierarchical Tree Alternative Path (HTAP) to control congestion by creating alternate routes from the spot where congestion is detected to the sink. The alternate route involves some of the nodes, which are not supposed to be working at that time. In this way, it divides the traffic load among all the nodes in the network without reducing transmission rate. All nodes have a table with information about their neighbor's buffer occupancy and it is updated each time by receiving an acknowledgement message from their neighbors when they transfer a packet. If receiving rate of a node becomes greater than its transmission rate, it will send a backpressure message to its previous node, to stop sending packets anymore. In addition, the previous node will start to create an alternate route with the least congested neighbors from its table.

Kang et al. (2007) propose Topology Aware Resource Adaptation (TARA) that utilizes network resources to eliminate congestion. Buffer occupancy and channel load are used as congestion detection parameters. When they cross a threshold value with the increased traffic flow, some extra nodes are employed from their sleep state. Here two nodes are important to discover; distributor and merger. Distributor is the node located in the front where congestion hotspot is. It distracts the traffic toward other nodes by making a detour path, to relieve the nodes in the congested area. While at the other end of hotspot, merger node combines the packets and forwards them toward the destination. This protocol needs to keep information about all the network topology to perform well, which does not make it viable for large-scale network.

Dynamic Alternative Path Selection Scheme (DAIPaS) proposed by Sergiou et al. (2014), is a topology-based algorithm and attempts to avoid congestion occurrence in the network by following alternate routes. A node receiving packets from its neighbors is said to be in soft stage, where it can handle the receiving data and stay out of congestion, as far as it is from one flow. When the number of flow increases, it warns the upper nodes with a backpressure message to adopt another route. If the specific node still gets packets and calculate that, it is likely going into congestion state, then it goes to hard stage, where it becomes temporarily or permanently unavailable for more packets. There are three causes, a node will go to hard stage;

1) Buffer is about to fill

2) Battery power becomes low

3) Unavailability of lower level nodes

2.6.6. Packet Drop

When traffic flow in the network increases from an event or from greater number of participating source nodes, congestion is obvious to occur in such cases. Because of their limited capabilities, sensors cannot handle burst of traffic flow. The buffer size is fixed in the sensors and it will results in random packet drop, once it is full. Sometimes the dropped packets can be of extremely vital, and dropping them will cause performance decline. Some researchers like, Chakravarthi and Gomathy (2010), and Halim et al. (2016) have worked on it and offered intelligent ways of discarding packets, so that it does not affect the overall throughput.

Chakravarthi and Gomathy (2010) assign priority to the data packets when congestion is detected from buffer occupancy. The buffer works on the principle of First In First Out (FIFO), so the last coming packets are discarded by default. However, this protocol drops packets according to the assigned priorities to maintain network throughput rather than randomly dropping them.

Halim et al. (2016) proposed a method that drops packets in case of congestion, based on the Time to Live (TTL) and their sizes. When TTL of a packet reaches to zero, then it becomes outdated and transmitting it will be waste of energy, so it is simply discarded. Similarly, the packets having size greater than 60 bytes are also dropped by this protocol because the greater the packet is, the greater it will have Bit Error Rate (BER), that is why only low sized packet are transmitted.

The table below lists all the methods discussed above to control the congestion in WSNs (see Table 2.2).

Table 2.2. Congestion Control Methods in WSNs

Protocol	Congestion Detection	Congestion Control	Aim	Control Mechanism	Traffic Type
HTAP (Sergiou et al., 2007)	Buffer occupancy	Back press., Alternate route	Control congestion	Resource control	Event based
(Kadam and Chatur, 2016)	Bandwidth thr. v/s trans. rate	Reduce trans. rate	Avoid congestion	Traffic control	Event based
HHCC (Sharma et al., 2010)	Node rank	Reduce trans. rate	Mitigate contention	Traffic control	Event based
(Hatamian and Barati, 2015)	Congestion score, buffer occupancy	Reduce trans. rate, prioritize data	Control congestion	Traffic control	Event based
PCCP (Patil and Dhage, 2012)	Congestion degree	Regulate trans. rate, prioritize nodes	Control congestion	Traffic control	Event based
DPCC (Heikalabad et al., 2011)	Congestion index	Fairly broadcast traffic	Control congestion	Resource control	Continuous
GMCAR (Banimelhem and Khasawneh, 2012)	Buffer occupancy	Multiple routes	Avoid congestion	Resource control	Continuous

Table 2.2 (cont'd). Congestion Control Methods in WSNs

Protocol	Congestion Detection	Congestion Control	Aim	Control Mechanism	Traffic Type
IPD (Chakravarthi and Gomathy, 2010)	Buffer occupancy	Prioritize packets	Control congestion	Drop packets	Event based
TARA (Kang et al., 2007)	Buffer occupancy & channel load	Alternate route	Control congestion	Resource control	Continuous
DAIPaS (Sergiou et al., 2014)	Buffer occupancy & channel load	Alternate route	Congestion control & avoidance	Resource control	Continuous

CHAPTER 3
PROPOSAL VERSUS RELATED WORKS

3.1. Routing Protocols in WSN

Based on network structure, routing protocols in WSN are divided into two categories; flat routing and hierarchical routing. In flat routing protocols, all nodes perform same tasks in the network and have the same functions. Data is usually flooded in the network and is transmitted hop-by-hop to the sink. Flat routing protocols perform well in small-scale networks but they are not effective for large-scale networks because all sensor nodes generate high data processing and use more bandwidth (Liu, 2012). Some famous examples of flat routing protocols are; Sensor Protocols for Information via Negotiation (SPIN) (Kulik, Heinzelman, and Balakrishnan, 2002), Rumor Routing (Braginsky and Estrin, 2002), Directed Diffusion (Intanagonwiwat, Govindan, Estrin, and Heidemann, 2003) and Gossiping (Haas, Halpern, and Li, 2006).

On the contrary, in hierarchical routing protocols, different nodes perform different tasks. They are arranged in clusters and each cluster has a head node (Cluster Head), whose task is to collect data from other member nodes and send them to the base station. Generally, the node with highest energy level is selected as Cluster Head (CH). Hierarchical protocols work in rounds, where a round includes; making of clusters, selecting CHs and delivering the collected data to the sink. Hierarchical routing protocols are more energy efficient than flat based routing protocols (Heinzelman et al., 2000; Liu, 2012).

Low-Energy Adaptive Clustering Hierarchy (LEACH) proposed by Heinzelman et al. (2000), is one of the most conventional protocols that follows a hierarchical routing protocol to arrange network in the form of clusters. The basic idea of hierarchical routing is to distribute traffic load among all nodes in the network and maintain a balance in the form of energy consumption, so that all parts of network can contribute equally. In cluster-based protocols, a CH is like any other node in the network, which is simply picked up to perform some additional tasks with the same capabilities that a normal node can have. Within a cluster, the nodes transfer their data to the CH, then the CH collects these information, aggregates them into a single signal and transmits it to the base station. This method is proved to be more energy efficient as compared to direct communication between sensor nodes and the sink (see Figure 3.1). It pushes network lifetime by allowing the nodes to live longer.

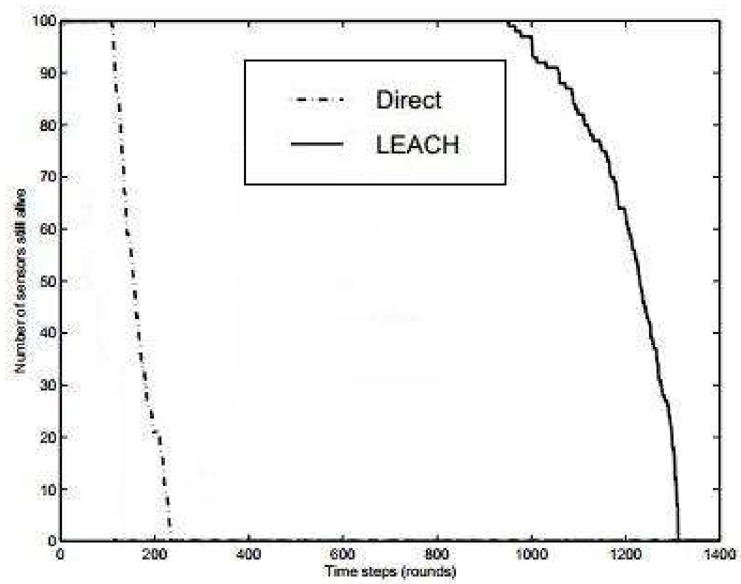

Figure 3.1. Lifetime of LEACH vs Direct Transmission (Heinzelman et al., 2000)

3.2. Making of Clusters

Clustering is one of the methods used to arrange the sensor nodes in groups, so that they can perform effectively and extend network lifetime. The clusters are made up of nodes that are geographically located near to each other. They gather their sensed information and send them to the base station collectively through a CH rather than transmitting them individually. The clustering idea is linked to the routing protocols, where in WSN, routing plays an important role to enhance network performance in terms of throughput, energy consumption, delay, and packet delivery ratio.

3.3. CH Selection

Even though the LEACH algorithm proves its energy efficiency, there are still many studies that are found to be more effective for CH selection. CH selection criteria has been discussed and changed in different studies to get more effective results. These improvements have been done in choosing different parameters for selecting CHs, like energy level, centrality, distance to base station, number of neighbor nodes, etc. (Heinzelman W. B., 2000; Gupta, Riordan, and Sampalli, 2005; Huang, Peng, Wen, and Yu, 2009; Din, Yahya, Taib, and Yassin, 2013; Jannu and Jana, 2014; Preethiya and Santhi, 2014). Base station has been involved to picking up the CHs because of its better knowledge about the network and ability to handle more complexities.

3.3.1. LEACH

Heinzelman et al. (2000) proposed LEACH protocol. It is a self-organizing and adaptive cluster based routing protocol and works in two phases: *setup phase* and *steady state phase*. The CHs are selected during setup phase and the criteria for CH selection is based on two conditions;

1) The percentage of CHs for the network and

2) How many times a node has been CH before

Based on these two conditions, all the nodes will select a random number between 0 and 1, and compare it with a threshold value. If this number is less than threshold, the node becomes CH for that round. In LEACH, sensors themselves do the process and each node get a chance to become CH.

However, there are some drawbacks in LEACH as highlighted by Ramesh and Somasundaram (2011) and Liu (2012), are important to be considered, so that they can be overcome while designing new protocols in future.

- Energy level of the nodes is not considered for CH selection. In fact, it is very important to consider because CH are inclined to consume more energy than a normal node.
- The number of nodes in the clusters are significantly different from each other. One cluster can have very high number of nodes while at the same time others can have very small.
- The location of candidate nodes for CH are not concerned. Which results in a non-uniform distribution of CHs in the network.
- The dynamic clustering approach increases overhead. The change of CH in each round requires advertisement and it drains more energy.

3.3.2. LEACH-C

LEACH-C (centralized) (Heinzelman W. B., 2000) is an improvised version of LEACH. It has the same steady state phase like in LEACH but the cluster making process is different. It utilizes a centralized mechanism for making clusters where all nodes send their location information and energy level to the base station in setup phase. Since the base station is supposed to be computationally more complex and vibrant, so it determines CHs for the network. CH selection is based on energy level and distance of nodes to the base station. It will guarantee to generate the desired number of CHs and they will be evenly distributed in the network.

Centralized protocols have some disadvantages when compared with distributed systems. In centralized protocols, base station has to take all decisions so that it should have all the knowledge about the network. For that reason, the nodes have to inform base station each time about their energy level and location for cluster formation and CH selection. Which causes extra control packets in the network and increased traffic overhead that results in more energy consumption. Due to these drawbacks, centralized protocols are not viable for large-scale networks (Enam, Qureshi, and Misbahuddin, 2014).

Distributed protocols are more suitable for large-scale networks. They have to exchange messages when selecting CHs in each round but these messages will be within the cluster. Though LEACH does that in the setup phase despite being a distributed protocol but later protocols such as; Ahn, Kim, Park, and Yoo (2013), and Nokhanji, Hanapi, Subramaniam, and Mohamed (2015) avoid this method.

3.3.3. Grid Based Clustering Protocols

In grid-based networks, sensor nodes in an area are arranged according to their locations into virtual grids of equal sizes. A grid will be taken as a cluster having a CH along with its member nodes, and the member nodes are not changed after each round, as cluster-based protocols do. It just rotate the function of CH within the grid. There are certain advantages that grid-based protocols have over cluster-based protocols (Liu, 2015).

- They have a simpler structure and the grids are simply formed on the bases of geographical locations without competition for CHs.

- The data is delivered efficiently, each node has a set of forwarder candidate nodes and simply they are used for transmission as intermediate nodes.

Jannu and Jana (2014) propose an energy efficient grid-based routing protocol that works in three phases; initialization phase, set-up phase and routing phase. It begins by dividing the area into equal sized grids with the defined sink position, and then the nodes are distributed into grids according to their locations. A CH is selected from each grid and its selection is based on two conditions 1) the node should be the most central compared to the others and 2) its energy level must be greater than the threshold value. This paper actually proposes a multipath routing approach, during its last phase, the CHs find out their entire neighbor CHs and select the one which has minimum distance to the sink for transmitting its data.

Banimelhem and Khasawneh (2012) propose Grid-based Multipath with Congestion Avoidance Routing protocol (GMCAR). It also works in three phases; *1) Grids formation phase:* logical grids of predefined size are formed in this phase and a grid Master Node (MN) is selected. The node with the highest energy in the grid will be the MN and its function will be to route data, generated within the grid and received from neighbor grids MNs. *2) Building routing tables:* the MNs in this phase discover the available paths to the sink through other MNs and store them in a table. *3) Data transmission phase:* the nodes in a grid send their data to MN, and it finds the neighbor node from the table and forward its data to that node and it goes on until the sink. When the energy level of MN is about to drain, it selects another node in the grid with highest residual energy and make it the new MN.

The CH selection is a bit complicated process to perform, without a proper mechanism, it will cause energy drain for the nodes. A CH should meet the conditions that are defined initially. Fuzzy logic system is proved to be an accurate and energy efficient decision maker for CH selection, because of its capabilities to work in robust systems, make it suitable for WSNs.

3.3.4. CH Selection with Fuzzy Logic

Fuzzy Logic (FL) (Zadeh, 1973) is a problem solving control system used to make decisions like human decision-making behaviors by using descriptive language. It achieves clear results based on the given inputs like a human operator and does not need complete environmental information to make any real time decision. Gupta et al.

(2005), Din et al. (2013), and Preethiya and Santhi (2014) use FLfor CH selection and it is proved to be more viable and energy efficient.

Fuzzy Logic Controller (FLC) consists of four parts; fuzzifier, inference engine, rule base and defuzzifier. Its decision making process is done in four steps (Naeimi, Ghafghazi, Chow, and Ishii, 2012; Nokhanji et al., 2015), (see Figure 3.2).

Fuzzification: The inputs are taken as crisp values and are converted into linguistic form according to the defined sets. Since the input values are always crisp, so it is important to fuzzify them.

Rule Evaluation: It contains a set of fuzzy rules that are predefined. They vary according to the changing behavior of fuzzified inputs.

Inference Engine: The inference engine takes the inputs and make conclusions based on fuzzy rules.

Defuzzification: The results from inference engine in defuzzication, are converted into crisp values and given as output.

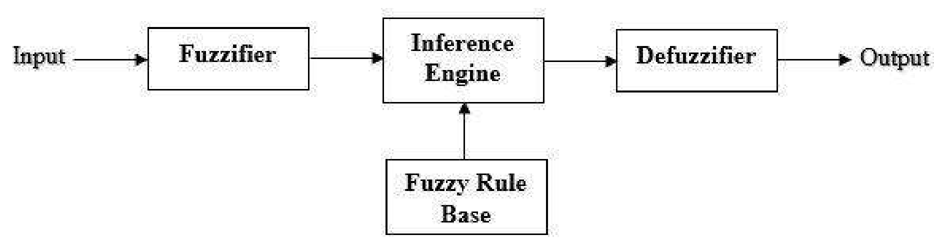

Figure 3.2. Architecture of FLC

Gupta et al. (2005) use FL for CH selection, where base station is responsible for deciding CHs. Since base station is more powerful and it is supposed to have global information about the network, so it can make decisions more precisely. Fuzzy rules are defined based on three parameters; energy, concentration and centrality. Energy refers to individual energy level of nodes, concentration means the density of network and centrality shows the degree of a node in the center with respect to the other nodes in the entire cluster.

In grid-based approach, FL is used by Mishra, Kumar, Kumar, and Singh, (2017) to select CHs and extend network lifetime. The nodes are deployed randomly and are divided into grids. Each grid is considered as a cluster where the CH selection is completely deterministic and based on two parameters; residual energy and distance to base station. It achieves to prolong network life by reducing the number of unnecessary communications and data processing.

Din et al. (2013) and Preethiya and Santhi (2014) also use FL for CH selection. Din et al. (2013) select CH based on two parameters; residual energy and centrality. While Preethiya and Santhi (2014) consider three parameters to select CH; initial energy of nodes, expected energy of nodes and mobility speed, anyhow this protocol is designed for a network with mobile nodes.

All the discussed methods for CH selection from the literature are listed in the table below (see Table 3.1).

3.3.5. Proposed CH Selection Approach

This thesis employs a distributed approach in clustering, where the clusters are selected as the form of grids and nodes are divided into different grids based on their locations. Each grid will be considered as a cluster and will have its own CH. Since grid based protocols work in distributed manner, so it make them feasible for large-scale networks.

FL is used for CH selection and its decision making process will be based on two parameters as done by Din et al. (2013);

Energy Level: The node having highest residual energy at that time.

Centrality: The most central node in the grid, i.e. the node having minimum distances from other cluster members.

Table 3.1. Various Protocols for CH Selection

Protocol	CH Selection Parameters	CH Selection Approach	Nodes Arrangement	Selection Approach
LEACH (Heinzelman et al., 2000)	Percentage of CHs, how many times a node has been CH before	Distributed	Cluster	Non-Fuzzy
LEACH-C (Heinzelman W. B., 2000)	Energy level, distance to BS	Central	Cluster	Non-Fuzzy

Table 3.1 (cont'd). Various Protocols for CH Selection

Protocol	CH Selection Parameters	CH Selection Approach	Nodes Arrangement	Selection Approach
(Gupta et al., 2005)	Energy, concentration, centrality	Central	Cluster	Fuzzy
(Din et al., 2013)	Residual energy, centrality	Central	Cluster	Fuzzy
LEACH-ERE (Preethiya and Santhi, 2014)	Node initial energy, node expected energy, speed of node	Distributed	Cluster	Fuzzy
(Jannu and Jana, 2014)	Centrality, energy level	Distributed	Grid	Non-Fuzzy
GMCAR (Banimelhem and Khasawneh, 2012)	Energy level	Distributed	Grid	Non-Fuzzy
EMHR (Huang et al., 2009)	Residual energy, distance to BS	Distributed	Grid	Fuzzy

3.4. VCH Selection

In WSNs, the sensor nodes have limited energy resources like battery and solar cells, which are usually irreplaceable in many conditions. These constraints encourage to design protocols that are energy efficient and can assist network to perform for a longer time. Hierarchical routing protocols are proved to be energy efficient approaches. However, their performances are further improved by adding new changes. Introducing Vice Cluster Heads (VCH) in the network is one of the changes and it resulted to save more energy and extends network lifetime. The VCH in a cluster can be seen in the figure below (see Figure 3.3).

In a cluster, VCH is usually the node, which has the highest energy level after CH and it is mostly used in the place of CH in the following conditions;

- When CH dies (Yassein, Al-zou'bi, Khamayseh, and Mardini, 2009; Ahlawat and Malik, 2013; Singh, Rathkanthiwar, and Kakde, 2016).
- When CH consumes a certain amount of energy (Zhao, Xu, and Li, 2012; Mehmood, Lloret, Noman, and Song, 2015).
- CH and VCH can also work simultaneously, to collect and route data (Hassan, Selim, and Sadek, 2015).

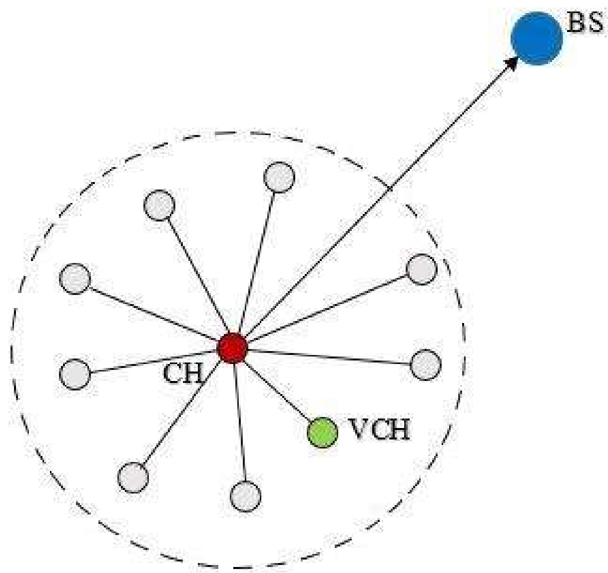

Figure 3.3. VCH in a Cluster

CH is the easiest target for congestion to occur because it is working like a hub and receiving more packets as compared to the other member nodes, especially the CHs located near to the sink. They route greater number of packets and are most prone to congestion and energy drain because they are handling the data packets created by their own members and as well as working like an intermediate node for the other CHs that are far and can’t reach the sink directly. In this situation, there is a great need for an alternate, when something goes wrong with the CH, like energy drain or buffer overflow. A network having VCHs can overcome this issue without causing any delay or packet loss by simply replacing CH with the VCH.

The functions that a CH performs are more than a normal node, it includes; overhearing, receiving, aggregation and transmission. These all are energy-consuming processes so they make the CH’s lifetime shorter as compared to the other nodes. The concept of VCH is raised to handle the nodes in the cluster after inadequacy of the CH. The protocols that utilize VCHs, actually want to maintain data transmission without any interruption.

Zhao et al. (2012) propose an improved version of LEACH protocol. It considers energy level of nodes while selecting them as CH and it also introduces a VCH in the cluster. The cluster members having the highest energy are selected as VCHs. After cluster formation, the member nodes send their data to the CH along with their energy levels. The CH selects the node with highest energy level as VCH, and appoints it as new CH when it consumes too much energy. The CH broadcast the information about VCH to its members so that every node consider this as their new destination.

Hassan et al. (2015) propose LEACH-C with addition of VCH. VCH is selected by CH and its function is to collect data from all member nodes and send them to the CH, CH later forward them to the sink. Since CH transmission range is higher so it consumes more energy and dies earlier. When its energy level reaches to a minimum value, VCH will function as CH and select a new VCH for himself.

Mehmood et al. (2015) select CH like LEACH protocol, then CHs collect energy information from all its member nodes and select the one having highest energy as VCH. VCH go to sleep and wake up by a call from CH, when energy level of CH decreases to a certain value (10%). VCH starts working as CH and announces himself in the cluster and all members respond with an ACK message. This CH will choose a VCH for himself in the same way it was chosen.

Ahlawat and Malik (2013) improve VLEACH performance by selecting a VCH which takes over when CH dies. CH selection is based on three factors minimum distance (to CH), maximum residual energy, minimum (transmission) energy, which is achieved when CH is near. Other protocols that utilizes VCH when CH dies are proposed by; Yassein et al. (2009), and Singh et al. (2016).

3.4.1. Proposed VCH Selection Approach

Similar to the CH selection, VCH is also selected based on energy level and centrality of the nodes. After selection, VCH does not participate in sensing and transmission processes to save its energy. Because the CH consumes more energy than the normal nodes, so it is a good idea to save the VCH's energy before it begins functioning as CH. When the energy level and buffer occupancy of the CH reaches to a threshold value, VCH takes over and start functioning as new CH. Later it will select a VCH for itself.

VCH has been used as an alternate when the energy level of CHs become low, (Yassein et al., 2009; Zhao et al., 2012; Ahlawat and Malik, 2013; Mehmood et al., 2015; Singh et al., 2016) but it has not been approached before to control congestion in CHs. The proposed study uses VCH in the place of CH when there is a congestion as well as energy shortage in the CH. The VCH is programmed to function in following two conditions;

1) When energy level of CH decreases to a threshold value

2) Congestion is detected in CH

3.5. Congestion in CH

The main constraints of sensor nodes are their capabilities to manage any unexpected situation in the network. They are able to process a limited amount of data, created during a time period. The load on a node gets heavier when the packet inter arrival time becomes greater than the packet inter service time (Chakravarthi and Gomathy, 2010; Ghanavati et al., 2013; Gholipour, Haghighat, and Meybodi, 2017). In clusters, the CHs are the nodes that are receiving data packets and processing them at the same time. When their receiving rate increases compared to their processing rate, the buffer occupancy increases. If this receiving rate remains same, the buffer overflows and packets will start to drop because of congestion.

The number of participating nodes in a cluster depends on its density. The dense clusters certainly have higher traffic generation. Their concurrent attempt of data delivery and lack of any transmission protocol causes data collision. To avoid simultaneous attempts of transmission and arranging them in order, an efficient Media Access Control (MAC) protocol is needed. Carrier Sense Multiple Access (CSMA) is commonly used because of its simplicity and robustness (Rhee et al., 2008). However, for cluster based networks Time Division Multiple Access (TDMA) is proved to work more efficiently for intra cluster communications. TDMA solves the collision problem in a cluster by allotting specific time slot to member nodes and each node utilizes their own time period for transmission (Leu, Chen, and Liu, 2014). However, it still does not completely eliminate the chances of congestion from the network, because a CH like any other node has limited capabilities, its processing ability and buffer memory is limited to handle large number of participating nodes. The CH not only manage its own member nodes but also working as a router for its neighbor CHs (see Figure 3.4).

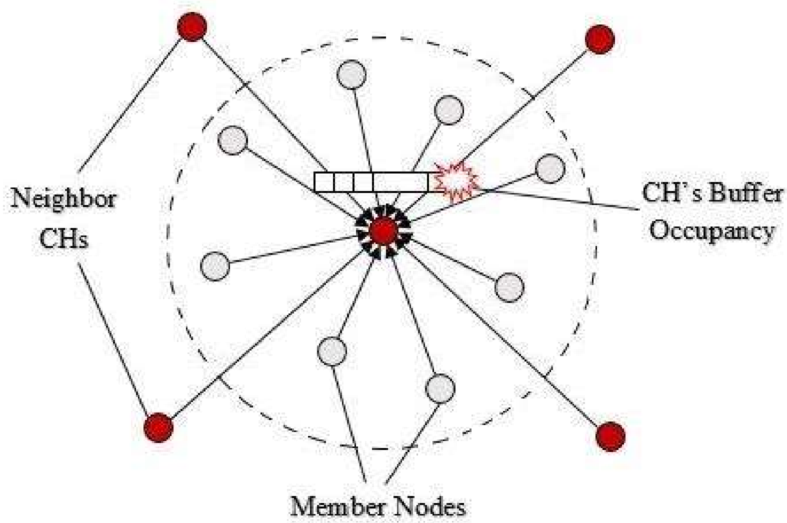

Figure 3.4. CH as an Intermediate Node

3.5.1. How to Detect Congestion

Congestion in WSN is detected by observing some parameters. Most commonly used parameters are; buffer occupancy, congestion degree, number of participants and traffic rate. They are explained in following;

<u>Buffer Occupancy:</u> The sensor nodes have a buffer memory where they store the packets before processing and transmitting them. Observing the total size and the present queue length of the packets in the buffer gives the state of congestion in that node (Chakravarthi and Gomathy, 2010; Deshpande, Chavan, Wadhai, and Helonde, 2012; Jaiswal and Yadav, 2013; Paranjape, S, Sutaon, and Mukherji, 2016; Gholipour et al., 2017).

<u>Congestion Degree:</u> It is the ratio of packet inter service time and packet inter arrival time in a sensor. Packet inter service time is the time, a packet takes when it reaches to the MAC layer until its transmission, and the packet inter arrival time is defined as the time interval between two consecutive packets arrival at a node (Patil and Dhage, 2012; Ghanavati et al., 2013; Gholipour et al., 2017).

Number of Participants: For congestion indication, this is also a useful parameter and it represents the number of nodes actively transmitting data to the targeted node, whose congestion level is being monitored (Jaiswal and Yadav, 2013).

Traffic Rate: It represents the number of packets transmitted per second by source nodes (Jaiswal and Yadav, 2013; Paranjape et al., 2016). The traffic flow will increase with the increase of source nodes.

Besides observing other parameters, buffer occupancy is the parameter, which is used by almost all proposed protocols as an important indicator for congestion occurrence. Chakravarthi and Gomathy (2010) use a threshold value in the buffer to detect congestion, they continuously monitor buffer size and check whether its queue length has reached the threshold or not. Jaiswal and Yadav (2013) use buffer occupancy to detect congestion with additional two parameters; traffic rate and number of participants by using FL. Their combined results are compared with threshold values and then traffic rate is regulated accordingly to mitigate congestion.

Paranjape et al. (2016) propose a congestion control mechanism for mobile wireless sensor network. It considers traffic intensity, number of contenders (participating neighbors) and buffer occupancy. Number of packets in the buffer tell about severeness of congestion in a node. Deshpande et al. (2012) monitor buffer occupancy of every node continuously to check their congestion level and regulate transmission rate according to that.

The discussed congestion detection parameters and control techniques are summarized in the table below (see Table 3.2).

3.5.2. Proposed Congestion Detection Method

The sensor nodes have a buffer memory where they store and process the incoming data packets before transmitting them any further. The buffer has a fixed size and cannot accept more packets once it is full. When the number of incoming traffic rate becomes greater than outgoing traffic rate, the buffer occupancy increases and if it is not resolved then receiving any additional packet will results in buffer overflow and packet drop.

This thesis utilizes buffer occupancy for congestion detection. It will find out how many packets are there in the buffer from incoming and outgoing traffic rate. When the incoming traffic rate increases and the buffer is occupied until the threshold limit than congestion is assumed to occur in that node.

Buffer occupancy has been largely used as compare to the other parameters. It can directly be calculated by monitoring the buffer memory of the nodes.

Table 3.2. Congestion Detection and Control Methods

Protocol	Congestion Detection Parameters	Buffer Occupancy	Congestion Control Technique
IPD (Chakravarthi and Gomathy, 2010)	Buffer occupancy	Use a threshold value in buffer, packet inter arrival time exceed packet inter service time	Drop packets
(Deshpande et al., 2012)	Buffer occupancy	Monitor buffer continuously and send congestion notification when it is >= 80	Regulate transmission rate
FBACC (Jaiswal and Yadav, 2013)	Traffic rate, participants, buffer occupancy	Total no of packets transmitted per sec / total no of packets received per sec	Regulate transmission rate
IICC (Paranjape et al., 2016)	Traffic intensity, buffer occupancy, number of neighbors	Detect congestion when packets in the queue reach to a certain number (Q > 250)	Regulate transmission rate
(Gholipour et al., 2017)	Buffer occupancy ratio, congestion degree	Number of packets in the queue buffer / buffer size	Regulate transmission rate

CHAPTER 4
METHODOLOGY

4.1. Proposed Method

Wireless sensors have many restrictions regarding their power resources, communication range and processing capabilities. They are supposed to perform their best and last network life as long as possible despite of all these limitations. A common problem faced by sensor nodes is congestion, which mainly occurs due to limited processing capabilities and buffer size in case of high traffic flow. The drawbacks caused by congestion in the network are; packet drop, decreased reporting rate, low throughput, energy loss and reduced network lifetime. Different methods have been presented to cope with this problem in the literature by; Kang et al. (2007), Sergiou et al. (2007), Heikalabad et al. (2011), Banimelhem and Khasawneh (2012), Patil and Dhage (2012), and Kadam and Chatur (2016), Sergiou et al. (2014). All these references have already been discussed in chapter 3.

This thesis presents a new approach to control congestion in WSN, i.e. CCVCH (Congestion Control with Vice Cluster Head). Its significant role is to present an alternate solution when congestion occurs in the CHs or when they suffer from energy dissipation. It is designed for cluster-based networks and works in two phases;

1) Setup phase
2) Transmission phase

Setup phase includes; making of clusters by dividing the network into grids, selecting CHs and VCHs for each grid, while the transmission phase includes; data transmission between member nodes to the CHs and from CHs to the BS. In following sections, they will be discussed in details.

4.1.1. Setup Phase

In this phase, the nodes are divided into grids after they have been randomly deployed in the area of interest. Each grid is considered to be a cluster and the nodes within a grid are taken as a part of that cluster. The figure below shows the network divided into grids (see Figure 4.1). The nodes are supposed to know their locations with a GPS or by any other means. In a grid, the sensors initially discover each other by broadcasting their coordinates. By hearing the coordinates, each node finds distances between each other and calculate their centralities with respect to other fellow nodes.

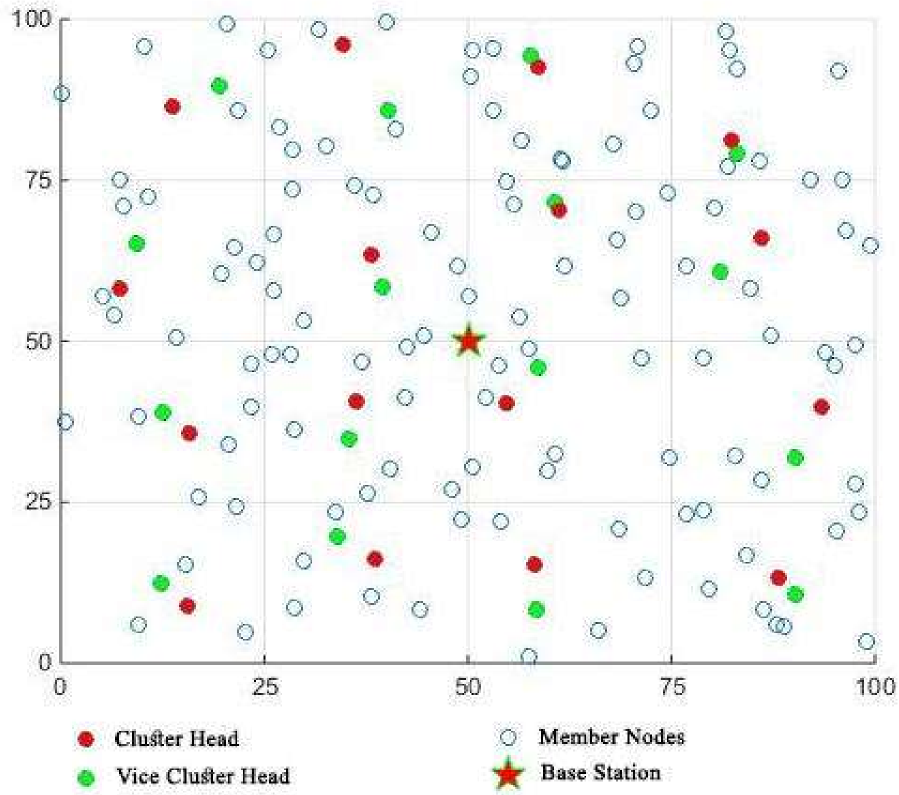

Figure 4.1. Grid Based WSN

In a grid the nodes function according to their ranks and the rank of a node depends on its centrality and residual energy. FLS is used to find the rank of nodes and its working mechanism is explained in chapter 3. The centrality and the residual energy of a node are taken as input parameters for FLS, which calculates and gives the ranks of all nodes in the grid. Centrality is the summation of distances from one node to the others in a grid, while residual energy is the present energy level of a node, initially they all have same amount of energy. From the calculated fuzzy logic results, the nodes perform according to the assigned ranks. The highest and the second highest ranked nodes will work as CH and VCH while the rest as member nodes (MN) respectively. The table below shows a grid having ten nodes with their initial energy level and centralities (see

Table 4.1). Based on the fuzzy logic rules as defined in section 4.4, the ranks are calculated. As it can be seen that Node 9 having highest rank, is selected as CH and Node 6, with second highest rank as VCH and the others are considered as MN.

The CH selection is distributed, that is the nodes decide and select the CH themselves, without involving the base station, as done by Heinzelman et al. (2000). After calculating the ranks, they are broadcasted. All nodes in the grid compare their ranks with each other. The one with the highest rank is nominated as CH. The selected CH declare the node with the second highest rank as VCH and allot time slots to the remaining members for data transmission. The VCH, after receiving the message from CH turns off its radio and does not participate in sensing and communication processes unless it gets a call from the CH.

Table 4.1. Division of Nodes, Based on Ranks

Nodes	Energy	Centrality	Rank	Type
Node 1	0.5000	184.8304	0.7810	MN
Node 2	0.5000	206.8647	0.7597	MN
Node 3	0.5000	168.5029	0.7952	MN
Node 4	0.5000	141.3036	0.8173	MN
Node 5	0.5000	130.8730	0.8259	MN
Node 6	0.5000	125.0339	0.8306	VCH
Node 7	0.5000	143.3182	0.8157	MN
Node 8	0.5000	181.6771	0.7838	MN
Node 9	0.5000	119.2142	0.8353	CH
Node 10	0.5000	188.6771	0.7775	MN

4.1.2. Transmission Phase

The transmission phase begins by collecting data from the cluster members when they have some sensed information. The CH collects and aggregates the data packets received from its members. The aggregation is done to remove redundancy and to reduce the size of overall information in order to minimize the transmission cost. After aggregation the data is routed toward BS. The routing is done through single hop and multi hop transmission according to the distance of CH to the BS. The CHs located near to the BS can communicate directly while the CHs that are far, need relays to reach the sink. All the CHs have information about their neighbor CHs, so when they have some information to transmit they use the most appropriate relay to reach the destination as discussed by Lai et al. (2012), and Nokhanji et al. (2015).

During all the processes, the role of CHs are significant because they are handling higher traffic load then the others and doing continuous communication tasks, which is energy exhausting. Therefore, they usually experience two common problems; either they suffer from congestion because of dealing high traffic rate or their energy drains due to multifunctioning tasks. Since CHs are the most central nodes that control the tasks in a cluster, so they have to be in a working condition. Therefore with the occurrence of either two conditions, CH is replaced by VCH. The VCH have all the capabilities and will start functioning as CH as soon as it receives a notification message from the CH. Later the CH functions as a normal node and the recently selected CH allot time slots to the members. The member nodes will send acknowledgement messages with their new calculated ranks, the highest ranked node is selected as VCH.

The replacement of CH is an on-demand process and is not part of the round, unlike LEACH. In other words it takes place when there is a requirement to do so. Yu, Qi, and Wang (2011), and Ahn et al. (2013) proposals work in the same way. The purpose of on-demand process is to avoid extra messages that are created during CH selection process and to save network from early energy dissipation. Where a round includes data collection from the member nodes by the CHs and then delivering the compressed and aggregated data to the BS.

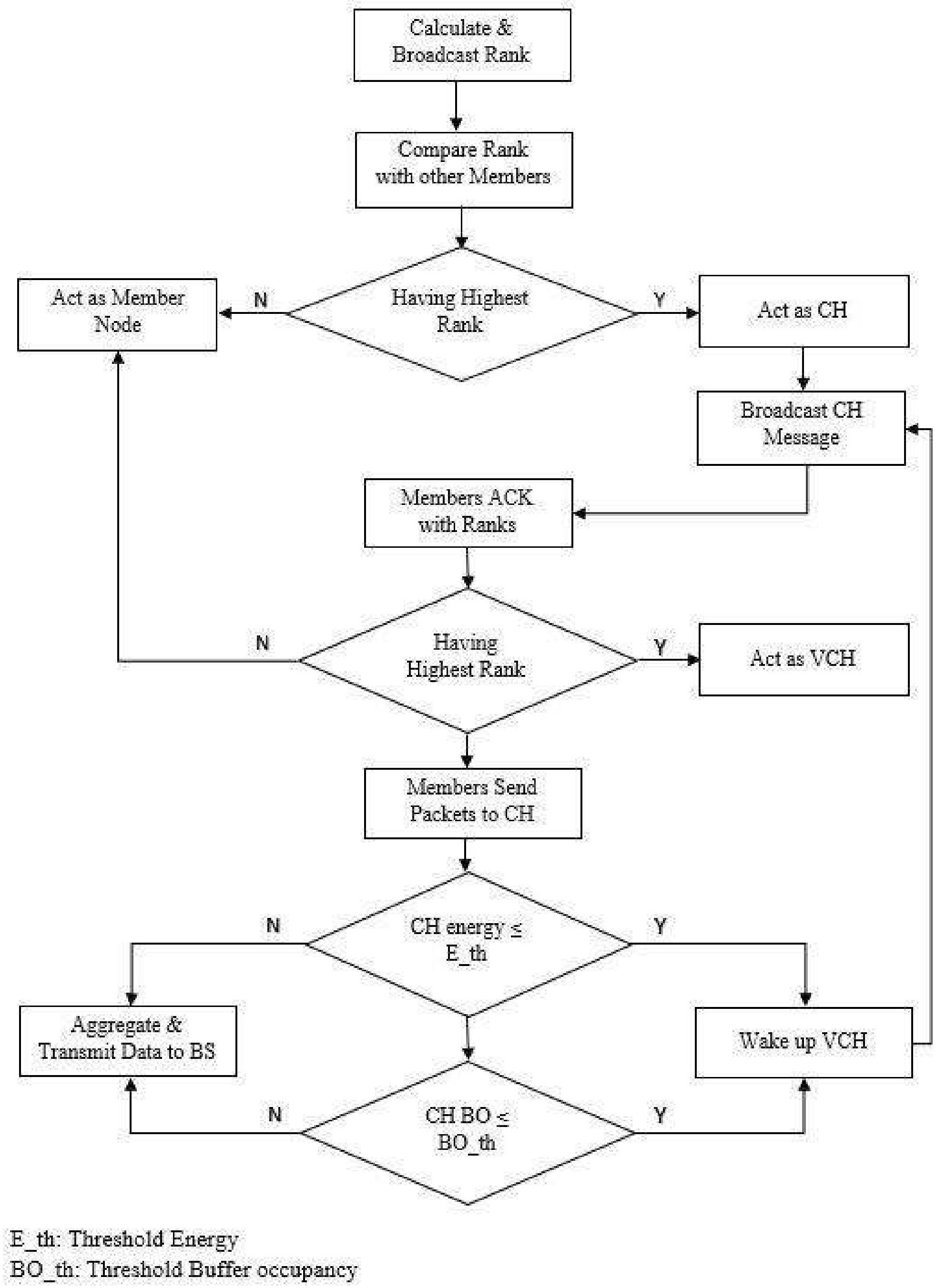

Figure 4.2. Flow Chart of Proposed Method

The complete operation of the proposed method is shown through the flow chart above (see Figure 4.2). It begins with the nodes calculating their ranks by using FL. The FL is used because of its energy efficiency and capabilities to handle uncertainty in a system, as discussed in chapter 3. The nodes perform tasks according to their ranks. The nodes in a grid compare their ranks with the fellow members. If a node has the highest rank, then it will act as the CH, otherwise it will act as a member node. The selected CH broadcasts a message in the grid to announce itself in the grid. The MNs acknowledge CH with their ranks. In this stage the CH analyzes them and selects the node with highest rank as VCH and the remaining continue to play as member nodes. They sense the environment and report the CH. The CH job is to collect their data, aggregate them and send it to the BS. Since the CH is handling higher traffic and performing more energy consuming tasks, it commonly suffers from two problems; either its energy drains or its buffer overflows. That is why there are thresholds set for each parameter. If the thresholds are reached by either way, VCH is waked up by CH to be the new CH in the grid, otherwise the previous CH continues to receive and deliver the data towards the destination.

4.2. Making of Grids

The nodes are deployed randomly in an area and then they are divided into virtually equal sized square grids. Each grid is considered as a cluster and a cluster based routing protocol is approached because of its better performance results (Liu, 2012). The grids are determined based on the ranges of sensors. A node in the grid that is picked up as a CH, should be able to reach all the nodes within the grid, as well as the other CHs of its neighbor grids. So that they can be used as intermediate node for routing purposes. For this reason, the longest possible distance is considered which is, the distance between two consecutive grid's CHs when they are at the diagonal corners (Xu, Heidemann, and Estrin, 2001; Gao, Blow, Holding, and Marshallband, 2004; Akl and Sawant, 2007), (see Figure 4.3). Arranging the grids according to the sensor's range have certain advantages; their size remains medium, neither too small nor too large. Suppose if the grid size are too small, then the number of clusters will be greater in the network and there will be a great number of CHs as well. In such a case, a packet has to travel through more CHs to reach the destination resulting in high energy consumption. Similarly, the large sized grids will have problem with greater number of member nodes in a grid. It will cause problem for CHs to handle a cluster with such a great number of nodes and reaching a neighbor CH for routing will not be guaranteed because of its limitation in the range.

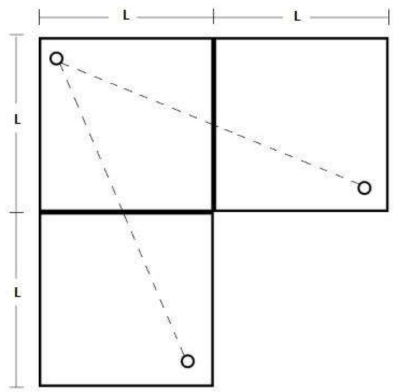

Figure 4.3. Grid Size Calculation

Assume R is the transmission range of a sensor node and the grids are supposed to be squares with each side having length L. Then the size of a grid can be calculated as:

$$L^2 + (2L)^2 \leq R^2$$
$$L \leq \frac{R}{\sqrt{5}} \quad (1)$$

4.3. CH Selection

The nodes will join the respective grids according to their locations, when the grids size are defined. In this way, the nodes falling in the same grid will be grouped as a cluster. Each cluster will have a CH and a VCH and they are selected in a distributed way. Once a CH is selected for a grid than it is not changed with each round rather it is replaced when its energy level becomes lower than the threshold energy or when it suffers from congestion. Yu et al. (2011), and Ahn et al. (2013) have also adopted this method. The pseudo code for CH selection is shown in the figure below (see Figure 4.4).

```
begin (CH selection)
  Calculate centrality && residual energy
  Compute Rank by using FL
  Broadcast Rank
  if Rank > other nodes Ranks
    It becomes CH && broadcast a CH message
  else
    It functions as a member node
  end
end
```

Figure 4.4. Pseudo Code for CH Selection

4.3.1. Residual Energy

The present energy level of a node is its residual energy. When nodes are being analyzed for becoming CH, residual energy is one of the most important parameters to consider. Because a CH have more functions to perform than a normal node, like listening, receiving, aggregating and transmitting, that requires a node to have high energy level. The residual energy can be calculated as (Din et al., 2013; Preethiya and Santhi, 2014):

Residual energy = Initial energy – Consumed energy

Initial Energy: The energy a node has at the time of deployment.

Consumed Energy: The energy used by the sensor from beginning until present condition.

4.3.2. Centrality

Centrality of a node is calculated as the sum of square distances of the nodes in a grid with the respective node (Nokhanji et al., 2015). It shows how much a node is central with respect to the other fellow grid members. The most central node has the lowest distance with other cluster members and it will consume less energy for transmission, as energy consumption is proportional to d^2. The longer the distance is, more energy will be consumed and vice versa.

To calculate centrality, a node first has to find distances between itself and the rest of nodes in the grid by using the distance formula (2). The most central node will be the one having minimum distance after summation.

If *M* is a node in the grid and wants to find its distance *D* from another node *N*, then it can be calculated as:

$$D = \sqrt{(N_x - M_x)^2 + (N_y - M_y)^2} \quad (2)$$

The sum of distances from node *M* to all other nodes $N_{1,2,\dots,n}$ in the same grid can be found as:

$$\sum_{k=1}^{n} D = D_1 + D_2 + \cdots + D_n \quad (3)$$

4.4. How Fuzzy Logic Works

The two parameters; residual energy and centrality will be used as the inputs for fuzzy system. They both have three states, so the total number of rules in fuzzy system will be 3 x 3 = 9. They are shown in the table below (see Table 4.2). Thus the nodes will be classified into nine different ranks and the one with highest rank will be selected as CH and the second highest ranked will be the VCH.

Mamdani fuzzy inference technique has been used for this process, where trapezoidal membership function is used for low, high, close and far. Triangle membership function is used for medium, low medium and high medium, as show in the figures below (see Figure 4.5, Figure 4.6 and Figure 4.7).

- Residual energy: Low, Medium and High (see Figure 4.5)
- Centrality: Close, Medium and Far (see Figure 4.6)
- Rank: Low, Low Medium, Medium, High Medium and High (see Figure 4.7)

Table 4.2. The Rules of FLS

Residual Energy	Centrality	Rank
Low	Close	Medium (M)
Low	Medium	Low Medium (LM)
Low	Far	Low (L)
Medium	Close	High Medium (HM)
Medium	Medium	Medium (M)
Medium	Far	Low Medium (LM)
High	Close	High (H)
High	Medium	High Medium (HM)
High	Far	Low Medium (LM)

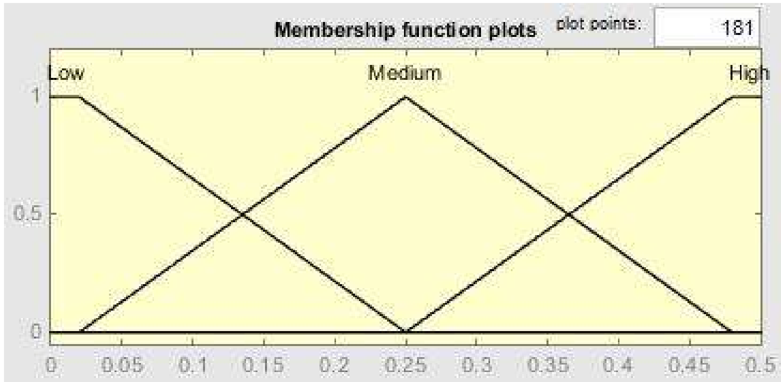

Figure 4.5. Membership Functions for Residual Energy

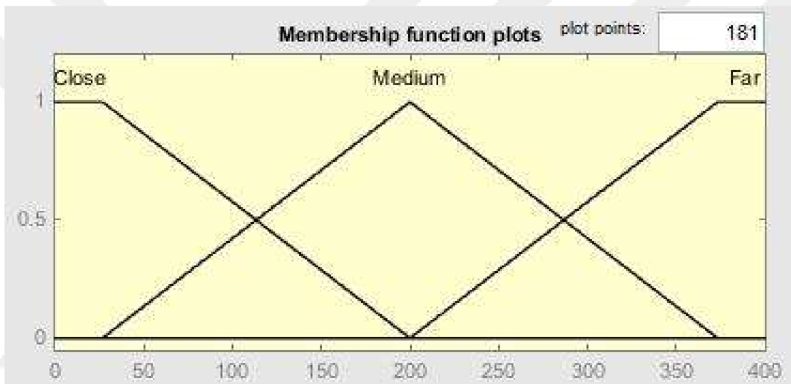

Figure 4.6. Membership Functions for Centrality

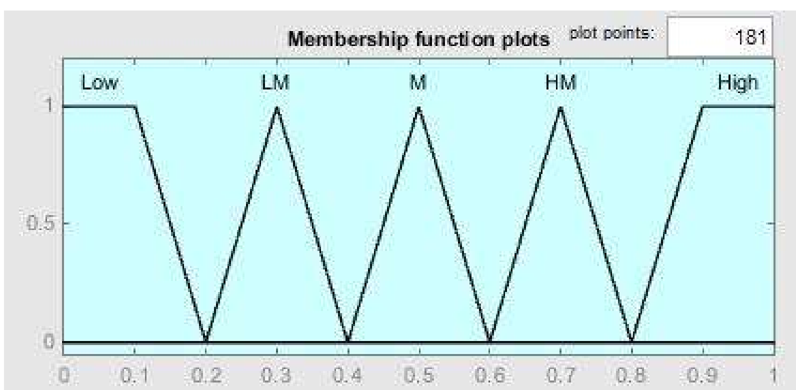

Figure 4.7. Membership Functions for Output Ranks

4.5. VCH Selection

The node with the highest rank among the member nodes will be the VCH and it is selected by the CH. The VCH does not participate in any sensing and communication processes. It simply waits for a call from the CH to function in its place. To be able to perform as next CH, it saves energy by not participating in any task. It seems against the utilization of network resources to not involve VCH in any process, but if we think of increasing the total life span of clusters then this technique proves to deliver better results (Mehmood et al., 2015).

Receiving the call from CH, VCH announces itself as the new CH in the cluster. The member nodes will give their feedback through an acknowledgement message along with their new calculated ranks. Again the node with highest rank will be selected as VCH. The pseudo code for VCH selection is shown in the figure below (see Figure 4.8).

The CH will send the message to VCH in following two conditions:

1. The energy level of the CH reaches the threshold value.
2. Congestion is detected in the CH.

```
begin (VCH selection)
  Member nodes send their Ranks to the CH
  if Rank > other nodes Ranks
    It is declared as VCH
  else
    It remains a member node
  end
end
```

Figure 4.8. Pseudo Code for VCH Selection

4.6. Energy Model

The radio model for energy consumption adopted, is same as used by Heinzelman et al. (2000), Yu et al. (2011), Beiranvand, Patooghy, and Fazeli (2013), Jannu and Jana (2014),Mehmood et al. (2015), and Nokhanji et al. (2015) (see Figure 4.9).. The free space model d^2 is used when the distance of transmission is less than the threshold value d_0. If distance is greater than d_0, then multipath fading model d^4 is used. To transmit a message of size k to the distance d, the energy dissipation will be:

$$E_{TX}(k,d) = \begin{cases} k \times E_{elec} + k \times \varepsilon_{fs} \times d^2, & \mathrm{d} \leq d_0 \\ k \times E_{elec} + k \times \varepsilon_{mp} \times d^4, & \mathrm{d} \geq d_0 \end{cases} \quad (4)$$

Where
$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \quad (5)$$

Energy consumption for receiving k bit message will be:

$$E_{RX}(k) = k \times E_{elec} \tag{6}$$

The considered parameters are:

- E_{TX} = Transmission cost
- E_{RX} = Receiving cost
- k = Length of message in bits
- d = Distance between transmitter and receiver
- E_{elect} = Consumed energy per bit
- ε_{fs} = Energy consumed by free space amplifier
- ε_{mp} = Energy consumed by multipath amplifier
- d^2 = Free space power loss
- d^4 = Multipath fading power loss

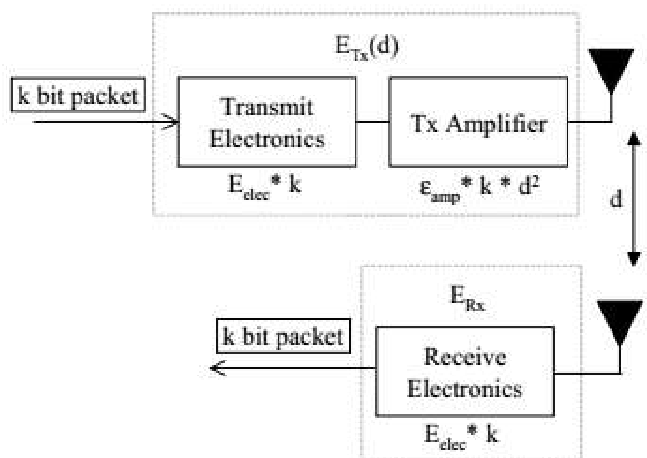

Figure 4.9. Radio Model for Energy Consumption (Heinzelman et al., 2000)

The CH in a cluster consumes more energy as compare to the other member nodes because of its additional tasks like listening, receiving, aggregation and transmission. Therefore its energy dissipates earlier. The VCH replaces CH when its energy decreased to the threshold energy level. The threshold energy is set to 1/10th of initial energy level (0.5J) of the nodes. So that even when CH being replaced it can still work as a normal node and continue to transfer the sensed data to the new CH.

4.7. Congestion Detection

When nodes send some data packets, they transmit them either directly to the sink, if the sink is in their range or they can send the packets through intermediate nodes, when they are distant from the sink. In case of cluster-based networks, the CHs are used as intermediate nodes. Since the CHs are collecting and forwarding data from their own members, in such a case routing the packets from other clusters significantly increases the load on CHs, which eventually leads to congestion. This condition need to be recognized and eliminated from the network, because a network without any congestion control mechanism, leads to random packet drop (Sergiou et al., 2007), which affect the packet delivery rate and overall throughput.

Buffer memory of a node is where the congestion occurrence is detected. By monitoring present queue length and the number of packets in the buffer with respect to its total size will give the present buffer occupancy (Chakravarthi and Gomathy, 2010; Uthra et al., 2014; Gholipour et al., 2017).

$$B = \frac{Number\ of\ packets\ in\ the\ buffer}{Total\ buffer\ size} \qquad (7)$$

The buffer size has been varied in different studies to store various number of incoming packets. Qiu, Feng, Xia, Wu, and Zho (2011) perform different experiments by varying the buffer size to get optimal node utilization. A cluster with seven nodes is considered and the buffer size is altered between 1 to 30 packets. According to the results, the optimal node utilization is obtained once the buffer size matches the number of nodes in the cluster. By increasing the size of buffer after that limit does not affect the performance anymore.

Based on the above study, buffer size is taken as 15 here. In this proposal, the node deployment is random. Fifteen is the average number of nodes a cluster can have. That is why this size of buffer is preferred to get optimal performance results. However, the threshold value to detect congestion is set at 80% of buffer occupancy. So that the system can react before the buffer is fully occupied, in order to avoid overflow.

CHAPTER 5
SIMULATION RESULTS

5.1. Simulation Environment

In this chapter, the performance of the proposed approach is evaluated by using MATLAB. The simulation results are analyzed and compared with LEACH (Heinzelman et al., 2000) and MODLEACH (Mahmood et al., 2013), by using some predefined parameters as listed in the table below (see Table 5.1). These values have been taken from the work of; Yu et al. (2011), Beiranvand et al. (2013), Enam et al. (2014), Jannu and Jana (2014), Mehmood et al. (2015), and Mishra et al. (2017),

LEACH is one of the most well-known protocols which employs a hierarchical routing method by dividing the network into clusters. The clusters have CHs which collect data from their members in each round and transmit them to the sink. The CHs are changed per round for each cluster. MODLEACH is a modified version of LEACH, its CH selection method is same as LEACH but it does not change CHs in each round unless their energy levels fall below a certain threshold value. This method gives a better throughout and longer network lifetime than LEACH. These two protocols are taken for comparison with the proposed methodology because of their accessible algorithms. The results show that the proposed approach performs much better than the other two protocols.

The performances are evaluated according to the following parameters;

- Network lifetime
- Energy consumption
- Delivery ratio of packets

The experimental area for simulation is taken as 100m x 100m. 100 nodes are randomly deployed in the field. The sensor nodes have same initial amount of energy (0.5 J). The energy dissipation varies according to the differences in distance. For free space model it is E_{fs} and for multipath model it is taken as E_{mp}.

Table 5.1. Simulation Parameters and Their Values

Parameter	Value
Network size	100m x 100m
Number of sensor nodes	100
Location of base station	50m x 50m
Initial energy (E_o)	0.5 J
Transmission energy (E_{TX})	50 nJ/bit
Receiving energy (E_{RX})	50 nJ/bit
Packet length	4000 bits
Free space amplifier energy (E_{fs})	10 pJ/bit/m^2
Multipath amplifier energy (E_{mp})	0.0013 pJ/bit/m^2
Data aggregation energy (E_{DA})	5 nJ/bit

5.2. Assumptions

- A large number of sensor nodes are deployed randomly in the field
- All nodes are homogenous and initially have same energy level
- BS is static and placed at the center of network
- All nodes are able to communicate with each other and with the CH
- Nodes transmit data packets of fixed size
- The CHs compress and aggregate data before transmission
- Nodes are always assumed to have some information to transmit

5.3. Network Lifetime

The number of alive node decreases as their energy dissipates with the increase in rounds, as it can be seen from the figure below (see Figure 5.1). The network lifetime depends on the alive nodes, the longer nodes take to die the higher will be the network lifetime. Figure 5.1 shows that LEACH and MODLEACH both lose almost all of their alive nodes after 1500 rounds, however in the proposed method, majority of nodes die after reaching 2500 rounds and the network lasts till 4340 rounds. From Table 5.2 if we compare the network lifetime in terms of last alive node then proposed method performs 64.4% and 51.8% better than MODLEACH and LEACH respectively.

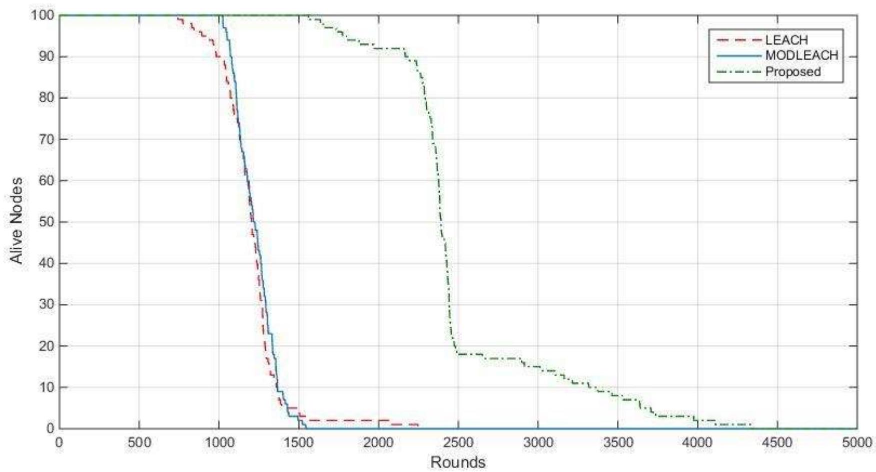

Figure 5.1. Network Lifetime

In this study, centrality is used as a parameter for CH selection with residual energy. The most central node has minimum distance from other nodes that automatically decreases the energy consumption for transmission. The second highest ranked node among member nodes is declared as VCH in each cluster. VCH is kept inactive until the CH is congested or suffered from energy dissipation. This gives additional and cumulative computing capability to every node in the cluster.

The death of first node defines the stability period of the network. A network is said to be more stable if it has a longer period until its first node dies. As it can be clearly seen from the figure below (see Figure 5.2) that the first node in the proposed approach dies after 1563 rounds, which shows that its stability period is 34.4% and 48.6% greater than MODLEACH and LEACH respectively.

Table 5.2. Number of Dead Nodes versus Rounds

Number of Dead Nodes	Rounds		
	Proposed	MODLEACH	LEACH
1	1563	1025	803
25	2325	1121	1104
50	2393	1219	1191
75	2452	1307	1271
100	4340	1547	2092

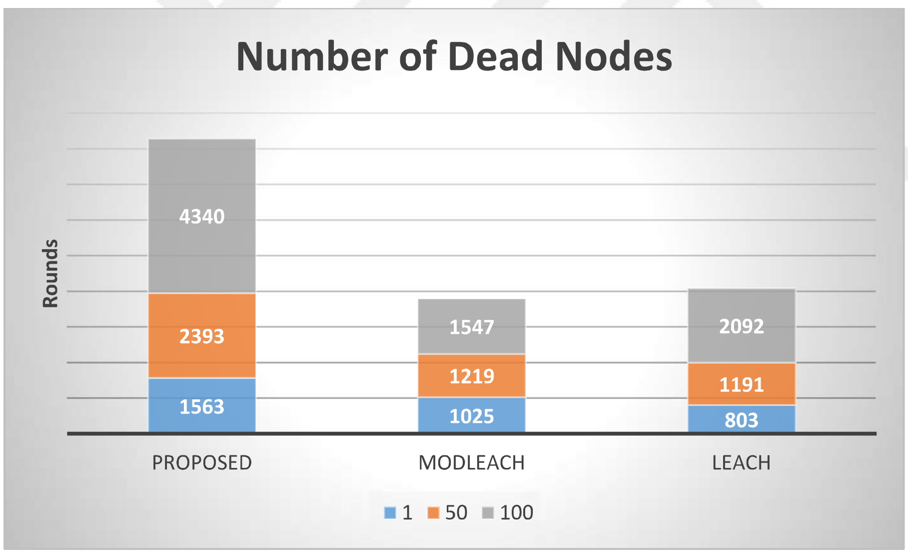

Figure 5.2. Number of Dead Nodes versus Rounds

5.4. Energy Consumption

Figure 5.3 shows the energy utilization in the network which is consumed during sensing, processing and communication processes. It is clear that energy consumption in the proposed method is less than MODLEACH and LEACH per round. This is mainly because of the differences in distribution of nodes into clusters, the process of CH selection and its replacement technique, avoiding retransmission in case of congestion by reducing the number of packet drop. The sensor nodes in the proposed method does not change the CHs in each round, unlike the other two protocols, which is an energy dissipating process because of the message transmissions that take place in the time of CH selection. The CH is replaced on-demand in the proposed approach, despite the number of rounds.

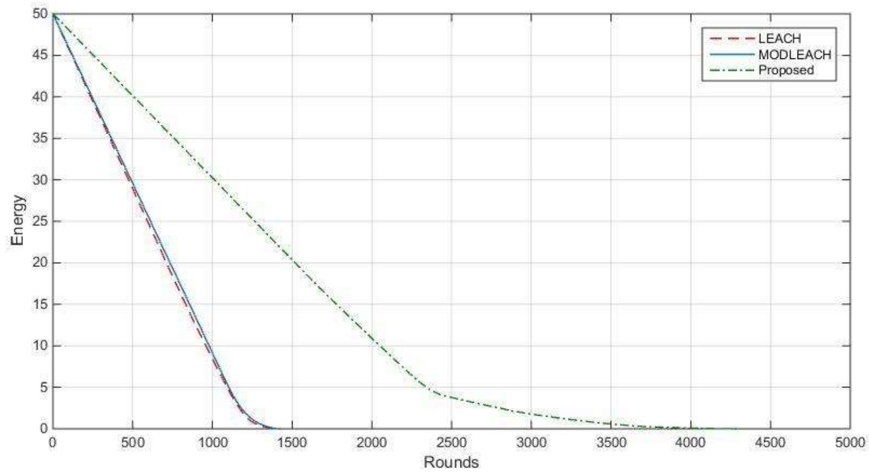

Figure 5.3. Energy Consumption

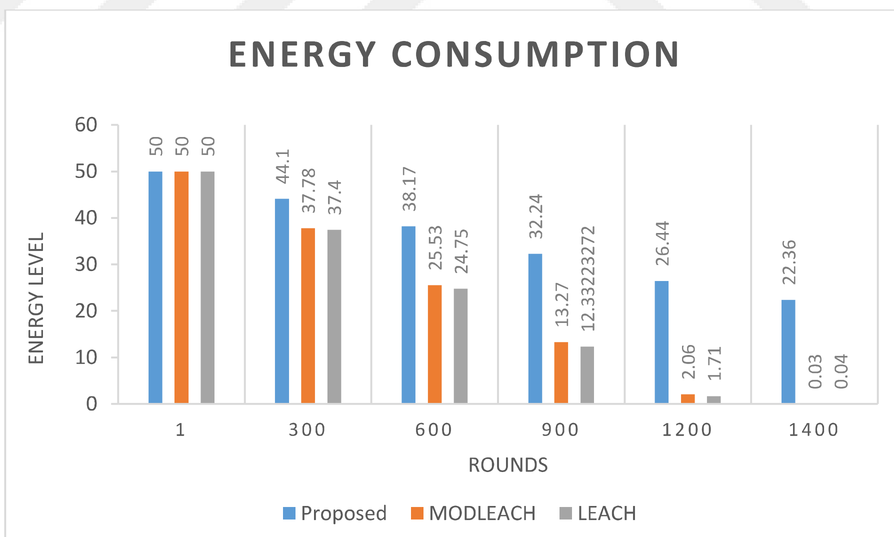

Figure 5.4. Energy Consumption versus Rounds

Figure 5.4 shows the energy level of network at different number of rounds. All three considered protocols initially have same amount of energy. It can be seen that energy dissipation is slower in the proposed method than the compared protocols. At round 300, energy consumption in the proposed approach is 11.8% but it is 24.4% in MODLEACH and 25.2% in LEACH which is likely twice of energy consumption in the proposed approach. Further at round 600, 900, 1200 and 1400 the energy consumption for MODLEACH is 48.59%, 73.4%, 95.9% and 99.93% while for LEACH it is 50.5%, 75.3%, 96.6% and 99.92%. They are clearly higher when compared with energy evaluation of the proposed approach, which is 23.6%, 35.5%, 47.1% and 55.3% respectively.

5.5. Delivery Ratio

The number of packets to the CH depends on the number of nodes in a cluster. If a cluster has N member nodes then the number of packets received by CH will be N. This will happen when all the nodes are alive and have some information to forward. In the simulation, it is assumed that the nodes always have some data to send and participate in transmission processes during each round. However, in real time example it cannot be the case all the time. It depends on the occurrence of an event in the specific area of the network and the presence of source nodes in that location.

The member nodes of a cluster do not change with each round in the proposed method because of the fixed grid sizes. That is why the number of packets sent to CH will be constant until a node dies. As it can be seen in the Figure 5.5, a straight line until round 1610 and then slowly it starts to decline because of decreasing number of alive nodes. However, the clusters are re-arranged and the number of their members are altered in each round in LEACH and MODLEACH. That is why their number of packets received by CHs vary per round according to the number of cluster members.

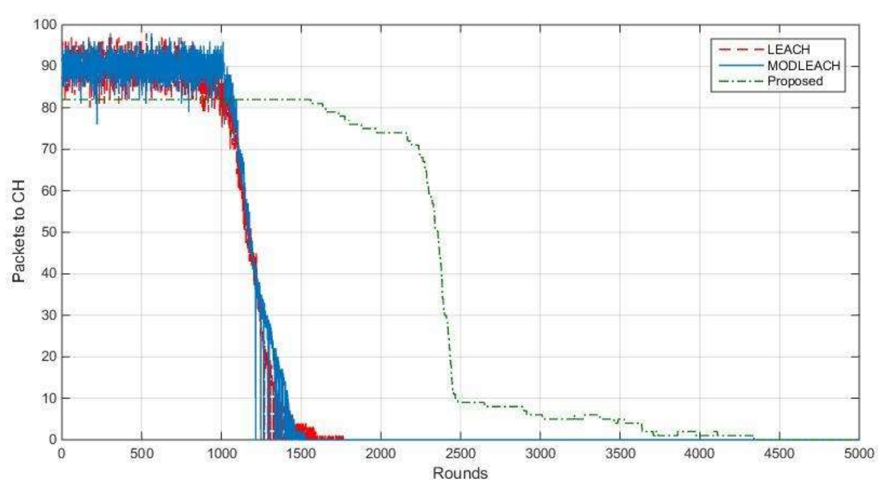

Figure 5.5. Packets to CHs

Figure 5.6 shows total number of packets received by CHs and it is obvious that in the proposed method the CHs get more packets, which is 44.8% and 46.1% greater than MODLEACH and LEACH respectively.

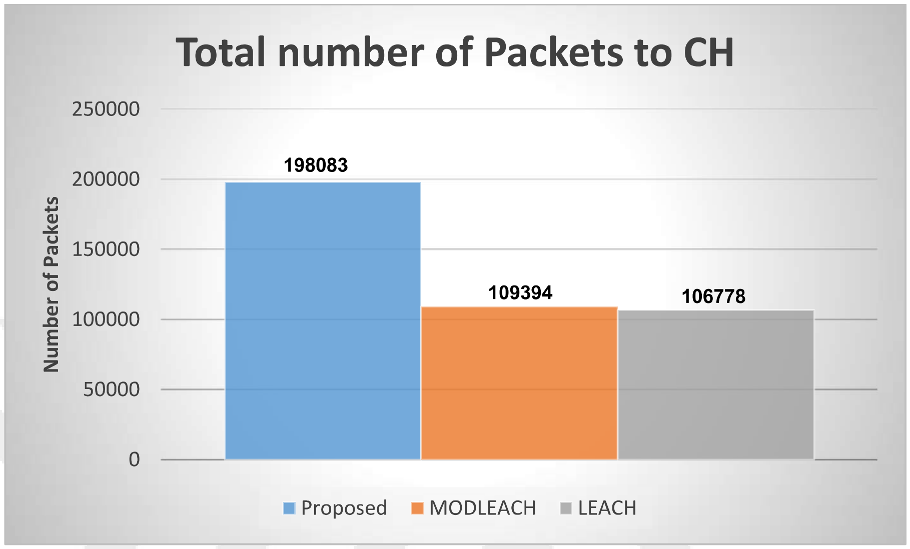

Figure 5.6. Total Number of Packets to CHs

The CHs do not transmit every packet they receive rather, they aggregate and eliminate the redundant data then send the processed packets toward BS. In this way the energy of sensor nodes are saved from extra transmission costs.

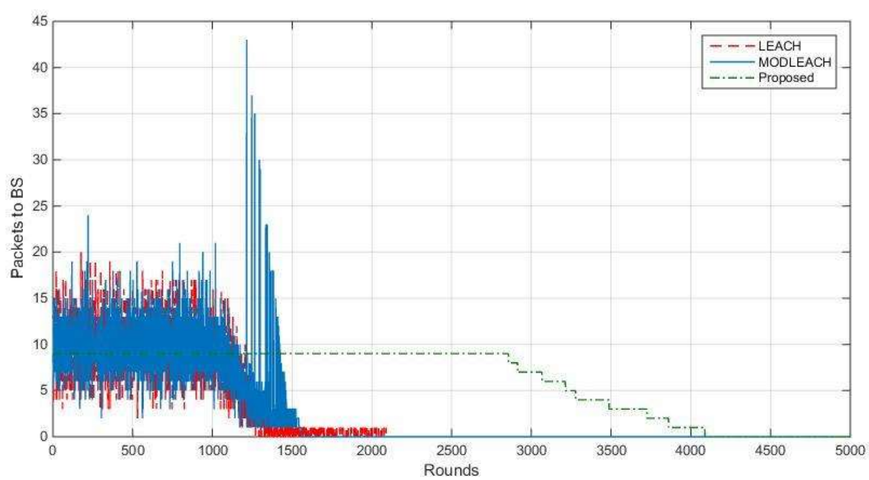

Figure 5.7. Packets to BS

The delivery ratio and throughput of a protocol depends on the number of packets successfully delivered to the destination. It is clear from the Figure 5.7 that the proposed method has higher delivery rate than the other compared protocols. The total number of packets received by BS is 30485 in the proposed method (see Figure 5.8) which is 57.2% and 60.5% greater than MODLEACH and LEACH respectively.

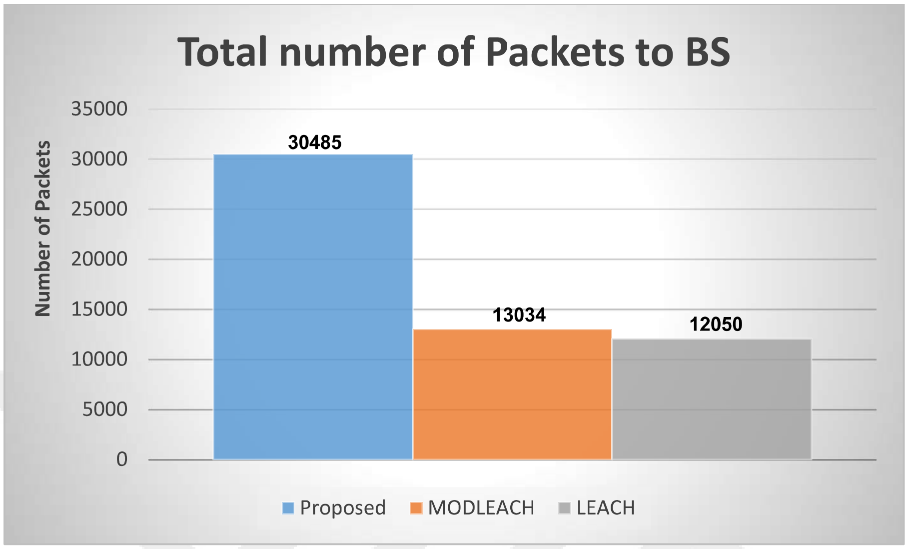

Figure 5.8. Total Number of Packets to BS

CHAPTER 6
CONCLUSION AND FUTURE WORK

WSN is a collection of identical sensor nodes. It is mainly arranged in an area to monitor the surrounding. Sensor nodes with limited processing, storage and battery capabilities often fail to handle high traffic flow. Traffic is mostly caused by creation of data packets from different events in the network, because all data generated from a specific series of events need to be delivered to the sink. When the nodes along the path to the sink receive packets with higher inter arrival time from the source nodes than their packet inter service time, congestion will occur in the network. The concurrent transmissions and many-to-one nature of traffic flow are also causes of congestion in WSNs.

Congestion causes critical outcomes in the network. It results in packet drop, low delivery rate, energy consumption and low throughput. The energy is mostly consumed in retransmitting the dropped packets, which ultimately shortens the network lifetime.

Many approaches have been adopted to eliminate congestion and its consequences from the network. This study presents a new approach to solve two most common problems faced by WSNs; congestion and short network lifetime. It is designed for cluster-based networks. The CHs in such networks are the main targets of congestion because of their greater number of tasks. That is why, this study presents an alternate (VCH) for CHs in each cluster, and that replaces CH's functions when they suffer from congestion or energy dissipation.

The concept of VCH has already been presented in the existing literature as discussed in chapter 3. However, it was mainly used to replace CHs when they suffered from energy dissipation. According to best of our knowledge, it is the first time that this method has been employed to control the congestion problem in WSNs, beside energy dissipation. The experimental results show its accomplishments to eliminate the effects of congestion from the network.

The nodes after their deployment are divided into grids in this method. The size of grids are defined according to the maximum ranges of sensor nodes. The grids are taken as clusters, and Fuzzy Logic System (FLS) is used to select the CH and VCH for each cluster. FLS calculates the ranks of each node by inferring the decision making process which is based on two parameters; residual energy level and centrality. The node with highest rank in the cluster is selected as CH. The CH selects the node with the second highest rank as VCH. The VCH does not participate in any process in order to save its energy and only starts functioning when it receives a call from the CH.

The performance of proposed algorithm is analyzed in MATLAB and has been compared with LEACH and MODLEACH algorithms. The results show that the proposed method significantly performs better than the compared protocols. It consumes less energy per round, delivers higher data rate to the CHs (44.8% and 46.1%) and BS (57.2% and 60.5%), when compared with MODLEACH and LEACH. The network lifetime increases 64.4% and 51.8% greater than MODLEACH and LEACH respectively.

Congestion almost occurs in all kind of networks. The proposed method of congestion control can be extended to other networks such as Internet of Things (IoT), for future works. IoT comprising of different devices with distinct bandwidths, becomes a challenging area for congestion detection and mitigation.

Instead of focusing the CHs as a target for congestion occurrence, this study can be extended by shifting the observations to the gateways in IoT. The gateways deal the generated information from various devices in the network. Their ability to handle higher complexities than sensor nodes, make it more viable to practice and implement new techniques to alleviate congestion and get rid of from its effects.

REFERENCES

Ahlawat, A., & Malik, V. (2013). An Extended Vice-Cluster Selection Approach to Improve V LEACH Protocol in WSN. *International Conference on Advanced Computing and Communication Technologies, ACCT*, (pp. 236-240).

Ahn, S., Kim, H., Park, J., & Yoo, J. (2013). On-demand Clustering Mechanism for Wireless Sensor Networks. *2013 International Conference on ICT Convergence (ICTC).*

Akl, R., & Sawant, U. (2007). Grid-based Coordinated Routing in Wireless Sensor Networks. *4th IEEE Consumer Communications and Networking Conference.*

Banimelhem, O., & Khasawneh, S. (2012). GMCAR: Grid-based Multipath with Congestion Avoidance Routing Protocol in Wireless Sensor Networks. *Ad Hoc Networks, 10*(7), 1346-1361.

Beiranvand, Z., Patooghy, A., & Fazeli, M. (2013). I-LEACH: An Efficient Routing Algorithm to Improve Performance & to Reduce Energy Consumption in Wireless Sensor Networks. *5th Conference on Information and Knowledge Technology (IKT*), (pp. 13-18).

Braginsky, D., & Estrin, D. (2002). Rumor Routing Algorithm for Sensor Networks. WSNA '02. *Proceedings of the 1st ACM International Workshop on Wireless Sensor Networks and Applications* (pp. 22-31). ACM.

Chakravarthi R, & Gomathy C. (2010). IPD: Intelligent Packet Dropping Algorithm for Congestion Control in Wireless Sensor Network. *Proceedings of the 2nd International Conference on Trendz in Information Sciences and Computing, TISC-2010*, (pp. 222-225).

Chitlange, M., & Deshpande, V. (2015). Effect of Node Density on Congestion in WSN. *2015 International Conference on Pervasive Computing.* Institute of Electrical and Electronics Engineers Inc.

Deshpande, V., Chavan, P., Wadhai, V., & Helonde, J. (2012). Congestion Control in Wireless Sensor Networks by using Differed Reporting Rate. *2012 World Congress on Information and Communication Technologies.*

Din, W., Yahya, S., Taib, M., & Yassin, A. (2013). Energy Efficient of WSN using Two Parameters Selection. *IEEE Conference on Systems, Process and Control, ICSPC 2013* (pp. 181-185). IEEE Computer Society.

Enam, R., Qureshi, R., & Misbahuddin, S. (2014). A Uniform Clustering Mechanism for Wireless Sensor Networks. *International Journal of Distributed Sensor Networks.*

Gao, Q., Blow, K., Holding, D., & Marshallband, I. (2004). Routing Analysis and Energy Efficiency in Wireless Sensor Networks. *Proceedings of the IEEE 6th Circuits and Systems Symposium on Emerging Technologies: Frontiers of Mobile and Wireless Communication.*

Ghaffari, A. (2015). Congestion Control Mechanisms in Wireless Sensor Networks: A Survey. *Journal of Network and Computer Applications, 52*, 101-115.

Ghanavati S, Abawajy J, & Izadi D. (2013). A Fuzzy Technique to Control Congestion in WSN. *Proceedings of the International Joint Conference on Neural Networks.*

Gholipour, M., Haghighat, A., & Meybodi, M. (2017). Hop-by-Hop Congestion Avoidance in Wireless Sensor Networks Based on Genetic Support Vector Machine. *Neurocomputing, 223*, 63-76.

Gupta, I., Riordan, D., & Sampalli, S. (2005). Cluster-Head Election using Fuzzy Logic for Wireless Sensor Networks. *Proceedings of the 3rd Annual Communication Networks and Services Research Conference*, (pp. 255-260).

Haas, Z., Halpern, J., & Li, L. (2006). Gossip-Based Ad Hoc Routing. *IEEE/ACM Transactions on Networking (ToN), 14*(3), 479-491.

Halim, N., Yaakob, N., & Isa, A. (2016). Congestion Control Mechanism for Internet of Things (IoT) Paradigm. *3rd International Conference on Electronic Design, ICED* (pp. 337-341). Institute of Electrical and Electronics Engineers Inc.

Hashemzehi, R., Nourmandipour, R., & Koroupi, F. (2013). Congestion in Wireless Sensor Networks and Mechanisms for Controlling Congestion. *Indian Journal of Computer Science and Engineering (IJCSE), 4*(3).

Hassan, T., Selim, G., & Sadek, R. (2015). A Novel Energy Efficient Vice Cluster Head Routing Protocol in Wireless Sensor Networks. *IEEE Seventh International Conference on Intelligent Computing and Information Systems (ICICIS).*

Hatamian, M., & Barati, H. (2015). Priority-based Congestion Control Mechanism for Wireless Sensor Network using Fuzzy Logic. *6th International Conference on Computing, Communication and Networking Technologies (ICCCNT).*

He, T., Blum, B., Stankovic, J., & Abdelzaher, T. (2004). AIDA: Adaptive Application Independent Data Aggregation in Wireless Sensor Networks. *ACM Transactions on Embedded Computing Systems TECS, 3*(2), 426.

Heikalabad, S., Ghaffari, A., & Abolga, M. (2011). DPCC: Dynamic Predictive Congestion Control in Wireless Sensor Networks. *International Journal of Computer Science Issues (IJCSI), 8*(1).

Heinzelman, W. B. (2000). *Application-Specific Protocol Architectures for Wireless Networks* (Doctoral Dissertation). Massachusetts Institute of Technology, Cambridge, Massachusetts, United States of America.

Heinzelman, W. R., Chandrakasan, A., & Balakrishnan, H. (2000). Energy-Efficient Communication Protocol for Wireless Microsensor Networks. *Proceedings of the 33rd Hawaii International Conference on System Sciences,* (pp. 1-10).

Huang, W., Peng, Y., Wen, J., & Yu, M. (2009). Energy-Efficient Multi-hop Hierarchical Routing Protocol for Wireless Sensor Networks. *2009 International Conference on Networks Security, Wireless Communications and Trusted Computing, 2*, 469-472.

Hussain, M., Singh, M., & Singh, R. (2013). Analysis of Lifetime of Wireless Sensor Network. *International Journal of Advanced Science and Technology, 53.*

Intanagonwiwat, C., Govindan, R., Estrin, D., Heidemann , J., & Silva, F. (2003). Directed Diffusion for Wireless Sensor Networking. *IEEE/ACM Transactions on Networking, 11*(1), 2-16.

Jaiswal, S., & Yadav, A. (2013). Fuzzy Based Adaptive Congestion Control in Wireless Sensor Networks. *2013 Sixth International Conference on Contemporary Computing (IC3).*

Jannu, S., & Jana, P. (2014). Energy Efficient Grid Based Clustering and Routing Algorithm for Wireless Sensor Networks. *2014 Fourth International Conference on Communication Systems and Network Technologies.*

Kadam, A. A., & Chatur, P. N. (2016). Energy Efficient Method for Congestion Avoidance System in Wireless Sensor Networks. *International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics.*

Kang, J., Zhang, Y., & Nath, B. (2007). TARA: Topology-Aware Resource Adaptation to Alleviate Congestion in Sensor Networks. *IEEE Transactions on Parallel and Distributed Systems, 18*(7), 919-931.

Kulik, J., Heinzelman, W., & Balakrishnan, H. (2002). Negotiation-based Protocols for Disseminating Information in Wireless Sensor Networks. *Wireless Networks, 8*(2-3), 169-185.

Lai, W., Fan, C., & Lin, L. (2012). Arranging Cluster Sizes and Transmission Ranges for Wireless Sensor Networks. *Information Sciences, 138*(1), 117-131.

Leu, F., Chen, H., & Liu, J. (2014). Improving Multi-Path Congestion Control for Event-Driven Wireless Sensor Networks by using TDMA. *Ninth International Conference on Broadband and Wireless Computing, Communication and Applications* (pp. 300-305). Institute of Electrical and Electronics Engineers Inc.

Liu, X. (2012). A Survey on Clustering Routing Protocols in Wireless Sensor Networks. *Sensors (Switzerland), 12*(8), 11113-11153.

Liu, X. (2015). Atypical Hierarchical Routing Protocols for Wireless Sensor Networks: A Review. *IEEE Sensors Journal, 15*(10), 5372-5383.

Mahmood, D., Javaid, N., Mahmood, S., Qureshi, S., Memon, A., & Zaman, T. (2013). MODLEACH: A Variant of LEACH for WSNs. *Eighth International Conference on Broadband, Wireless Computing, Communication and Applications, BWCCA,* (pp. 158-163).

Mehmood, A., Lloret, J., Noman, M., & Song, H. (2015). Improvement of the Wireless Sensor Network Lifetime using LEACH with Vice-Cluster Head. *Ad-Hoc and Sensor Wireless Networks, 28*(1-2), 1-17.

Mishra, A., Kumar, R., Kumar, V., & Singh, J. (2017). A Grid-Based Approach to Prolong Lifetime of WSNs using Fuzzy Logic. *Advances in Intelligent Systems and Computing, 509*, 11-22.

Naeimi, S., Ghafghazi, H., Chow, C., & Ishii, H. (2012). A Survey on the Taxonomy of Cluster-Based Routing Protocols for Homogeneous Wireless Sensor Networks. *Sensors (Switzerland), 12*(6), 7350-7409.

Nokhanji, N., Hanapi, Z., Subramaniam, S., & Mohamed, M. (2015). An Energy Aware Distributed Clustering Algorithm Using Fuzzy Logic for Wireless Sensor Networks with Non-uniform Node Distribution. *Wireless Personal Communications, 84*(1), 395-419.

Paek, J., & Govindan, R. (2010). RCRT: Rate-Controlled Reliable Transport Protocol for Wireless Sensor Networks. *ACM Transactions on Sensor Networks, 7*(3).

Paranjape, S., S, B., Sutaon, M., & Mukherji, P. (2016). Intra and Inter Cluster Congestion Control Technique for Mobile Wireless Sensor Networks. *2016 Conference on Advances in Signal Processing (CASP).*

Patil, D., & Dhage, S. (2012). Priority-based Congestion Control Protocol (PCCP) for Controlling Upstream Congestion in Wireless Sensor Network. *International Conference on Communication, Information and Computing Technology, ICCICT 2012.*

Preethiya, T., & Santhi, G. (2014). Enhancement of Lifetime Using Fuzzy-Based Clustering Approach in WSN. 2014 *International Conference on Computer Communication and Informatics (ICCCI-2014).*

Qiu, T., Feng, L., Xia, F., Wu, G., & Zho, Y. (2011). A Packet Buffer Evaluation Method Exploiting Queueing Theory for Wireless Sensor Networks. Computer Science and Information Systems (ComSIS), 8(4).

Ramesh, K., & Somasundaram, K. (2011). A Comparative Study of Cluster Head Selection Algorithm in Wireless Sensor Networks. *International Journal of Computer Science & Engineering Survey (IJCSES), 2*(4).

Rana, S., & Kamboj, P. (2016). Resource Utilization based Congestion Control for Wireless Sensor Network: A Review. *International Conference on Computing for Sustainable Global Development.*

Rhee, I., Warrier, A., Aia, M., Min, J., & Sichitiu, M. (2008). Z-MAC: A Hybrid MAC for Wireless Sensor Networks. *IEEE/ACM Transactions on Networking, 16*(3), 511-524.

Sergiou, C., Vassiliou, V., & Paphitis, A. (2014). Congestion Control in Wireless Sensor Networks through Dynamic Alternative Path Selection. *Computer Networks,* 226-238.

Sergiou, C., Vassiliou, V., & Pitsillides, A. (2007). Reliable Data Transmission in Event-based Sensor Networks During Overload Situation. *Power*, 31.

Sharma, K., Singh, H., & Patel, R. (2010). A Hop by Hop Congestion Control Protocol to Mitigate Traffic Contention in Wireless Sensor Networks. *International Journal of Computer Theory and Engineering, 2*(6), 1793-8201.

Singh, A., Rathkanthiwar, S., & Kakde, S. (2016). Energy Efficient Routing of WSN using Particle Swarm Optimization and V-Leach Protocol. *International Conference on Communication and Signal Processing*, (pp. 2078-2082).

Torres, M. G. (2006). *Energy Consumption in Wireless Sensor Networks Using GSP* (Master's thesis). University of Pittsburgh, Pittsburgh, United States of America.

Uthra R, & Raja S. (2012). QoS Routing in Wireless Sensor Networks - A Survey. *ACM Computing Surveys, 45*(1), 1-12.

Uthra, R., Raja, S., Jeyasekar, A., & Lattanze, A. (2014). A Probabilistic Approach for Predictive Congestion Control in Wireless Sensor Networks. *Journal of Zhejiang University-SCIENCE C (Computers & Electronics), 15*(3), 187-199.

Wireless Sensor Network. (n.d.). In *Wikipedia*. Retrieved 19 September 2017, from https://en.wikipedia.org/wiki/Wireless_sensor_network

Xu, Y., Heidemann, J., & Estrin, D. (2001). Geography Informed Energy Conservation for Ad Hoc Routing. *Seventh Annual ACM/IEEE International Conference on Mobile Computing and Networking* (pp. 70-84). ACM SIGMOBILE.

Yassein, M., Al-zou'bi, A., Khamayseh, Y., & Mardini, W. (2009). Improvement on LEACH Protocol of Wireless Sensor Network (VLEACH). *International Journal of Digital Content Technology and its Applications, 3*(2).

Yu, J., Qi, Y., & Wang, G. (2011). An Energy Driven Unequal Clustering Protocol for Heterogeneous Wireless Sensor Networks. *Journal of Control Theory and Applications, 9*(1), 133-139.

Zadeh, L. A. (1973). Outline of a New Approach to the Analysis of Complex Systems and Decision Processes. *IEEE Transactions on Systems, Man, and Cybernetics,* 28-44.

Zawodniok, M., & Jagannathan, S. (2007). Predictive Congestion Control Protocol for Wireless Sensor Networks. *IEEE Transactions on Wireless Communications, 6*(11), 3955-3963.

Zhao, F., Xu, Y., & Li, R. (2012). Improved LEACH Routing Communication Protocol for a Wireless Sensor Network. *International Conference on Control Engineering and Communication Technology.*