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Intelligent Methodologies for Data Aggregation in wireless Sensor Network

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بِسْـمِ اللَّـهِ الرَّحْمنِ الرَّحِيمِ

﴿وَعَلَّمَـكَ مـاَ لَمْ تكُـنْ تَعْلَمُ وَكَـانَ فَضْلُ اللَّـهِ عَلَيْـكَ عَظِيمـا﴾

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DEDICATION

To my father and mother

With love and respect

To my dear sisters and

Brother

Acknowledgements

First of all, I give my sincere uncountable thanks and praise to Allah for all His Blessings.

I would like to send my deepest thanks and appreciation to my supervisor, ***Dr. Nadia Adnan shiltagh*** *for being a great helping hand during this unforgettable journey. During the year my supervisor has guided me in the right path and without her enthusiasm and ongoing support I would not be here this day with my completed work.*

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Maab

Abstract

Data aggregation is the basic approach in Wireless Sensor Network (WSN), in order to reduce the number of transmissions of sensor nodes, and hence minimizing the overall energy consumption in the network. Data centric techniques, like data aggregation via modified algorithm based on fuzzy clustering algorithm with voronoi diagram which is called **modified Voronoi Fuzzy Clustering Algorithm (VFCA)** has been presented in this work.In the modified algorithm, the sensed area is divided into a number of voronoi cells by applying voronoi diagram, with fuzzy C-means method (FCM) to reduce the transmission distance. Three parameters are used in this algorithm, these parameters are: **energy, distance between Cluster Head(CH) and its neighbor sensors and packet loss values**. Furthermore, data aggregation is employed in each CH to reduce the amount of data transmission which leads to extend the network lifetime and reduce the traffic that may be occurred in the buffer of sink node.

A comparative study between modified VFCA and LEACH protocol shows that the modified VFCA with threshold and without threshold is more efficient than LEACH protocol in term of network lifetime; the result shows an improvement due to the use of the voronoi diagram . In term of average energy dissipation the rate of energy consumption of the modified VFCA with and without threshold is lower than the rate of energy consumption in LEACH protocol.

Another comparative study between modified VFCA and K-Means clustering algorithm show that the modified VFCA is more efficient than K-Means clustering algorithm in term of packets transmitted to sink node. The modified VFCA is better than K-Means algorithm, in term of buffer utilization of sink node .In term of packet loss values from each cluster head node the modified VFCA is better than K-Means ,and in term of the running

time that the running time of VFCA less than running time of K-Means algorithm.

A simulation process is developed and tested using Matlab R2010a program in a computer having the following properties: windows 7 (32-bit operating system), core i7, RAM 4GB, hard 1TB.

Contents

List of Abbreviations

Abbreviation	***Full meaning used in this thesis***
AC	Address-Centric Protocol
BS	Base Station
CH	Cluster Head
DA	Data-Centric Protocol
DC	Direct Communication
FCM	Fuzzy C-Means
GPS	Global Positioning System
GUI	Graphical User Interface
LEACH	Low Energy Adaptive Clustering Hierarchy
MTE	Minimal Transmission Energy
QOS	Quality of Service
TDMA	Time Division Multiple Access
VBGA	Voronoi based Genetic clustering Algorithm
VD	Voronoi Diagram
VF	Voronoi Fuzzy
VFCA	Voronoi Fuzzy Clustering Algorithm
VS	Versus

WSN	Wireless Sensor Network

List of Symbols

Symbol	***Description***	***Unit***
BU	Buffer Utilization	Unitless
BUF	Buffer size	Unitless
BU_{sink}	size of the sink buffer	Unitless
C	Center location for all sensor nodes	Meter
C{i}	Voronoi Cell of node i	Unitless
D	Data sensed by sensor nodes in one cluster	Unitless
d_i	Data sensed by node i	Unitless
dij	The Euclidean distance between node i and the center of cluster j.	Meter
E	Initial Energy for each node	Joule
$e(p_i, p_j)$	An edge between the Voronoi regions V_i and V_j	Unitless
Ea	Average energy consumption	Joule
E_{ck}	The current energy level of a node k	Joule
E_{ik}	The initial energy level of a node k	Joule
ERX_CH	Received energy dissipated for each cluster head	Jule/bit
ERX_node	Receiver Electronics Energy dissipated for each node	Jule/bit
ETX	The energy dissipated to run the electronics circuits	nJ/bit
ETX_CH	Transmitted energy dissipated for each cluster head	Jule/bit

ETX_node	Transmitter Electronics Energy dissipated for each node	Joule
K	Iteration steps	Unitless
m	Fuzziness index	Unitless
N	Number of nodes	Unitless
o	Objects	Unitless
P	Packets	Unitless
$\mathbf{P_i,P_j}$	The location of sensor node	Meter
Pl	Packet loss	Unitless
$\mathbf{P}_{total}$	Total packets received at sink buffer	Unitless
R	Total rounds of the network lifetime	Unitless
$\mathbf{V(P_i)}$	Voronoi cell of node (p_i)	Unitless
$\mathbf{V_i,V_j}$	Voronoi region of points i,j	Meter^2
$\mathbf{x_i}$	The x-axis of the node location	Meter
$\mathbf{y_i}$	y- axis of the node location	Meter
$\boldsymbol{\mu_{ij}}$	Degree of membership function of node i to cluster j	Unitless

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CHAPTER ONE

Introduction

Chapter One

Introduction

1.1 General Introduction

The wireless sensor network (WSN) is some type of ad-hoc network. It consists of small and light weighted wireless devices called sensor nodes, these nodes are distributed in a physical or environmental condition. These devices monitor physical parameters such as temperature, sound, pressure, and humidity [1].

A wireless sensor network contains hundreds or thousands of these nodes. These sensor nodes have the capability to communicate either directly to an external Base-Station (BS) or with each other. A larger number of sensor nodes allows for sensing over larger geographical areas with greater accuracy. Figure (1.1) shows the graphical diagram for the components of the sensor node. Every sensor node contains sensing unit, processing unit, transmission unit, mobilize unit, position finding system, and power unit (some of these units are optional like the position finding system). Figure (1.1) shows the communication architecture of a WSN. Sensor nodes are usually dispersed in a sensing area, which is represents the area where the sensor nodes are distributed. Sensor nodes arrange themselves to provide information have high-quality about the physical environment. The sensor node determines his decision depending on the task at hand, on the information it currently has, and on its knowledge of its, e.g. (computing, communication, and resources of energy). Every one of these dispersed sensor nodes has the ability to gather and forward the data either to other sensors in the network or to an external Base Station (BS). A base-station can become either a fixed or a mobile node, has the ability to communicate the nodes in the network to an infrastructure communication or to the Internet where the user can have access to the needed data [2].

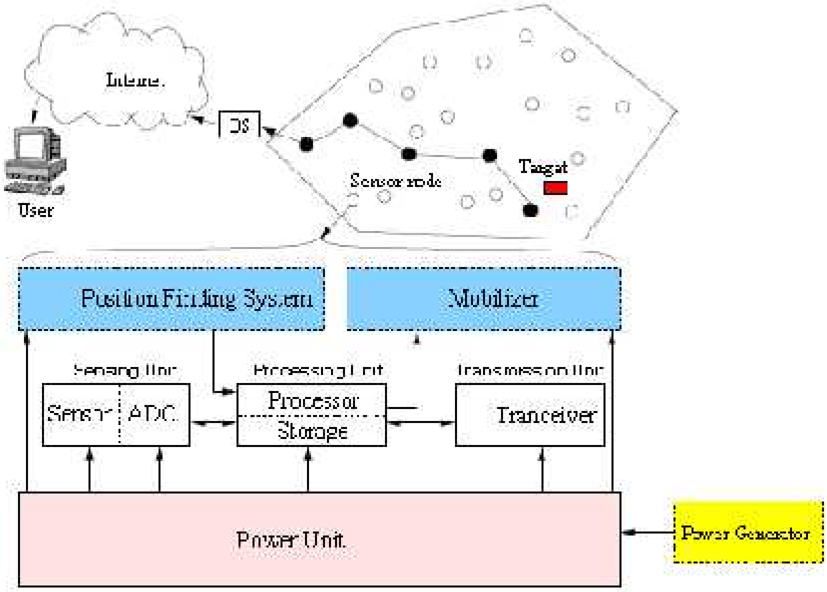


Figure (1.1): The components of a Sensor Node [2]

A Wireless sensor networks are consisting of great numbers of small, battery-powered, light weighted wireless sensor nodes. Those sensor nodes are arranged in the sensing field to monitor physical environments at fine temporal and spatial scales. Wireless sensor networks will be independently deployed in great numbers. The key design criterion for these sensor networks is energy-efficiency [3].

Wireless sensor networks (WSNs) can be used for many applications such as military monitoring, facility monitoring and environmental monitoring. Generally WSNs have a great number of sensor nodes have the ability to communicate with each other and also to communicate with an external base-station. The sensors could be dispersed randomly in cruel environments such as a battlefield or placed deterministically at a specified locations. The sensors arranged themselves to form a network, the communication among them can be either single multi-hop network or hierarchical organization with many clusters and cluster heads. The role of sensors can be summarized as follows: first it senses the data, then process it and finally transmits these data to the base station periodically. The frequency of the number of sensors which report data and data reporting usually depends on the particular application [4].

A WSN is assumed to have a remote BS as shown in Figure (1.1). A BS is a smart gateway node associated with the high computation power. To obtain long lifetime for WSNs, when one want to design the algorithms or protocols for WSNs it is necessary to take the accounts how to save the energy, where costs of communication are usually more costly than computing costs [5].

The location of the base station has a primary role on the energy consumption of the sensor nodes. This is because of the fact that whenever the distance between the base station and the sensor nodes increased, the higher the energy is consumed. On the same hand, the lesser the distance between the base station and the sensor nodes, the lower the energy consumed. Therefore, choosing an optimal location of the base station is decisive and will enormously affect the operational lifetime of the WSNs. For instance, if the base station placed in the center of the sensing area, the sensor nodes that are located at the boundary of the sensing area will consume more energy to transmit sensed data to the base station compared to sensor nodes that are close to the base station. This will create different energy consumption among all sensor nodes and moreover reduced the network energy efficiency [6].

Sensor networks are categorized into two types. The first type is a Mobile Sensor Network, which is contain a collection of sensors have the ability to move, sense, compute and transport data between themselves. The sensors that have the ability to move can followed the moving target easily and this can happen by fixing these nodes on the target field only. The second type is a Static Sensor Network which it does not has the capabilities of Mobile Sensor Network [5].

By providing sink nodes that connect sensor nodes to the other networks, wireless sensor networks can improve remote access to sensor data, such as Internet, using wide-area wireless links. If the sensors share their notes and process these notes so that meaningful and useful information is available at the sink nodes, users can restore information from the sink nodes to monitor and control the environment from away [7].

WSN applications can be categorized into two categories: monitoring and tracking as in Figure (1.2). Monitoring applications contain indoor/outdoor environmental monitoring, health and wellness monitoring, inventory location monitoring, power monitoring, factory and process automation, seismic and structural monitoring. Tracking applications contain tracking objects, humans, animals, and vehicles. [8].

Figure (1.2): Application of Wireless Sensor Network **[8]**

1.2 Features of Wireless Sensor Networks [9]

The major feature of a WSN is to transmit wirelessly the data, acquired by sensors in different environments, to the elements (in the same network or in other network) in charge of processing this information. Usually these networks are composed by a large number of nodes. This means that some characteristics like small size, low power consumption, low complexity and low cost are suitable goals when designing a WSN. Using a system that needs the batteries to be charged every day can become a quite bothersome task if the number of devices is completely high. In addition if each device in the system is complex as much to design as to manufacture, this system is not going to be cost-effective to the market. Because of these reasons users expect batteries to last months to years, and designers expect a simple technology which implies fast and simple designs in order to get globally standard inexpensive systems. Every technology, protocol and topology designed for and related to the WSN must take into consideration these characteristics. Protocols must ensure the nodes to realize simple tasks in order to facilitation their functionality and also they must ensure too that the transmitters and receivers works the minimum possible time in order to reduction power consumption and by this way increase the battery life, and, of course, everything must be done at a price that allows an reasonable cost for a network that integrates a high density of sensor nodes [9].

1.3 Data aggregation [10, 11, 12]

Nodes in a WSN sense the data from the environment and aggregate these sensed data then send the aggregated data to the base station. Many nodes report comparable readings as data in a WSN are associated. Thus, a large amount of energy is consumed during the transmission of many redundant data. Moreover, when nodes transmit their sensed data to the base station through an intermediate nodes, significant amount of energy is consumed at communication. One technique used to reduced the number of redundant data transmitted and thus pro-long the network lifetime is the process of data aggregation. During data aggregation, the intermediate nodes combine the data that received from other nodes into a single value. The conserved energy of the network can be get through a decreasing in the number of packets being exchanged among the nodes in the network. However, in many techniques of data aggregation, some of redundant data still sent to the base station. The sensor network lifetime can faced by stringent energy consumptions [10].

The goals of data aggregation protocols is to eliminate the redundant data transmission and thus improve the lifetime of energy constrained wireless sensor network. In wireless sensor network, data transmission occurred in multi-hop fashion where each node forwards its sensed data to the neighbor node which is closer to sink. Since closely placed nodes may sense same data, the above approach cannot be considered as energy efficient. Data aggregation is a process of collecting the sensors data by using aggregation algorithms. Figure (1.3) illustrated how the data aggregation algorithms are work in general[11].

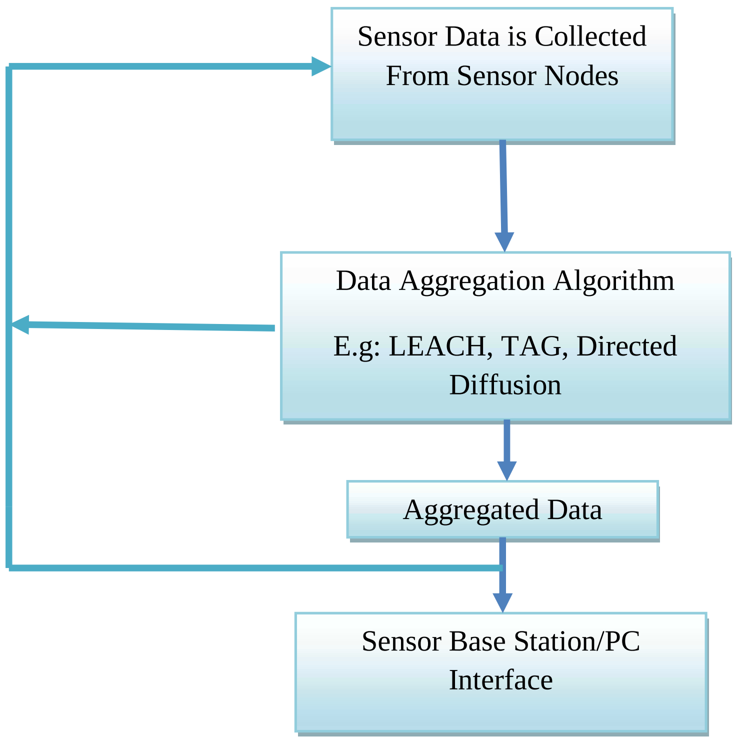


Figure (1.3): General Architecture of the Data Aggregation Algorithm [11]

Data gathering is defined as the formal collection of the sensed data from many sensors to be finally transmitted to the base station for processing. If all sensor nodes transmit their sensed data directly to the base station, it is become inefficient process, due to the energy constrained of sensor nodes. Neighboring sensors generate data much correlated and have redundant among them. In addition, it is enormous for the base station to process all the generated data from huge number of nodes in the large sensor networks. Hence, the designers may need data combining methods that produced information with high quality either at the sensor nodes or at an intermediate sensor nodes. These methods can help to reduce the packets that transmitted from the sensors in the network to the base station, resulting in keeping of energy and bandwidth. This can be executed by data aggregation. It is possible to define the process of data aggregation as a process of aggregating the data that sensed by many sensors in order to reduce the number of redundant transmissions and provide integrated information to the base station. Data aggregation is a process that usually involves the collection of data from many sensors at intermediate nodes and then send the collected data to the base station directly [11].

The concept of data aggregation lies in how the data digest is generated. The aggregation function is a function that takes raw data as input and produces a digest as output. Clearly, the type of aggregation function used depends on the type of statistics that want to derive from the raw data. For example, one might be interested in the maximum, the minimum, the sum, or the average of the raw data [12].

1.4 Literature survey

Researchers have a lot of in-depth study of data aggregation in wireless sensor networks. A brief description of these researches is submitted in the following paragraphs.

- P. S. Bishnu and V. Bhattacherjee in (2009) [13], proposed a clustering technique by using voronoi diagram with K-Means algorithm to uncover the hidden pattern in a given dataset, using K-Means and Voronoi diagram based on clustering results in high sturdiness and quality and are capable to recognize the noise. The algorithm performs very well. The algorithm is less user dependent because there are only two user defined parameters for the algorithm.

- N.. S. Patil and P. R. Patil in (2010) [11], proposed studied for query processing, data aggregation, which they are the two most important parts of data communication in sensor networks, and realized how sensor networks is different from other wireless networks in communication. Energy in wireless sensor network is consumed when transmit and receive data, because the wireless sensor networks are energy constrained network, then the process of data aggregation is the most important issue and optimization that is needed. The results of the work shows that when the data sent from the source node, it is send to the sink in a multi-hop fashion via its neighboring nodes. By reducing the power needed to transmit and receive data, if one compare the energy consumption, when using data aggregation. With the case of sending data directly to the sink, can conclude that the consumption of energy with aggregation is lower than the direct transmission case. Then the aggregation of data reduces the amount of data transmission.

- K. Maraiya et al. in (2011)[1], discussed the approaches of data aggregation based on the routing protocols in the wireless sensor network , also the algorithms that used for data aggregation in the wireless sensor network, and they also discussed the advantages and disadvantages of different performance measures of data aggregation in the network.

- S. Nithyakalyaniand and S. S. Kumar, in (2012) [14], proposed an energy efficient data aggregation approach related to the Voronoi based Genetic clustering (VBGC) Algorithm. In the algorithm, an efficient energy is achieved by reducing the transmission of data to the cluster head and from cluster head to the Base station (BS) in each round. The Base Station executes the proposed algorithm periodically to decides which node can be selected as a new Cluster-Heads after a time period. They employed the voronoi diagram in VBGC to determine the sensing range for each sensor node since the overall energy consuming is carefully concerned with both the number and position of cluster-head nodes.

- S.Nithyakalyani1 and S. Suresh Kumar in (2013) [15], proposed novel algorithm which is a combination of modified Fuzzy C-Means clustering algorithm with voronoi diagram. The resulting algorithm is called voronoi fuzzy (VF) algorithm. The selection of Cluster Head (CH) for VF algorithm is depends on some parameters. Furthermore, the process of data aggregation is employed in each cluster's CH in order to reduce the amount of data transitions and this lead effectively to extends the network lifetime. The efficiency of the algorithm was (60%) higher than K-Means algorithm.

- S. Kannadhasan et al. in (2013) [16], proposed a secure data aggregation based on clustering techniques using fuzzy logic. They performs the clustering and cluster head election process in the network. For each cluster they calculate the distance, power consumed and faith value, they based on these parameters to get the secure data aggregation by using fuzzy logic techniques. The cluster heads send the aggregated data from the members to the base stations . They conclude that this work has less energy consumption to prolonging and increase the network lifetime for wireless sensor networks.

- M. Hadjila et al. in (2013) [17], proposed two algorithms. Nodes organized themselves into clusters -in the former- using fuzzy c-means (FCM) algorithm then at each cluster a random node chooses itself as cluster head. Then in the next rounds the node having higher residual energy elected as cluster head. The normal nodes (non-cluster head) transmit their sensed data to its cluster head. The cluster head then performs data aggregation on the received data and directly send the aggregated data to the base station. In the second algorithm, they use the same basics in forming clusters and selecting cluster heads, but in this algorithm the data operates in multi-hop manner when routed from cluster head nodes to the sink node. These schemes show best performance than the schemes of direct transmission to sink in both energy consumption and network lifetime as represented in the simulations results. Moreover, scalability of the proposed two algorithms is also verified over simulation.

- V. Akila, and T. Sheelain (2013) [5], analyzed a data aggregation based on routing protocols for WSNs. They reviewed the routing protocols of structured architecture like cluster-based, tree-based, chain-based and unstructured architecture such as structure-free. They conclude that one of the key techniques to solve the resource-constrained problem in WSN is the data aggregation. A variety of new data aggregation based routing protocols targeted specifically at the wireless sensor networking environment have been proposed. All these protocols are focused on optimizing important performance measures such as network lifetime and energy consumption.

Enhancing the network lifetime and reducing the redundant data in a WSN is an important issues, since redundant data cause congestion, and the congestion can cause huge packet losses; energy waste, and lower throughput. To avoid the previous challenges one can apply data aggregation. The previous researches make the performance of data aggregation control a greater degree of improvement.

1.5 Aim of the Thesis

The main aim of this thesis is to design an efficient aggregation algorithm, many points are considered as a target for this thesis. The main points can be summarized as follows:

- Reduce the amount of redundant data that may be sent from sensor nodes to the cluster head.
- Increasing the network lifetime.
- Solving coverage problem for the sensing field.

In order to achieve these targets, an aggregation algorithm called Voronoi Fuzzy Clustering Algorithm (VFCA), which combined voronoi diagram and Fuzzy C-Means clustering algorithm .The aim of this modified algorithm is to present the role of voronoi diagram in solving the coverage problem in WSN. In addition, decreasing the amount of the dissipation energy from the network, and reducing the congestion in the buffers by decreasing the packet loss parameter in each cluster head node. Also present the role of clustering process for these voronoi cells in the sensing field, that is also decrease the distance of transmitted data. This may lead to decrease the dissipated energy. Then presents the benefit of using both of voronoi diagram and clustering in the modified aggregation algorithm to enhance the network lifetime.

1.6 Thesis Layout

The thesis is organized into five chapters , In addition to the current chapter there are four other chapters and their contents can be summarized as follows:

- **Chapter Two:** General background information of data aggregation in WSNs is given, then voronoi diagram that is used to solve the problem of coverage in wireless sensor network and help in increasing the network lifetime is described.

- **Chapter Three:** presents the proposed aggregation algorithm based on the Fuzzy C-Means clustering and voronoi diagram used to find the aggregated data. This chapter also includes flowcharts that explains how modified algorithm is implemented.
- **Chapter Four:** contains the evaluation of the results obtained from the simulation process, to check the consistency of the modified algorithm to achieve the desired parameters.
- **Chapter Five:** contains the conclusions and some suggestions for future work.

CHAPTER TWO

Theory of Data Aggregation and Voronoi Diagram

Chapter Two

Theory of Data Aggregation and Voronoi Diagram

2.1 Introduction

Data aggregation is a process of combination of data from different sources according to a certain aggregation function, e.g., sum , minimum, maximum and average [2]. In the sensor network, data generated from different sensor nodes may be highly correlated and redundant. As a result, similar packets from multiple nodes can be aggregated instead of transmitting all packets [18]. This chapter provides an outline of the data aggregation in WSNs focusing on the strategies needed for avoiding or mitigating redundant data and increase the network lifetime as well as on the algorithms that is used to control it. Fuzzy c-mean clustering algorithm with voronoi diagram is introduced to provide a control system that are control the data aggregation in WSN.

2.2 Routing Models [19,20]

A single network flow is assumed to be consisting of a single sink node tries to aggregate information from a number of sources. Some of routing schemes use data aggregation (which is called as data-centric), and other schemes which do not use data aggregation (called as address-centric). In both cases assume there are some common elements - the sink first sends out a query or interest for data, the sensor nodes that have the appropriate data then replay with the data. They vary in the way to send the data from the sources to the sink node:

1. **Address-Centric Protocol (AC)**

Based on the route that the queries took, each source node independently sends the sensed data through the shortest path to the sink node (“end-to-end routing”).

2. **Data-Centric Protocol (DC)**

The routing nodes routing the sources sensed data to the sink looking at the content of the data and perform some form of aggregation functions on the data originating at multiple sources.

Figure (2.1) shows the difference between AC and DC schemes. In the address-centric approach, each source node sends its sensed data separately to the sink (source 1 send the data labeled “1” through node A, and source 2 send the data labeled “2” through nodes C and B). In the data centric-approach, the data from the two sources is aggregated at node B, and the aggregated data (labeled “1+2”) then sent from B to the sink node. The latter results in energy savings because it required fewer transmissions to send the sensed data from both sources to the sink node [19].

The combination of data-centric communication with reducing communication costs surely leads to the concept of data aggregation. Data aggregation consist of forwarding a digest of multiple data packets instead of the packets in their entirety. For example, if the aim of the specific data type is to compute the maximum value of a certain measurement in the network, a node can compare all of the readings it receives and forward only the greater value, by this way one can save the energy by reducing the total amount of data transmitted [20].

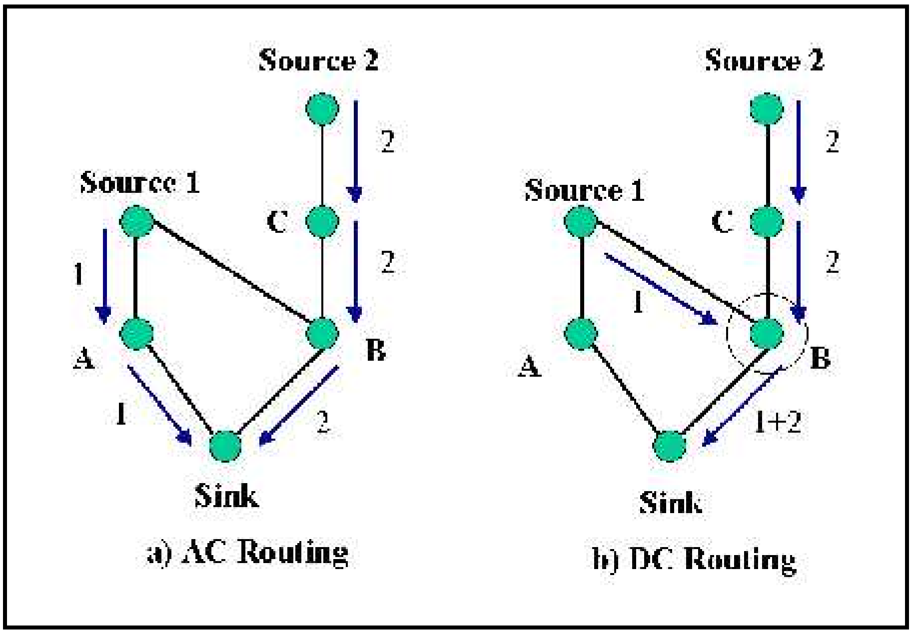


Figure (2.1): Illustration of AC versus DC routing [19]

2.3 Data aggregation in wireless sensor network [21, 22, 23, 24, 25]

Data aggregation tries to collect the most critical data from the sensors and produce it to the sink in an energy efficient manner with minimum data latency. One of the most important issue in many application such as environment monitoring is data latency, another important issue is the freshness of data. It is necessary to develop energy efficient data aggregation algorithms in order to enhance the network lifetime. There are many factors to determine the energy efficiency for a sensor network such as network architecture, the data aggregation mechanism and the underlying routing protocol. These factors are:

Energy Efficiency: The functionality of the sensor network should be extended as long as possible. In an ideal data aggregation scheme, each sensor should have consumed the same amount of energy in each round of data gathering. If the data aggregation scheme enhance the lifetime of the network, it is considered as energy efficient scheme. If one assumes that all sensors are equally important(homogeneous), then it minimize the energy consumption of each sensor node. This idea is captured by the network lifetime which quantifies the energy efficiency of the network.

Network lifetime: Network lifetime can be defined as the number of data aggregation rounds till some of sensors die, where the number of sensors is specified by the designer. In applications that the time of all nodes operate together is vital, lifetime can be defined as the number of rounds until the first sensor is drained of its energy.

Data accuracy: The data accuracy definition depends on the application for which the sensor network is designed. For instance, the estimation of target location at the sink determines the data accuracy in a target localization problem.

Latency: Latency is defined as the delay engaged in data transmission, routing and data aggregation. Latency can be measured as the time delay between the data packets received at the sink node and the data generated at the source nodes.

The design of efficient data aggregation algorithms is an inherently challenging task [21].

A Sensor Network (SN) that consists of **n** sensor nodes deployed over an area **R**. Each sensor node **s** is equipped with different types of sensory devices. In general, the sensor nodes are not of the same type. Then they are monitoring different types of data values depending on their task in the network. Each sensor in the node **s** continuously samples a value **v** measuring the phenomenon being monitored (e.g., a temperature sensor samples the temperature degree at the location of the sensor node) [22].

The large sensor networks are energy constrained networks therefore it is inefficient for sensors to transmit the data directly to the sink. In such scenarios, sensors can transmit the data to a local aggregator or to cluster head that aggregates data from all its members and transmits the aggregated packet to the sink node. This process leads to saving the energy of the energy constrained sensors. Figure (2.2) shows the organization of a cluster based sensor network. The communication between cluster heads and sink node can be either directly via long range transmissions or multi hopping through other cluster heads [21].

There are some important terms in Figure (2.2) these terms are:

Sensor Node: sensor node represents the basic component of wireless sensor network. It has the ability of sensing, processing, routing, etc.

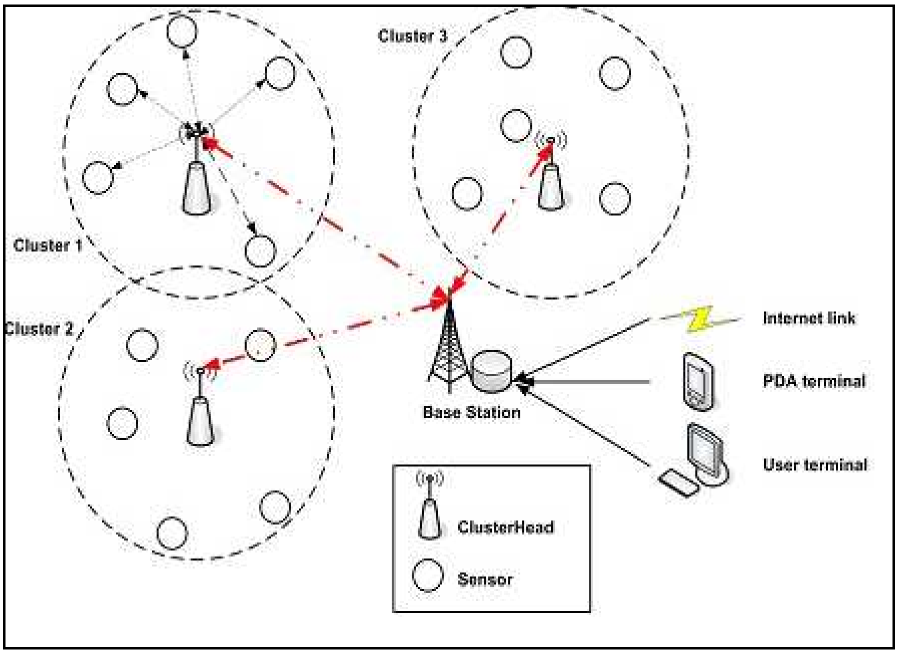


Figure (2.2): Clustered Sensor Network [23]

Cluster Head: The Cluster Head (CH) is considered as a leader for its cluster. The CH is responsible for data aggregation, scheduling in the cluster, data transmission to base station, and other different activities carried out in the cluster.

Base Station: Base station is the main node to aggregate data for the entire sensor network. It considers as a bridge (via communication link) between the sensor network and the end user. Normally the base station node is considered as a node with no power constraints.

Cluster: It represents the organizational unit of the network, created to simplify the communication in the sensor network [23].

Data aggregation is an effective technique that saving the energy of WSNs, data aggregation can be defined as the process of aggregating the data from multiple nodes to eliminate redundant transmission and provide fused data to the BS. Clustering data is the most popular data aggregation method, in which each CH received data from its members, aggregates the received data and transmits the aggregated data to the BS [24].

In clustering, the sensor nodes are divided into different clusters. Each cluster is managed by a node known as cluster head (CH) and other nodes are known as cluster members. Cluster members do not communicate directly with the sink node. They have to forward its collected data to the cluster head. Cluster head then aggregate the collected data, which received from cluster members and transmits it to the base station. This process minimizes the energy consumption and reduced the number of messages communicated to base station. And the number of active nodes in communication is reduced also. Extreme result of clustering process for the sensor nodes is prolonged the lifetime of the network.

Data aggregation helps to reduce the transmission of data and also save energy in clustering routing scheme. Furthermore, clustering with intra-cluster and inter-cluster communications can reduce the number of sensor nodes performing the transmissions for long distance communications, thus allowing fewer energy consumption for the entire network. In addition, only the CH nodes perform the data transmission task in clustering routing scheme, which can save a lots of energy consumption [24].

Some of cluster-based algorithms have been developed on hierarchical structures. There are many advantages for clustering in theory in addition to the network scalability support. Also, it minimize the size of routing table that stored at the individual nodes, and this may allow to safe the bandwidth of the communication because it limits the cluster interactions scope to the head of clusters [25].

2.3.1 Data Aggregation in Cluster Based Networks [26, 27]

Different protocols are being produced for the clustering the sensor networks like Direct Communication (DC), Minimal Transmission Energy (MTE), Low-Energy Adaptive Clustering Hierarchy (LEACH), K-Means, and Fuzzy C- Means. In DC, the sensor nodes that are located far away from the base station get depleted with its energy at a quicker rate, whereas in MTE, the nodes that are located near to the base station get depleted. In LEACH, the election of cluster head nodes is based on predetermined probability; the other nodes choose the cluster by finding the nearest distance to the cluster heads elected. However, there is a randomized election of cluster heads, where some of the clusters are devoid of cluster heads, resulting in poor clustering. In K-Means clustering, which is known as hard clustering, the nodes near to the boundary region are affected since the degree of belongingness is described either in terms of zero or one, the edge nodes may have the same degree of belongingness to more than one clusters, resulting in poor cluster formation [26].

There is an optimal cluster formation in the Fuzzy C-Means algorithm, which is an unsupervised, nondeterministic iterative method. The sensor nodes are assigned to a cluster, depending on the degree of belongingness to different cluster in the deployed area, but the degree of belongingness needs to be computed for every sensor node in every round [26].

Some methodologies used in data clustering are numerical or analytical, and the fuzzy clustering method is the most intelligent methodology. The most common, efficient, and reliable fuzzy clustering method is the Fuzzy C-Mean “FCM” algorithm [27].

Description of some of these clustering algorithms are explained below:

2.3.1.1 Low-Energy Adaptive Clustering Hierarchy (LEACH) [28]

LEACH protocol is the first clustering protocol. It provides an ideation of rounds. LEACH protocol runs in many rounds. Each round consists of two phases: cluster setup phase and steady state phase. In cluster setup phase, it constitutes a cluster in self-adaptive mode; in steady state phase, it transfers data. The time taken by the second phase is usually longer than the time of first phase for saving the protocol payload [28].

2.3.1.2 Fuzzy C-Means Clustering (FCM) [26, 29, 17]

The FCM’s is a soft clustering algorithm, it calculates the degree of belongingness in the range between [0, 1]. The sensor nodes calculate the degree of belongingness using Euclidean distance between the sensor node and the cluster head node. The objective function of used FCM is to reduce the distance between the sensor nodes to the cluster head nodes and the inter cluster distance. The FCM’s goal is to reduce the objective function. Euclidean distance is used to calculate the distance between the sensor node and the cluster head node as shown in Eq. (2.1) [26].

$$d(x_i,y_j)=\Sigma\ [(x_i - y_j)^2]^{1/2} \qquad \dots (2.1)$$

where:

x_i: is the sensor node, i= 1,…,n.

y_i: is the cluster head, j= 1,…,c.

$d(x_i,y_j)$: the distance between sensor node to different clusters.

The Fuzzy C-Means algorithm is divided into three phases:

i. Clustering Calculation

The standard FCM's algorithm is used to cluster the sensor nodes. The sensor nodes at the beginning send HELLO packets to the base station containing its GPS location, and then the degree of belongingness is assigned for each node in which each node is assigned a degree of belonging to a CH rather than being a member of just one cluster. Therefore, the node with the least degree of belongingness is assigned to that special cluster.

ii. Cluster Head Selection

After the cluster head is elected, other sensor nodes send its sensed data to the base station, via its cluster head. There are many clustering approaches, these approaches are :

(1) Deterministic approach: the process of election of cluster head is either depends on the ID of the node, or depending on the number of neighbors.

(2) Adaptive approach: the process of election of cluster head done according to high weights of power or cost of communication.

(3) Random approach: select random nodes to become a cluster head nodes for the first iteration.

Only the initial decision of cluster head election is done by the base station, but the election of the cluster head in the other rounds is done by the existing cluster head.

iii. Data Aggregation and Transmission

After the election of cluster head, the sensor nodes begin to transmit the sensed data to their cluster head. The power of transmission is optimized because its achieved minimum spatial distance to the cluster head. Then TDMA scheduling protocol is used, as such the sensor nodes need to turn on their radio component during its transmission and for the rest of the time it's in off state. Data aggregation is done at the cluster head nodes, amount of data is reduced, and the CH send the aggregated data to the base station [26].

The algorithm is as follows:

1. divide a set of n objects o = $\{o_1, o_2, ..., o_n\}$in Rd dimensional area into c (1 < c < n) fuzzy clusters
2. Calculate Z = $\{z_1, z_2, ..., z_c\}$ cluster centers.
3. The fuzzy clustering of objects is described by a fuzzy matrix μ. μ_{ij} represents the element in the ith row and jth column in μ , indicates the degree of association or membership function of the ith object with the jth cluster.
4. The characteristics of μ are represented in the following equations [29]:

$$«_{ij} \in [0,1], \forall i = 1,2,..., n, \; j = 1,2,..., c \qquad \text{… (2.2)}$$

$$0 < \sum_{j=1}^{c} «_{ij} < n \qquad \forall j = 1,2,..., c \qquad \text{… (2.3)}$$

The objective function (J_m) of FCM algorithm is to minimize Eq. (2.4) [29]:

$$J_m = \sum_{j=1}^{c} «ij_{dij}^{m} \qquad \text{… (2.4)}$$

Where μ_{ij} is a degree of association of the ith node to the jth cluster. d_{ij} is the Euclidean distance between node i and the center of cluster j., where:

$$dij = \left\| o_i - z_j \right\| \quad \text{… (2.5)}$$

Where:

o_i: is the node i, i=1,…,n.

Z_j: is the cluster j, j=1,…,c.

Where, m (m>1) is a scalar, termed the weighting exponent and controls the fuzziness of the resulting clusters and d_{ij} is the Euclidian distance from object o_i to the cluster center z_j . The z_j , centroid of the jth cluster, is calculated using Eq.(2.6) [29].

$$z_j = \frac{\sum_{i=1}^{n} \mu_{ij}^{m} o_i}{\sum_{i=1}^{n} \mu_{ij}^{m}} \quad \text{… (2.6)}$$

The degree μ_{ij} of node i respected to cluster is computed and fuzzified with the real parameter m>1 as in Eq.(2.7) [29]:

$$\mu_{ij} = \frac{1}{\sum_{k=1}^{c} \left(\frac{d_{ij}}{d_{kj}}\right)^{2/(m-1)}} \quad \text{… (2.7)}$$

The FCM algorithm is iterative and can be clarify as follows:

1- Select m (m >1), initialize the membership function values μ_{ij} , i = 1,2,..., n , j = 1,2,..., c.

2- Calculate the cluster centers z_j , j = 1,2,..., c, according to (2.6).

3- Calculate the Euclidian distance d_{ij} , i =1,2,..., n ; j = 1,2,..., c

4- Update the membership function μ_{ij} , i = 1,2,..., n ; j= 1,2,..., c according to (2.7).

5- If not converged, go to step 2 [17].

2.3.1.3 K-Means Clustering Algorithm [23]

K-MEANS is unsupervised clustering algorithm which is the simplest algorithm used for clustering. This algorithm divide the data set into k clusters using the cluster mean value so that the resulting clusters have high intra cluster similarity and low inter cluster similarity. K-Means is iterative in nature. Figure (2.3) illustrates the original K-MEANS algorithm. The following steps represent the follow of the algorithm:

1. Generate ***k*** points (cluster centers) arbitrarily, ***k*** represents the number of clusters.
2. Compute the distance between each of the data points and each of the centers, and assign each point to the nearest center.
3. Compute the new cluster center by calculating the mean value of all data points in the particular cluster.
4. With the new centers, repeat step 2. If the assignment of cluster for the data points changes, repeat step 3 else stop the process.

The distance between the data points is computed using Euclidean distance as follows: the Euclidean distance between two points which are:

$X_1 = (x_{11}\ x_{12}, \ldots, x_{1n})$, $X_2 = (x_{21}, x_{22}, \ldots , x_{2n})$ [23].

$$\mathrm{Dist}(X_1,X_2) = \sqrt{\sum_{i=1}^{n} (x_{1i} - x_{2i})^2} \qquad \ldots (2.8)$$

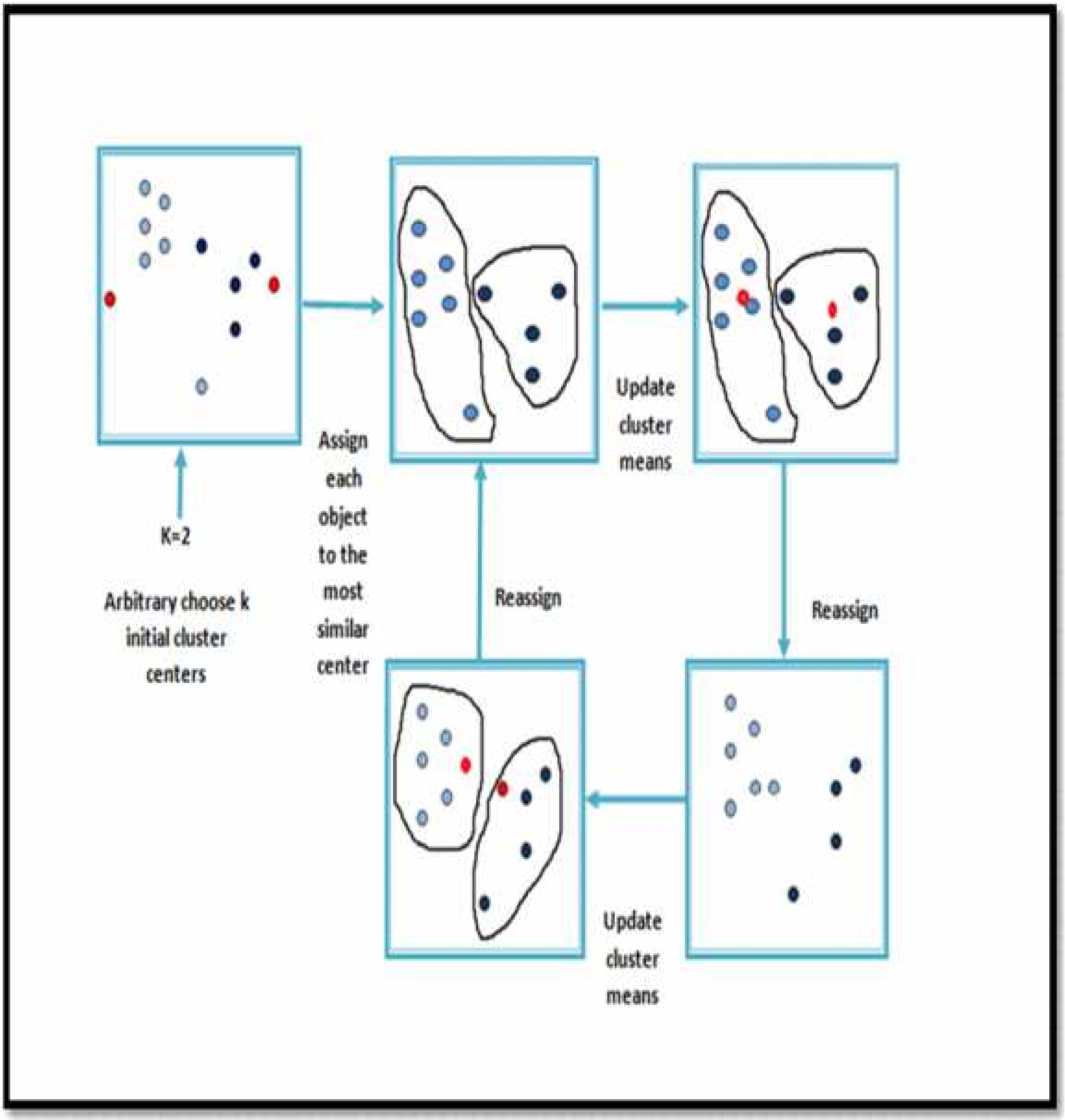


Figure (2.3): Original K-MEANS Clustering Algorithm [23].

Figure (2.4) shows the flowchart of K-Means clustering algorithm.

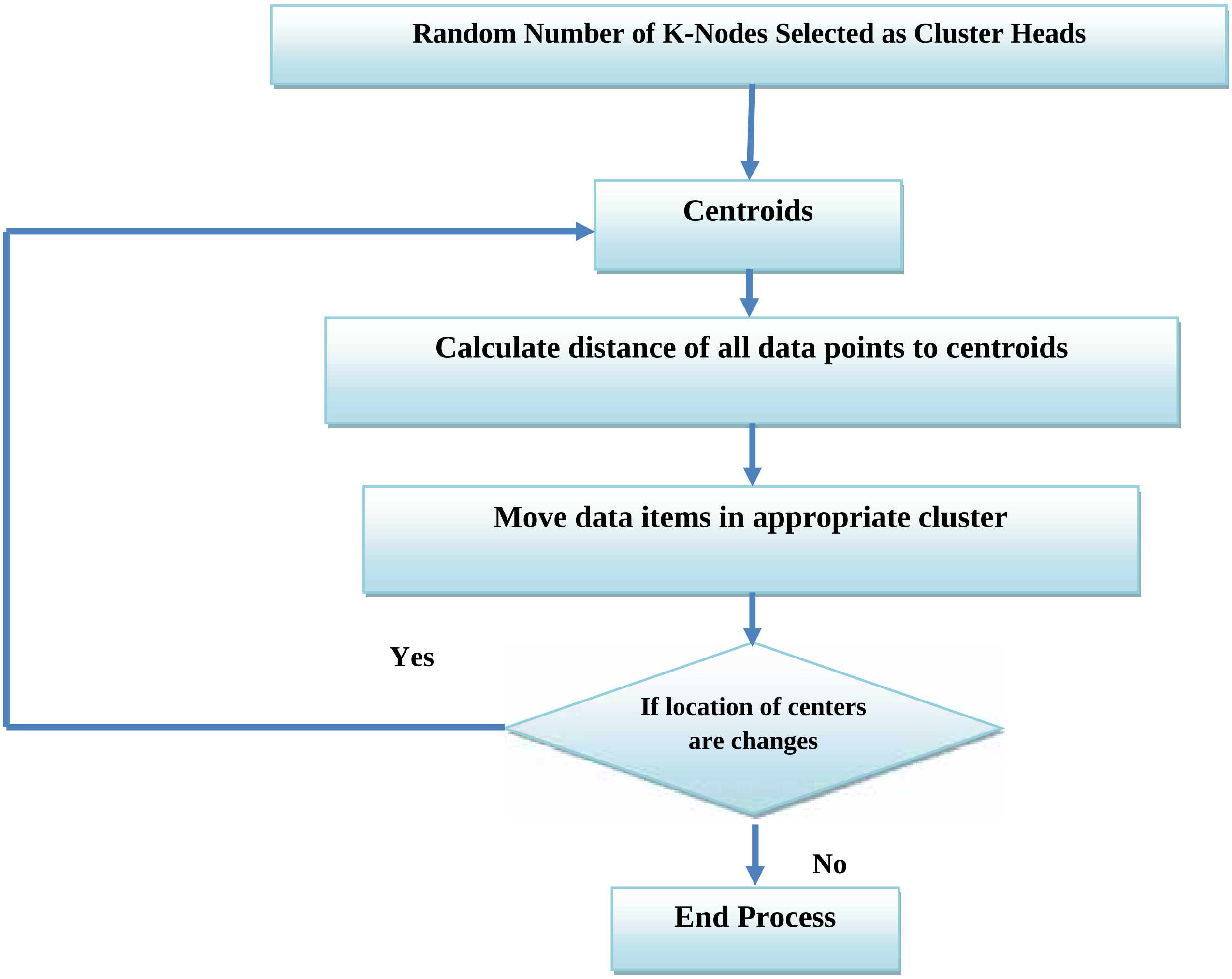


Figure (2.4): K-Mean Clustering Process [23]

2.3.2 Advantages of Clustering [23]

There are several advantages for the process of clustering of nodes in a WSN, some of them are listed below:

- Transmit aggregated data to the sink node.
- Reducing the number of nodes that transmits their data through the network.
- Efficient Energy consumption.
- Scalability in the case of large number of nodes.
- Reduces the overhead that results from communication.
- Efficient use of resources in WSNs.

2.4 Coverage in wireless sensor network [30, 31, 32]

The area-coverage initially provided by the sensor network cannot be guaranteed to be optimal when the sensors are randomly deployed, as in the deterministic deployment [30]. Different applications would require different degrees of coverage in the sensing field .There are several factors that must be considered when developing a plan for coverage in a sensor networks. Many of these will be dependent upon the particular application that is being addressed. The capabilities of the sensor nodes that are being used must also be considered. The different types of coverage are:

1. **Blanket/Area coverage**: the main objective of the sensor network in area coverage is to cover (monitor) a region, and each point of the region need to be monitored.

2. Point Coverage: The point coverage scheme focuses on determining sensor nodes' exact positions, which guarantee efficient coverage application for a limited number of immobile points (targets).

3. Target coverage: Considered as number of targets with known location that needs to be continuously observed (covered) and a large number of sensors closely deployed to the target.

4. **Barrier coverage**: Barrier coverage refers to the detection of movement across a barrier of sensors. This is useful in applications where the major goal is to detect intruders as they cross a border or as they penetrate to a protected area.[31]

Applications of wireless sensor networks request from sensors to sense, process, and transmit data from different areas of the sensing field. For example, a user might request temperature data of a given region or might like to know the position of a strange object in the sensing field. All such applications require sensors to provide information about their vicinity. The

Voronoi diagram (VD) allows sensors to spread the sensing task by dividing the space in a meaningful way, then it can help in solving coverage problem in WSNs. The Voronoi cell of a sensor ***s*** is a part of the plane in which all points are closer to ***s*** than to any other sensors [32].

2.5 Voronoi Diagram [14, 22,30, 33, 34]

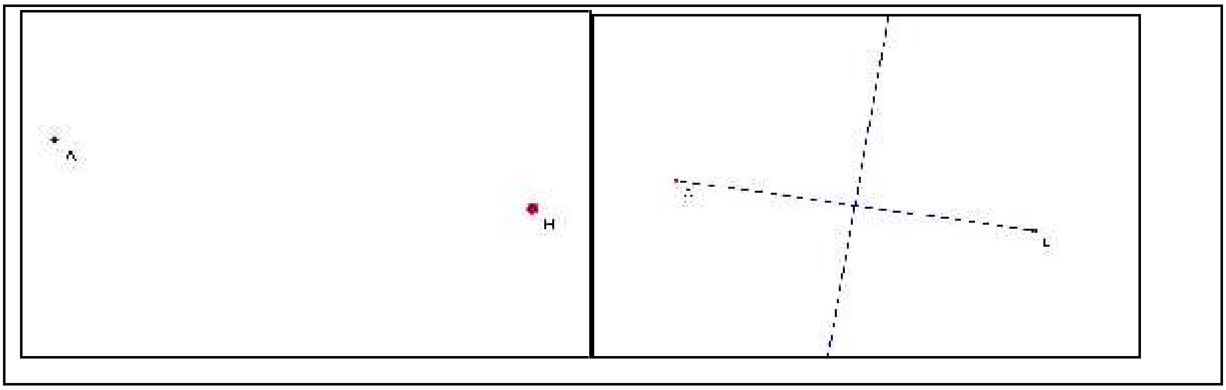
Computational geometry is always used to get optimization in WSN coverage; Voronoi diagram and Delaunay triangulation are the most commonly used computational geometry approaches. Voronoi diagram is a division of cells in a meaningful way that points inside a voronoi cell are closer to that voronoi cell than any other cells thus one of the vertices of the cell is the farthest point of the cell to the site inside it. Therefore Voronoi diagram can be used as one of the sampling method in determining WSN coverage, where sensors act as the sites. The field is fully covered if and only if all Voronoi polygons vertices are covered otherwise coverage holes exist [14].

Assume there is a set of N nodes distributed in an area without any constraints, the Voronoi diagram will partition the entire area into N subareas, and each subarea has a single node inside it. The characteristic of Voronoi diagram is that each subarea is represents the area closest to the node inside it, as opposed to the other nodes. The generation of the Voronoi diagram needs information about the location of all sensor nodes. Voronoi diagrams are very useful in solving the coverage problem of wireless sensor networks. The entire sensing field can be covered if each sensor node can cover its own Voronoi subarea. Voronoi diagrams are used for calculating whether there are any uncovered areas. [30].

In the context of sensor networks, a sensor's Voronoi cell represented by the area closer to that sensor than to any other sensor. This area has many natural interpretations in sensor networks, for example, it might be the area where that sensor has the most reliable or representative readings. However, while the computation of Voronoi cells is a norm problem in computational geometry, it is much less understood in the distributed setting of sensor networks. A sensor network usually is composed of a great number of small battery-powered systems or motes distributed over a wide area, communicating over low-powered, short range radios. These motes are often aware about their own locations, either by using GPS or through an array of inference techniques. They can perform different of measurements in their environment. Actually, Supporters of sensor networks have proposed networks of thousands or hundreds of thousands of sensor nodes communicating and working together. However, the maximum scale involved, combined with the low bandwidth between sensors and node/link failures, result in many challenges.

In particular, protocols for sensor networks must capable to tolerate failures while being completely parsimonious in their communication. Sensor network applications typically want to learn about the environment being sensed, not about the sensors or systems themselves, whether gathering individual measurements or calculating averages or other functions. For example, consider a query for the average temperature from an area where sensors are distributed randomly. As pointed, the average through an area is not the same as the average through the sensors, and in practice, these two quantities can be completely different. A simple average of all the sensor readings, for example, will be biased towards the areas that have more sensors. Instead, a more accurate approximation to the average temperature over the region could be got by weighting each sensor’s reading proportional to the area which is nearest to that sensor. These regions averaged are in fact the Voronoi cells of each individual sensor. Thus Voronoi cells give a real weighting scheme for such applications [33]. The use of Voronoi diagram which is sometimes referred to as Thiesson polygons is based on Tobler’s first law of geography. The law says: "Everything is related to everything else, but nearby things are more related than distant things". This fact implies spatial autocorrelation for the observations in a geographic space. This means that there is a relation between the values sensed at the neighboring locations. In this method one assigns the value of the closest location to the location with an unknown value in the observation set. Therefore, there is always a unique value interpolated for each location. In other words, the space is divided with n sensor nodes (i.e., observation points) into n convex polygons (Voronoi cells) such that each polygon contains only one sensor node and every other location in a given polygon is closer to its corresponding sensor node than to any other node. The value of each location is interpolated to the value at its closest sensor node [22].

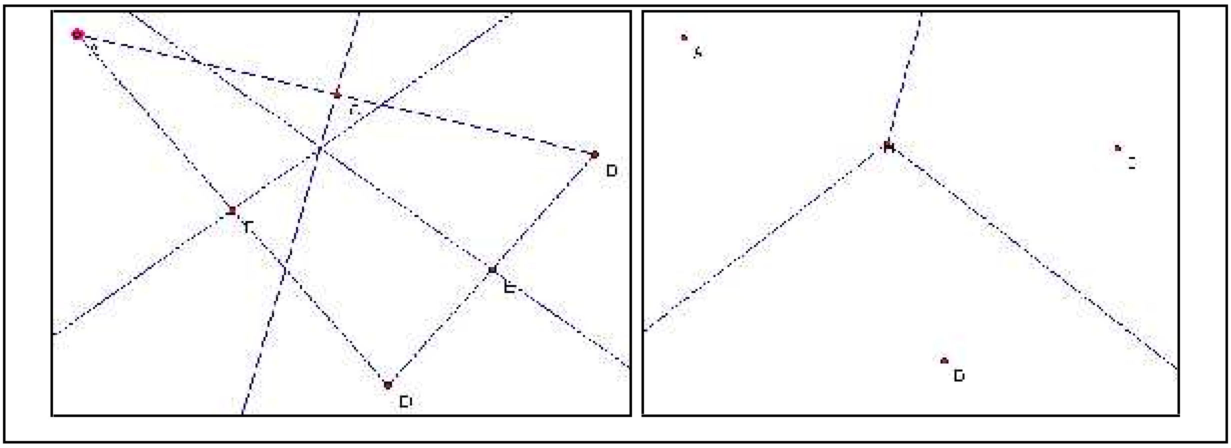
A simple geometric construction algorithm: The construction of a Voronoi diagram depends on the perpendicular bisectors. When the system contains two sites only it is a very easy to construct a Voronoi diagram, the perpendicular bisector of the segment that joining two sites is all the necessary thing to do as in Figure (2.5)a and b.



a b

Figure (2.5): Build a Voronoi Diagram for Two Sites [34]

To construct a Voronoi diagram for three sites (points A, B, D in Figure (2.6) a) firstly should construct a triangle with vertices at the three sites. From here one must rely on the fact that the perpendicular bisectors of the three sides of a triangle meet at a single point. All this illustrated in Figure (2.6) a and b. To complete the diagram one should simply remove the superfluous rays, line segments, and points which used in the construction Figure (2.6) b.

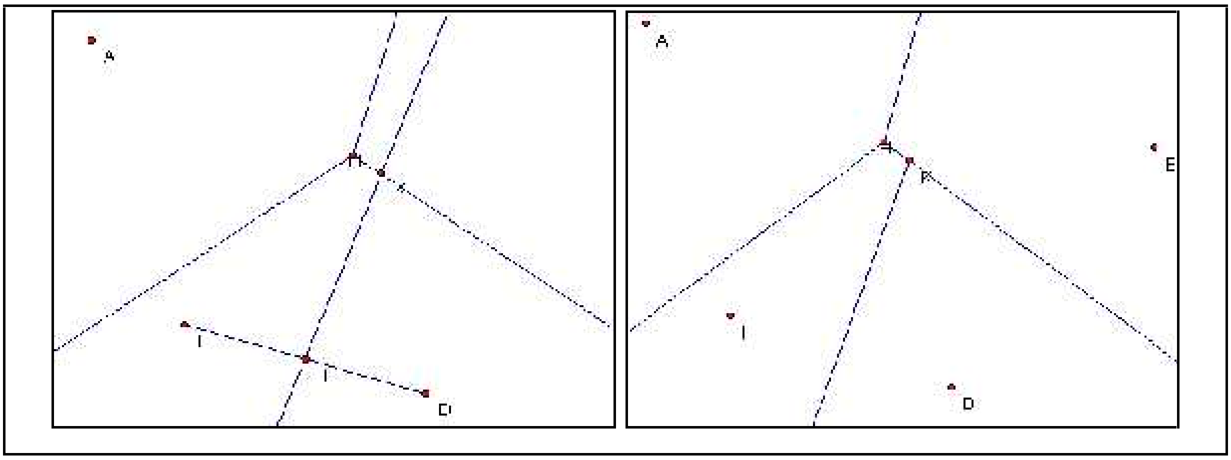


a b

Figure (2.6): Build a Voronoi Diagram for Three Sites [34]

Things become more complicated when have four sites. One should begin with the existing diagram of three sites, then add another site (point I in Figure (2.7) a, and adjust the diagram accordingly. To do this one must generates perpendicular bisectors between I and each previously existing site. These bisectors allow determining which parts of the diagram need to be modified.

Begin by constructing the perpendicular bisector between I and D in Figure (2.7) a. From this, one can see that everything to the left of the line KJ belongs to I's cell. Then modified the diagram accordingly and remove the unnecessary parts as in Figure (2.7) b.



a b

Figure (2.7): Build a Voronoi Diagram for Four Sites [34]

This approach is suitable for any number of sites. From the four sites system in Figure (2.7) the voronoi diagram can be constructed a five site system by adding a site and considering which boundaries need to be adjusted for each new pair of sites. Continuing in this manner one can build the system as wish [34].

2.5.1 Structure of a Voronoi diagram [35, 36, 37]

The Voronoi diagram consist of three elements**: generators, edges, and vertices.** As shown in Figure (2.8).

P is the set of generators**,** an edge (e) between the Voronoi regions V_i and V_j is $V_i \bigcap V_j = e(p_i, p_j)$.

If e $(p_i,p_j) \neq 0$, V_i and V_j are considered adjacent. Any point $\vec{x}$ on (p_i, p_j) has the property that:

$$\left\| x - \vec{x_i} \right\| = \left\| x - x_j \right\|$$

A vertex is a point that located at location that is equidistant from the three (or more) nearest generator points on the plane. Vertices are denoted qi, and are the endpoints of edges [35].

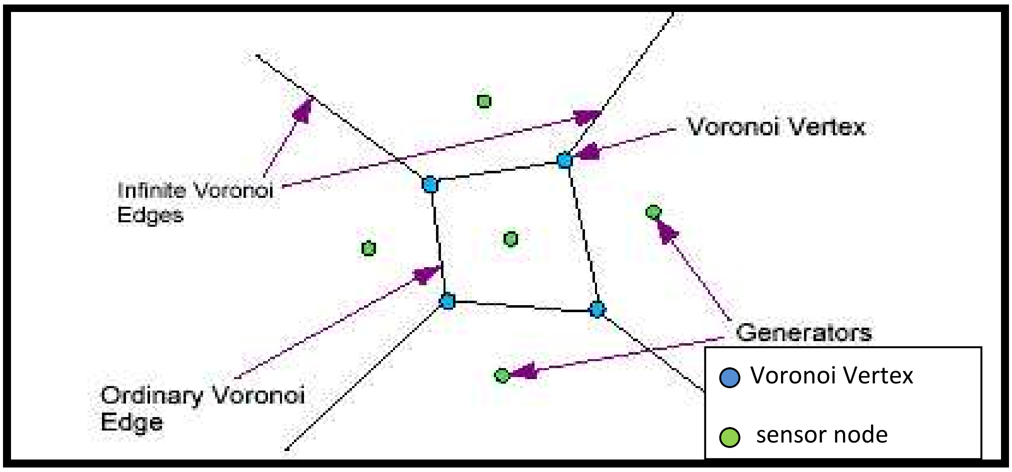


Fig (2.8): Voronoi Diagram [36]

- A region that corresponds to a generator p_i is called its Voronoi region and is denoted as $R(p_i)$.
- A common boundary of two Voronoi regions is called a Voronoi edge.
- A point at which the boundaries of three or more Voronoi regions meet is called a Voronoi vertex [36].

The Voronoi region V (p_i) for each p_i is explained as in Eq. (2.9):

$$V(p_i) = \{x: |p_i - x| \le |p_j - x|, \ \forall j \neq i\} \quad \ldots (2.9)$$

V (p_i) consists of all points that are closer to p_i than any other site. The set of all sites form the Voronoi Diagram V(S) [37].

2.5.2 Properties of Voronoi Diagram

- A Voronoi edge between two Voronoi regions R (p_i) and R (p_j) is a part of the perpendicular bisector of the line segment connecting the two generators p_i and p_j.
- A Voronoi vertex is the center of the circle that passes through the three generators, whose regions are incident to the vertex, i.e., it is the circum center of the triangle with those generators as the vertices.

- A Voronoi region R (p_i) is a convex (possibly unbounded) polygon containing the corresponding generator p_i [36].

2.5.3 Distributed Calculation of the Voronoi Cell

It is hard to construct the Voronoi diagrams. However, to detect and compute the coverage hole, each sensor needs only to know its own Voronoi cell, whose computation can be simplified as follows: take sensor s_0 as an example. Initially, as shown in Figure (2.9) a, the Voronoi cell of s_0 is set to be a large rectangle. After receiving the hello message from sensor s_1, s_0 knows the location of s_1 and fined the bisector line of s_1 and itself. This line is added to the original graph and two cells are generated. Shown in Figure (2.9) b, the cell including s_0 becomes the new view of s_0's Voronoi cell.

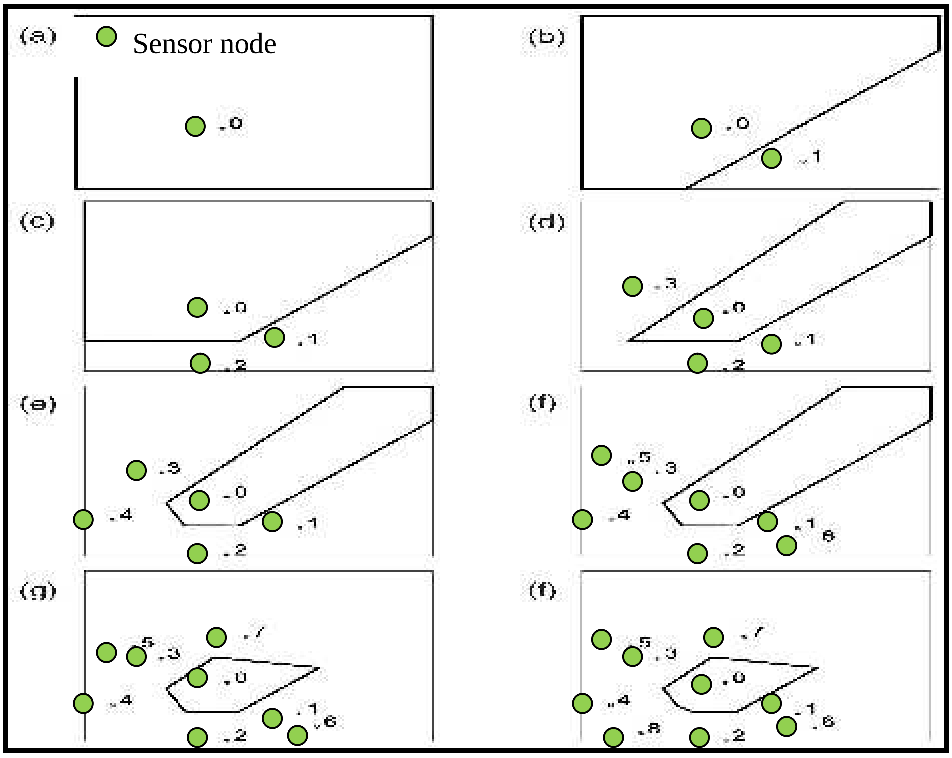


Figure (2.9): An example of a Voronoi Diagram [38]

Later, after s_0 receives the hello messages from s_2, s_3, and s_4, its Voronoi cell changes from Figure (2.9)c to Figure (2.9) e accordingly. The Voronoi cell will not change if the calculated bisector line has no intersection with it. As shown in Figure (2.9) f, knowing s_5 and s_6 does not affect s_0's Voronoi cell. Finally, the true Voronoi cell is generated after s_0 knows the existence of s_7 and s_8 [38].

2.6 Advantages of Voronoi Diagram

The using Voronoi diagram has an advantage over other geometrical structures, for instance the grid, these advantages are as follows:

1. Its computational complexity can be controlled only by one parameter. This parameter is represented by the number of sensors in the network.
2. Its solidity.
3. Its speed,
4. The simplicity in its concept as well as application.

The building of Voronoi Diagram is simple and the voronoi diagram is one of the stable geometrical structures [36].

CHAPTER THREE

Modeling of Modified Voronoi Fuzzy Clustering Algorithm (VFCA)

Chapter Three

Modeling of modified Voronoi Fuzzy Clustering Algorithm (VFCA)

3.1 Introduction

In this chapter, the modified algorithm that combined the voronoi diagram and FCM clustering algorithm which is called the Voronoi Fuzzy Clustering Algorithm (VFCA) is implemented to enhance the data aggregation and to reduce the amount of data transmission which is effectively expand the network life time. System modeling and simulation are done using MATLAB version 7.11.0.584 (R2010).

3.2 The Network Model

In this section consider a Wireless Sensor Network consists of **N** sensor nodes distributed randomly and stationary over the coverage area with one sink node. Some properties of this model are as follows:

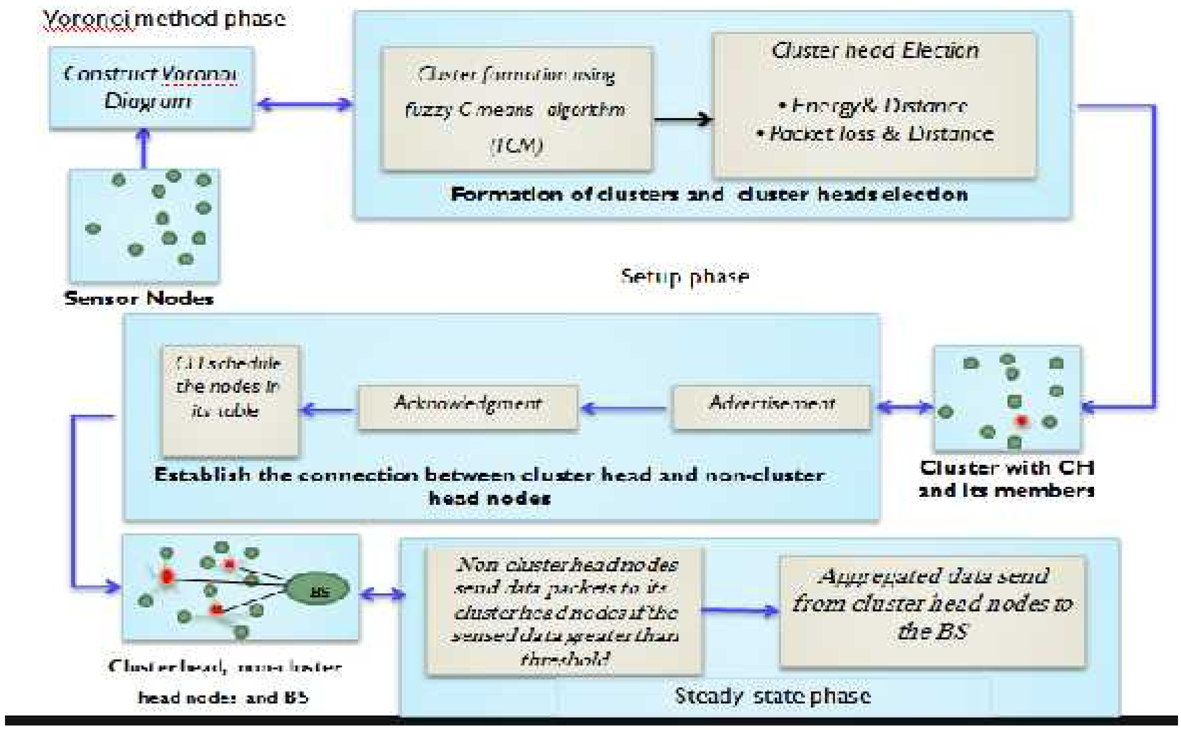
- The sensor nodes in the network are stationary and do not have mobility.
- Sensor nodes have the same characteristics (homogenous), and allocated with equal initial energy.
- The communication is over a wireless links. Wireless links are considered bidirectional and symmetric so any two nodes in range of each other can communicate using the same transmission power levels.
- Single sink node is presented in the network. Data sensed from the sensor nodes can be forwarded to its cluster heads and then the cluster head perform data aggregation on the received data from its members

and send the aggregated data to the sink node. Sink node is responsible for gathering data and forwarding them to the outer world, e.g. the Internet.

- Sensor nodes and cluster head nodes communicate via single hop wireless links, but cluster head nodes communicate with the sink either via single hop or via multi-hop wireless links. When an event occurs, sensor nodes send their sensed data (e.g. temperature) to its cluster head, the cluster head aggregate these data by taking (e.g. maximum) from all received data then each cluster head send the maximum value to sink node, by this process one can reduce the redundant data that can be transmit to sink node and also reduce the congestion that may be occurred to the buffer of sink node.

3.3 The Modified Voronoi Fuzzy Clustering Algorithm(VFCA)

The main purpose of the Voronoi Fuzzy Clustering Algorithm(VFCA) is to increase the network lifetime. The simulation is implemented as a number of rounds. Sensors are placed to detect an event occurring in the sensing area the sensed data need to be transmitted to the sink node for acquiring knowledge. However a lot of energy is spent in transmitting sensed data. Henceforth to overcome from the spending of energy and increase the network life time, data aggregation and modified Voronoi Fuzzy Clustering Algorithm are proposed. Initially voronoi method is applied to partition sensor network locations into voronoi cells, each cell represent a cluster to many point in its area but the sensor node represent all these points. Then clustering process is starting. Finally data transmission and aggregation is implemented. The modified VFCA is shown in Figure (3.1).



Figure(3.1):Modified Voronoi Fuzzy Clustering Algorithm

Setup phase in Figure (3.1) contains two steps the first step is a cluster formation, and the second step is a cluster head election, the cluster formation is done by applying FCM clustering algorithm, the cluster head election process based on different parameters. In this work two parameters (distance and energy of each node) are considered as a first case and (distance and packet loss for each node) as a second case.

3.3.1Modified VFCA based on distance and energy

The modified VFCA is built for clustering and aggregating the data. With distance and energy as a parameters to select the cluster heads. The VFCA consists of three phases these phases are :

A. The Voronoi Method phase

In the modified algorithm, all nodes are assumed to be stationary and any sensor node position can get by **x** and **y** coordinates. That is for any sensor node $\mathbf{p_i = s = (x_i,y_i)}$ (where $\mathbf{p_i}$ is the position of sensor **s**) the distance function to compute voronoi diagram is given by Eq. (3.1) [15]:

$$d = \sqrt{(x_s - x_r)^2 + (y_s - y_r)^2} \qquad \ldots(3.1)$$

Where**, r** is a set of all neighboring nodes.

At the beginning, the network has a number of points in the plane (sensor nodes), these points are known as sites. The network in the voronoi method phase will partitioning the plane into disjoint regions called cells, each cell contains exactly one site, so all the points within a cell are closer to that cell's site than to any other site. If $\mathbf{P = \{ p_1,p_2, \ldots, p_n \}}$ is a set of distinct points (sites) in the plane. Voronoi diagram divide the plane into **n** voronoi cells, so that each cell has exactly one site. An arbitrary point **(x,y)** is in a cell returns to a site $\mathbf{p_i}$with a location$\mathbf{(x_{pi} , y_{pi})}$ if and only if ,the Euclidean distance from **(x,y)** to any other site is greater than the distance from **(x,y)** to $\mathbf{p_i}$, for all $\mathbf{p_j}$with $\mathbf{j \neq i, 1 \leq i,j \leq n.}$ [33].

$$(d = \sqrt{(x - X_{pi})^2 + (y - Y_{pi})^2}) < (d = \sqrt{(x - X_{pj})^2 + (y - Y_{pj})^2}) \qquad \ldots(3.2)$$

The voronoi region of p_i is $V(p_i)$ may also be referred to as V_i. All Voronoi regions in an ordinary Voronoi are connected and convex. One can call as a set given by: $V = \{V (p_1), V (p_2), \ldots , V (p_n)\}$. The boundaries of the each cell will be composed of straight lines and segments forming convex polygons and will be defined by the perpendicular bisectors of segments that joining each pair of sites. It is unnecessary to calculate the distance to each site to determine which site is closest to a particular point with a Voronoi diagram. The voronoi cell of any sit contains the point will always be closest to this sit.

The modified VFCA based on distance and energy is implemented by matlab. Graphical User Interface (GUI) facilities are used in the implementation. At the beginning, input the number of nodes in the network (for example 100 sensor nodes). Then voronoi diagram is applied for these nodes, to cover all the sensed area. Then number of clusters are selected to divide these voronoi cells by applying FCM clustering algorithms as shown in Figure (3.2).

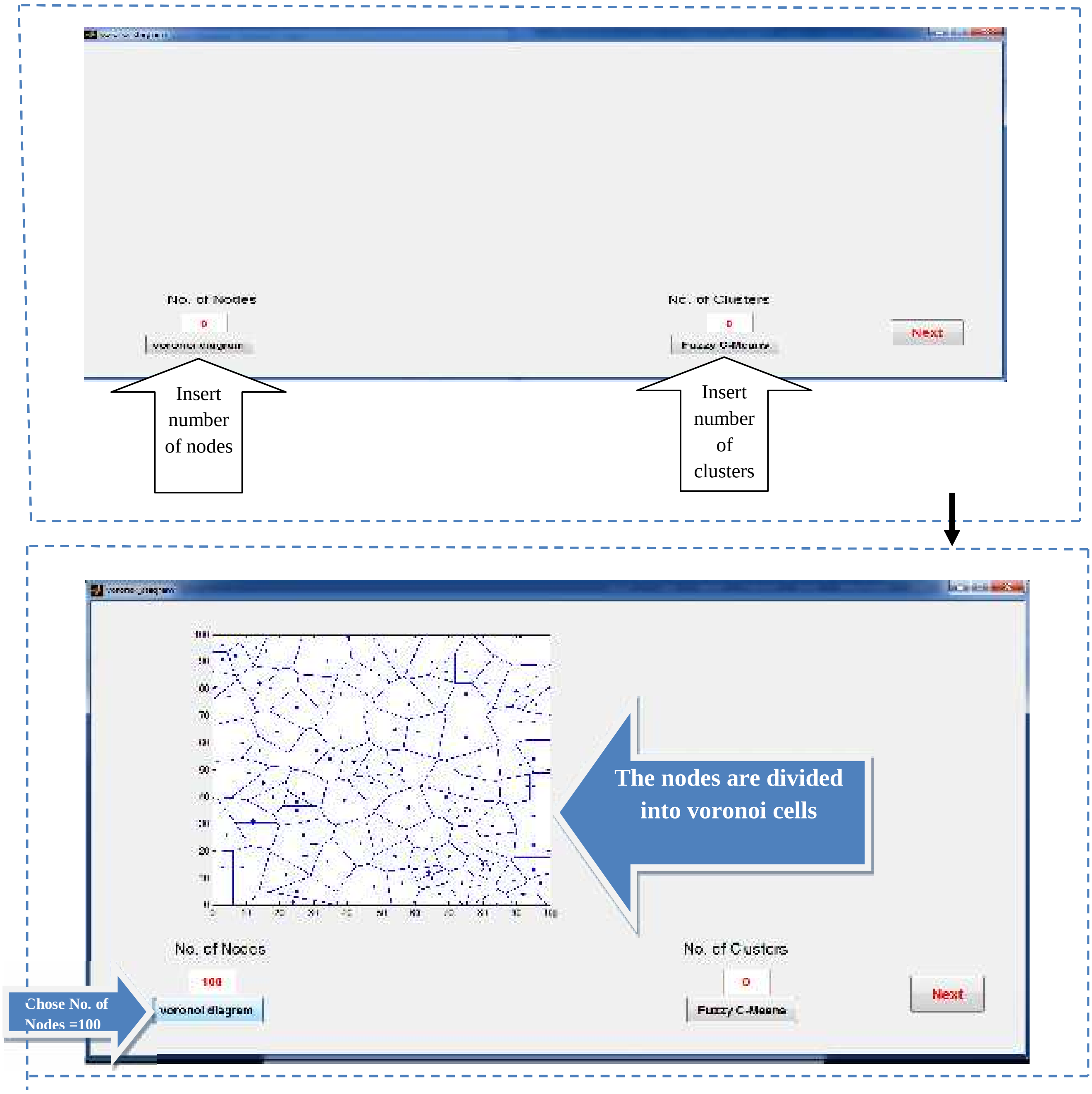


Figure (3.2):The Network after First Voronoi Method Phase

A Voronoi diagram is a method of decomposing an area. If there is a set of N nodes distributed in an area without any constraints, the Voronoi diagram will divide the entire area into subareas which is equal to the number of nodes, and each subarea has a single node inside it. From the characteristic of Voronoi diagram each subarea is composed of the area closest to the node inside it, as opposed to the other nodes. The generation of the voronoi diagram requires the location information of all nodes. Voronoi diagrams are very useful in the coverage problem of wireless sensor networks. If each sensor can cover its own voronoi subarea, the entire sensing field can be covered. Each sensor can generate a local voronoi diagram based on the information that is receives from its neighboring sensors. Each sensor adjusts its sensing range according to its distance to the vertices of its voronoi subarea.

B. Setup phase of VFCA

The main goals of the setup phase are formation of clusters, and cluster head election. After divide the sensed area into voronoi cells the sensors should be divided into clusters. In this thesis the fuzzy logic approach of clustering which is called Fuzzy C-mean is implemented for this purpose.

Successfully clustered of nodes is formed by using Fuzzy C-Means clustering algorithm, the first requirement of clustering is to select cluster head and then its members. Each cluster contains a set of a nodes and the number of nodes is not necessary equal in the clusters, a cluster head is initially elected in each cluster. The node nearest to the center selected as cluster head. This is done only at the beginning but after a rotation mechanism based on the distance and energy for every node, the next cluster head is selected. First step is to distribute **N** sensor nodes in the sensed area then apply voronoi diagram for these nodes in order that each node has its own voronoi cell. Then apply FCM to the voronoi cells as follows:

Each node has membership function to all clusters, in the range **[0-1]**. By iteratively update μ_{ij}, using Eq. **2.6** (for cluster center) and calculate new centers by Eq.**2.7** (for membership), until the termination condition is satisfied. The termination condition is the difference between the old centers and new centers, it should be less than or equal to **0.00001**. If this condition is satisfied, the process of FCM terminated, and the FCM algorithm iteratively moves the cluster centers to the right location. As shown in Figure(3.3), which shows the location of the final centers when choosing number of clusters for example (5-clusters).

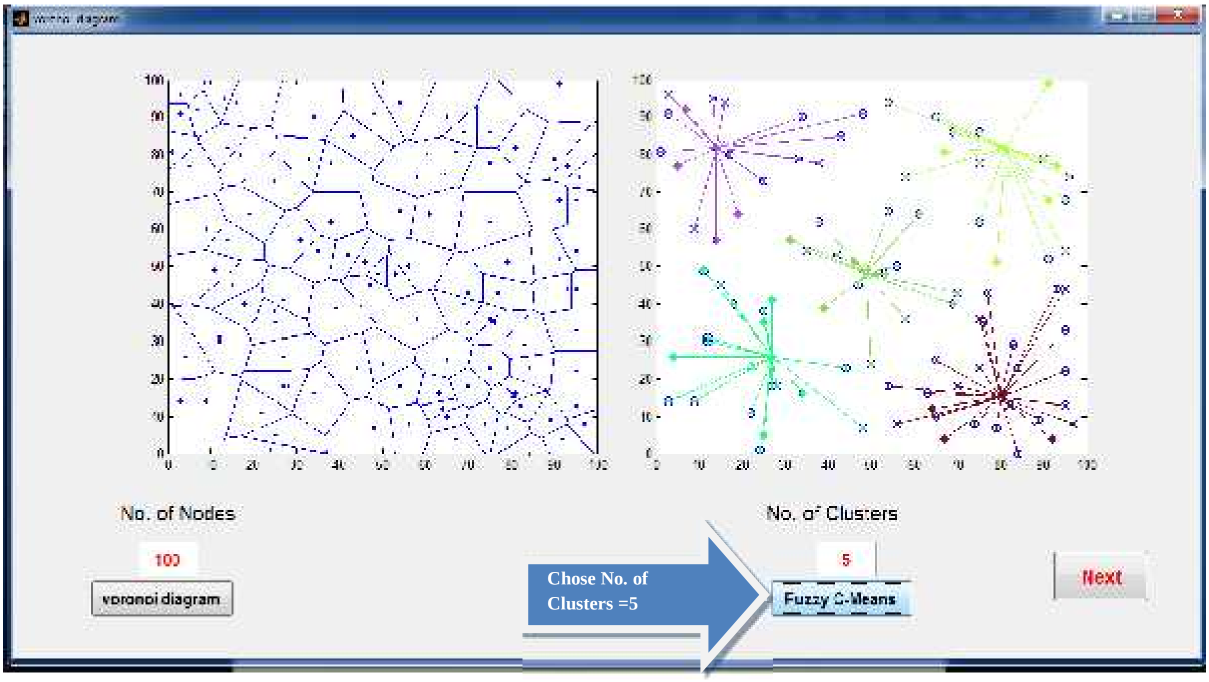


Figure (3.3): The Sensor Nodes after Clustering

In order to create uniform distributed clusters, sensor nodes are classified into clusters according to the maximal degree of membership in each cluster, the algorithm select the nearest node to each of centers as cluster head. After select the cluster head nodes, the algorithm will be assigned the nodes to the nearest cluster head by finding Euclidean distance for each node with all selected cluster head nodes and will be assigned the node to the nearest cluster. After applying FCM clustering as shown in Figure (3.3), one can get five clusters with their cluster heads chosen according to the distance from center for the first round only. Figure (3.4) shows these five clusters.

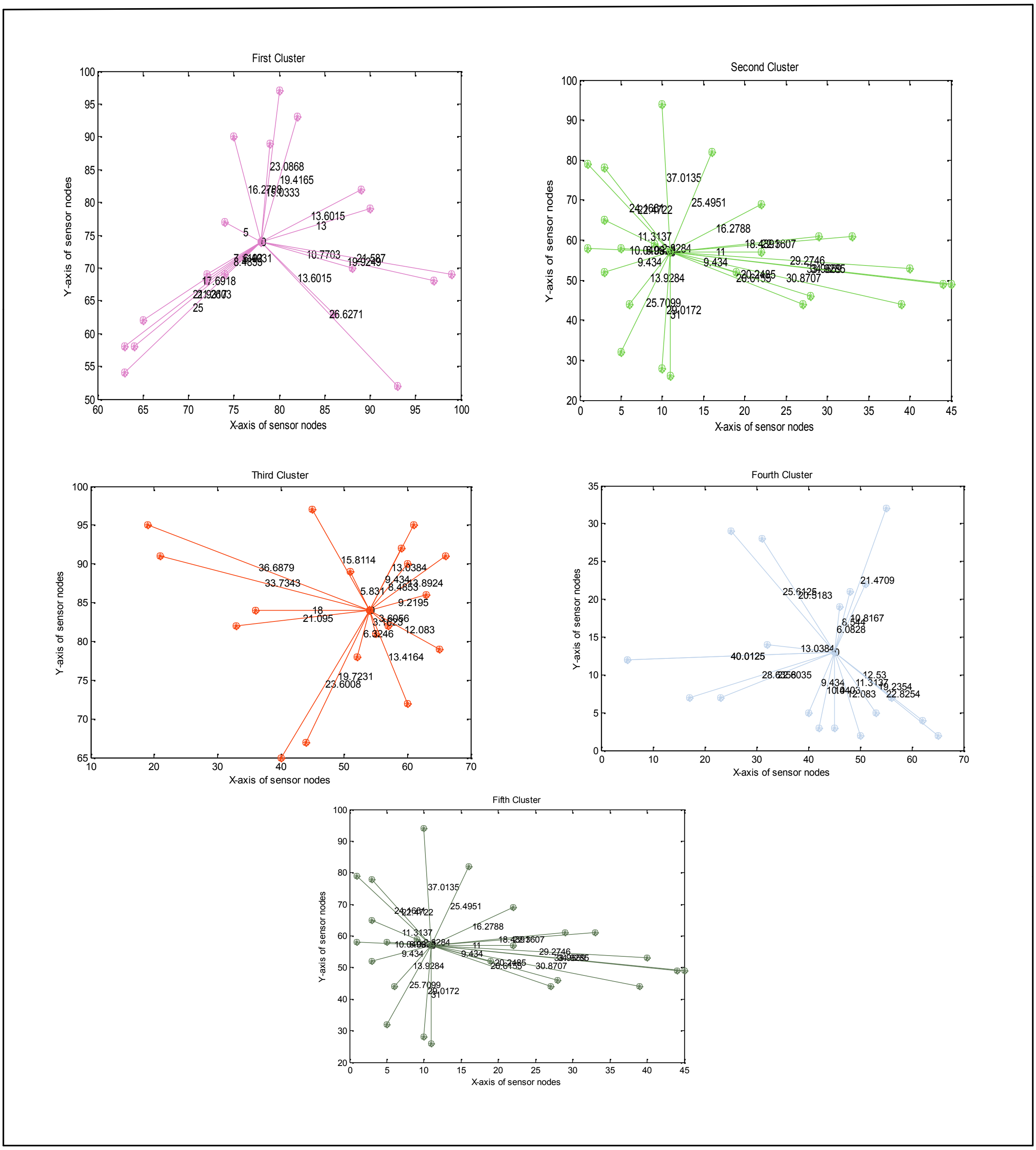


Figure (3.4): Sensors after Applying Fuzzy C-Means

The flowchart of the setup phase steps of the modified VFCA can be shown in Figure (3.5).

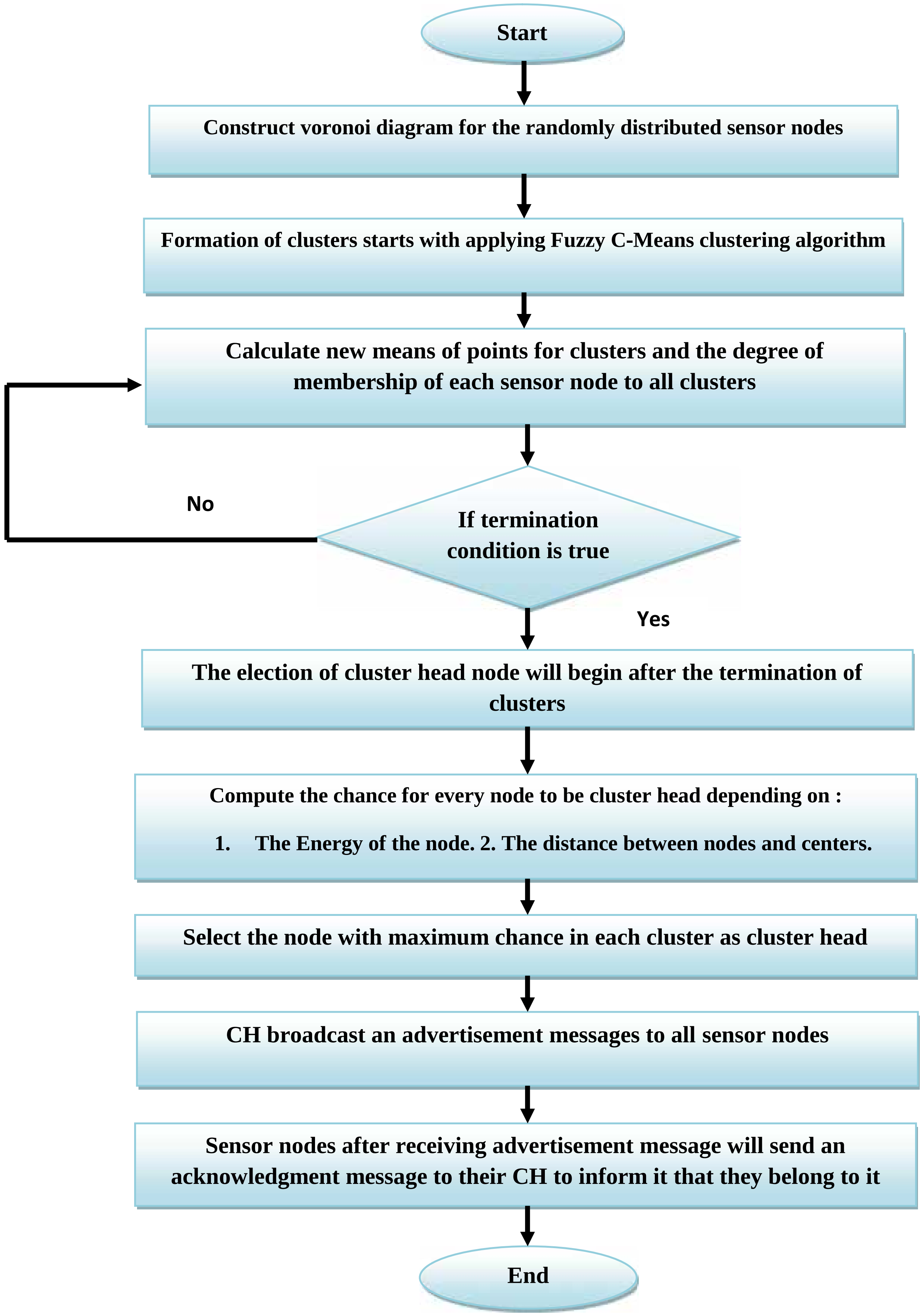


Figure (3.5): Flowchart of Setup Phase when depending on the Energy of the node and the distance between nodes

C. **The Steady-State phase of VFCA**

Data transmission can begin once the clusters are created and cluster heads are elected. The data transfer is proceeding starting from each node in the cell or cluster to communicate with the base station. This communication does not pass directly, the node communicates with CH, and all heads are transfer data directly to the main base station.

In wireless sensor network, each sensor node transmits its sensed data to the CH. The cluster head calculates the average value, maximum or minimum value of the received sensory data which are sent to the sink node for a fixed interval of time. The modified algorithm controls the traffic of the wireless sensor network and also, saves energy of the cluster head; this helps to increase the network lifetime.

In the modified VFCA algorithm, the cluster head node does not receive data from all its members. Because for each node in the network, the algorithm assign threshold value for these nodes. This value is compared with the sensed data from the cells for each member in the cluster. If the sensed data less than threshold value the node does not send it. This process also help to decrease the number of the data that may be stored in the buffer of the cluster head node, and also lead to decrease the traffic on the buffer. All that lead to decrease the energy that the cluster head node losses in receiving sensed data and aggregating them, because if one or more of the nodes in the cluster sensed data with values less than the threshold value, then the CH does not dissipate energy to receive data from these nodes. Figure (3.6) shows an example for the process of comparing sensed data with the threshold value at CH.

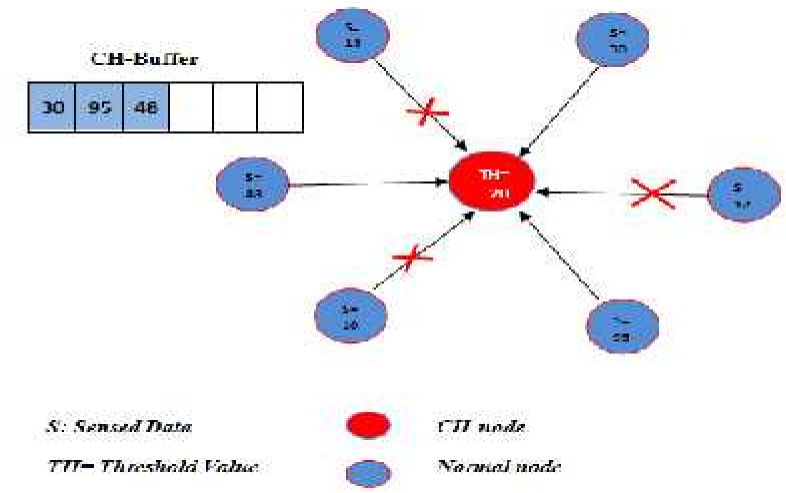


Figure (3.6) An Example of Comparing With a Threshold at the Cluster Head

Every member in each cluster transmits the sensed data ($V(p_i)$ (d)) to its corresponding cluster head .Each ($V(p_i)$ (d)) comprises value of data. The cluster head receive the data until its buffer full then the data aggregation computed using one of the following equations [15]:

$$\textbf{\textit{Avg}}=\frac{\sum_{i=1}^{n} di}{n} \quad \ldots (3.3)$$

$$\textbf{\textit{Max}} = \max(D) \quad \ldots (3.4)$$

$$\textbf{\textit{Min}} = \min(D) \quad \ldots (3.5)$$

Where: di : is the data sensed by node i.

D: is the total sensed data received in each cluster head.

Avg: average value of (D).

Max: maximum value of (D).

Min: minimum value of (D).

n: number of nodes in each cluster.

By taking the aggregation function for the received data in each cluster head, the cluster heads send the aggregated data to the sink node. The sink node also take the same aggregation function for the received data. By the process of aggregation, one can reduce the redundant data, because the nearest cells may sense same or nearest values of data. So when take the max of these values the similar values are ignored. This process reduces the traffic on the sink buffer, because when aggregate the sensed data in each cluster , only the packets that represents the maximum sensed data will be send to the sink buffer, instead of sending all sensed data packets. The voronoi diagram on the other hand helps to cover all sensed area by the given sensors, by divided the area into many cells.

For each sensor node, the energy is dissipated because of receiving and transmitting data, depending on the distance between transmitter and receiver. After sending data, the energy dissipated for each node and each cluster head to transmit and receive data should be calculated, in order to use it as a parameter behind the distance to select new cluster head. If the energy of cluster head reach to zero, this means that the cluster head will be die, and a new node from that cluster should be elected as CH with highest remaining energy and nearest to the center. Figure (3.7) shows the flowchart of data transmission.

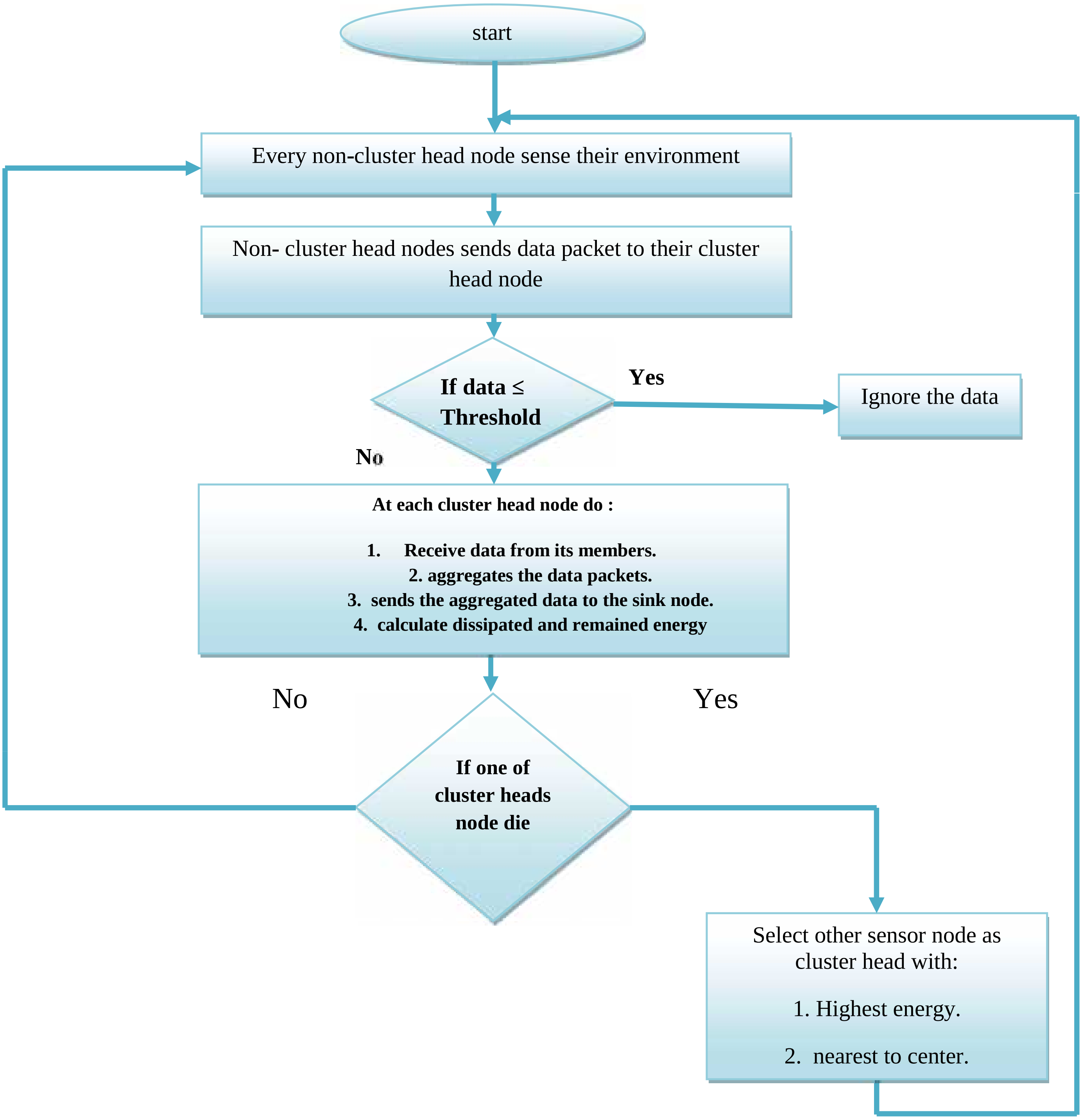


Figure (3.7): Flowchart of data transmission when depending on the Energy of the node and the distance between nodes

The dissipated energy for transmitted data should be calculated for each node in the network, because each node has sensed data need to be transmitted to its cluster head, and for each cluster head, because the cluster head has aggregated data needs to be transmitted to the sink node. The dissipated energy for receiving data should be calculated for each cluster head node, because the cluster head receive data from thrirs members. The energy dissipated for transmitting and receiving data for normal nodes is calculated as in Eq (3.6) .

$$ETX_{nodei} = E_{elec} * \text{distance } (i,j) \qquad \ldots(3.6)$$

Where:

ETX_{nodei}: Transmitter Electronics Energy dissipated for each node.

distance (i,j) : Distance between node i and its cluster head j.

E_{elec}:is the energy dissipated to run the electronics circuits.

Where the energy dissipated from node to receive data equal to the energy dissipated for transmit data.

Then the remaining energy for each node can be calculated by subtracts the dissipated energy for the transmitting and receiving from the energy of that node.

The energy dissipated for transmitting and receiving data for cluster head nodes is calculated as in Eq (3.7).

$$ETX_{CH} = E_{CH} - \left(\sum_{i=1}^{n} (ETX_{nodei})\right) \qquad \ldots(3.7)$$

Where:

ETX_{CH}: Transmitted energy dissipated for each cluster head.

E_{CH}: Initial energy for cluster head node.

n: number of nodes in the cluster.

Where the energy dissipated from cluster head to receive data equal to the energy dissipated for transmit data.

From Eq. (3.7) one can conclude that the cluster head node has dissipated energy in transmitting data to sink and dissipated energy to receiving data from its members, while the normal nodes has only dissipated energy for sending data to its CH.

After the end of the data transmission and energy calculation, the round is done and the next round begins with setup and steady-state phases repeatedly. The cluster head will be change in the next round, if and only if its energy reaches to zero. When the CH die a node with highest energy from the same cluster is chosen as CH, and the rounds continue until all nodes in the network die.

3.3.2 Modified VFCA based on distance and packet loss

In this section, a modified VFCA with distance and packet loss as parameters to select cluster heads is introduced. This algorithm also consists of three phases as shown in Figure (3.1).

A. The first voronoi diagram method phase is similar to section 3.3.1 (A). The simulation environment consists of **20** sensor nodes which are distributed randomly within a **100mx100m** region. After applying voronoi diagram to the nodes in the network the voronoi diagram is shown in Figure (3.8).

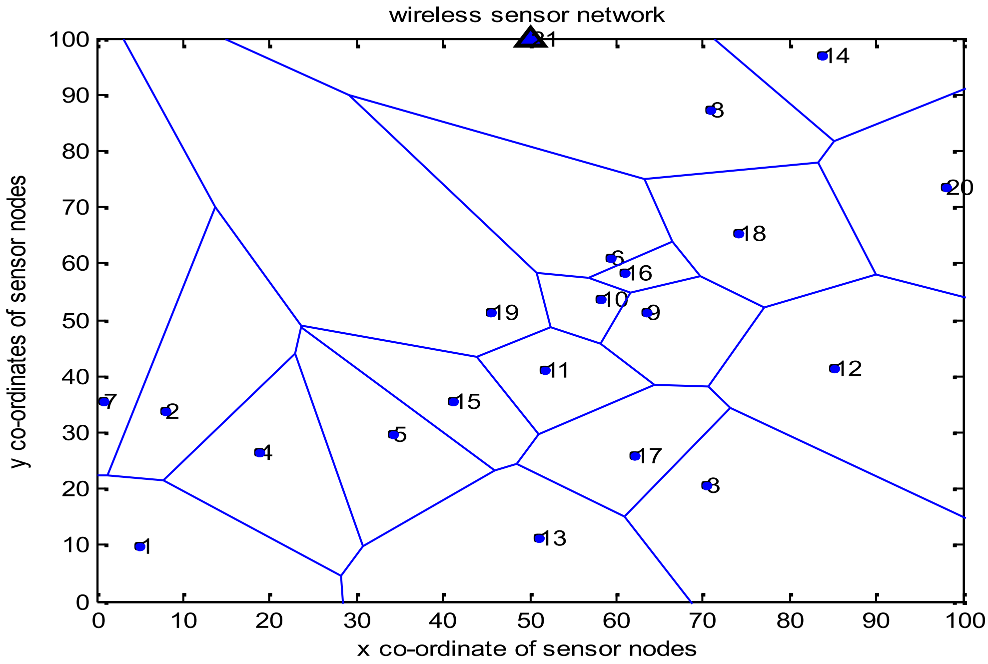


Figure (3.8): The Network after Applying Voronoi Diagram

After applying voronoi diagram on the area containing 20-sensor nodes then the network will has 32 voronoi vertices each group of these vertices surrounds one voronoi cell these vertices shown in table (3.1), where V.xd is the x-axis of the vertices, and V.yd is the y-axis of the vertices.

Table (3.1): Positions of all voronoi vertices of 20-sensor nodes

Vertices No.	V.xd	V.yd
1	Inf	Inf
2	85.1378	81.7354
3	22.9867	44.0096
4	63.1357	74.8736
5	77.1041	52.2024
6	83.2550	77.9541
7	61.7258	54.7099
8	28.2141	4.42642

9	30.6766	9.65298
10	7.72074	21.6268
11	45.8529	23.3116
12	1.176584	22.4538
13	13.7512	70.0951
14	50.9904	29.5970
15	23.6988	48.7981
16	43.8902	43.3684
17	23.6809	49.0974
18	52.4692	48.6529
19	29.2065	89.8237
20	58.2298	45.6930
21	50.8358	58.3965
22	66.4828	63.9344
23	56.8760	57.47385
24	-17.17908	24.4473
25	-0.68839	11.0993
26	48.5893	24.4283
27	64.4056	38.5719
28	61.0539	15.1893
29	73.1143	34.3498
30	70.5526	38.1995
31	69.7491	57.7693
32	90.0586	58.1001

Figure (3.9) represents the voronoi diagram of all sensor nodes in the sensed area. It show each cell and assign it's vertices as in the table (3.2).

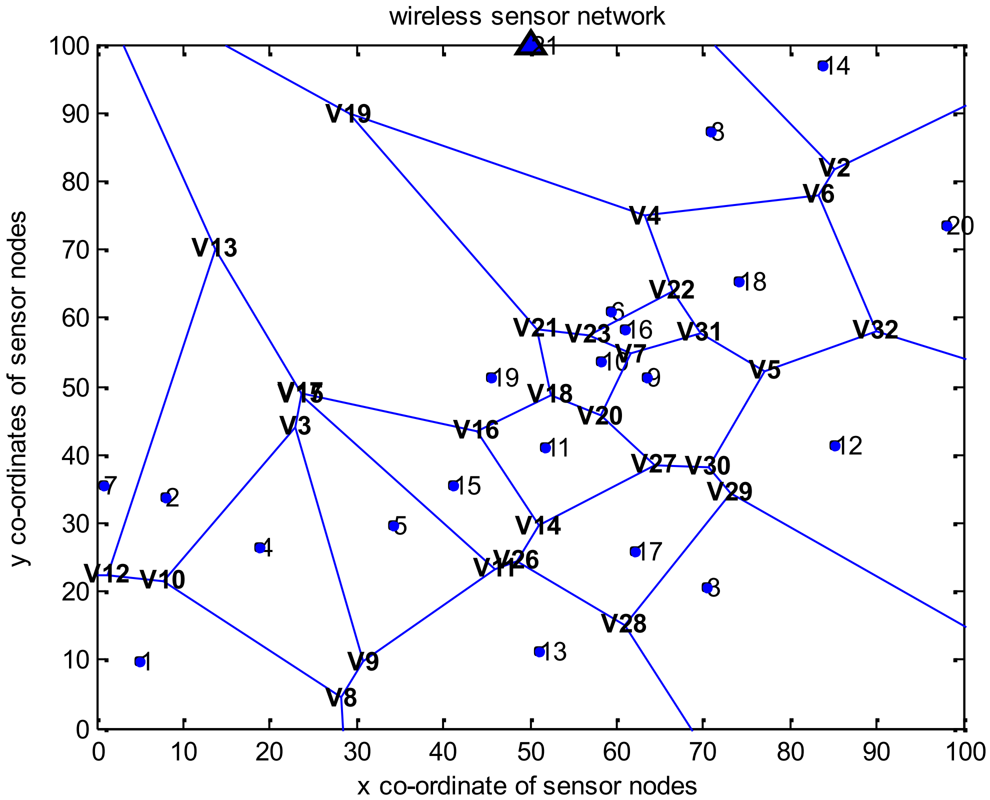


Figure (3.9): The sensed area divided into voronoi cells with representation of the voronoi vertices for each cell

Table (3.2): Vertices of each cell in the voronoi diagram

Voronoi cells	Voronoi vertices					
C{1}	1	8	10	12		
C{2}	3	15	17	13	12	10
C{3}	1	29	28			
C{4}	3	10	8	9		
C{5}	3	9	11	15		
C{6}	4	19	21	23	22	
C{7}	1	12	13	25	24	
C{8}	2	24	25	19	4	6
C{9}	5	31	7	20	27	30

C{10}	7	23	21	18	20		
C{11}	14	27	20	18	16		
C{12}	1	32	5	30	29		
C{13}	1	28	26	11	9	8	
C{14}	1	24	2				
C{15}	11	26	14	16	17	15	
C{16}	7	31	22	23			
C{17}	14	26	28	29	30	27	
C{18}	4	22	31	5	32	6	
C{19}	13	17	16	18	21	19	25
C{20}	1	2	6	32			

Table (3.3) shows which cell is neighboring to other cell.

Table (3.3): The neighboring for each cell

Voronoi cells	It's Neighboring cells
1	2
	4
	7
	13
2	1, 4, 5, 7, 15, 19
3	12
	13
	17
4	1
	2
	5
	13
5	2
	4

	13
	15
6	8
	10
	16
	18
	19
7	1
	2
	19
8	6
	14
	18
	19
	20
9	10
	11
	12
	16
	17
	18
10	6
	9
	11
	16
	19
11	9
	10
	15
	17
	19
12	3
	9
	17
	18
	20
13	1

	3
	4
	5
	17
14	8
	20
15	2
	5
	11
	17
	19
16	6
	9
	10
	18
17	3, 9, 11, 12, 13, 15
18	6, 8, 9, 12, 16, 20
19	2, 6, 7, 8, 10, 11, 15
20	8
	12
	14
	18

B. After ending the voronoi method phase, the setup phase is begin similar to steps in the section 3.3.1 (B), the voronoi cells that are resulted from voronoi diagram are divided into clusters using FCM clustering algorithm. Figure(3.10) shows the location of the final centers (red triangle).

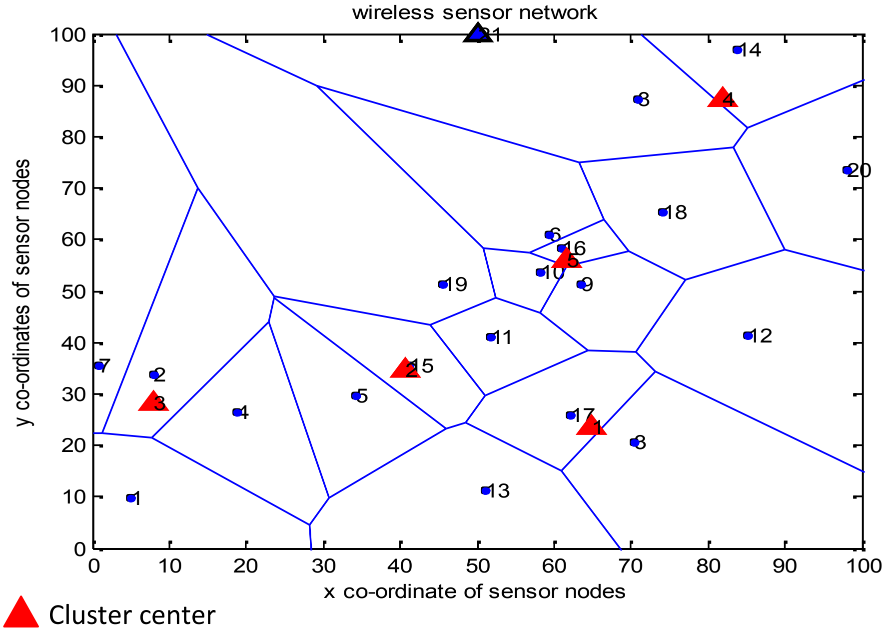


Figure (3.10): Location of final Centers

Figure (3.11) shows the final locations of clusters, their centers, cluster heads, and their members.

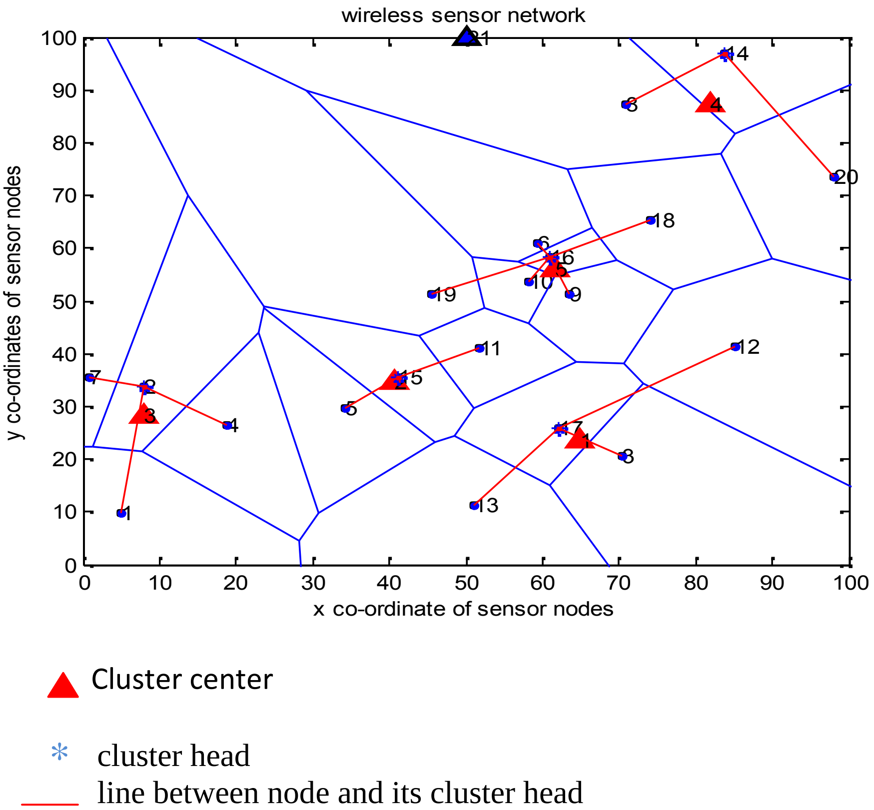


Figure (3.11): The final Locations of Clusters, their centers and cluster heads

Since sensor nodes are assumed to be static in their location, the first round creation of clusters are made but the next rounds, the creation of new clusters are made only when one of the selected cluster head nodes has packet loss value. Because this CH has congestion in its buffer.

After applying FCM clustering algorithm that has been explained in section (2.3.1.2) to voronoi cells, the network has five centers. The location of these centers are near to each other as shown in Figure (3.12) as red triangle. After achieves the termination condition each of these centers lies in one voronoi cell as red triangle as shown in Figure (3.13).

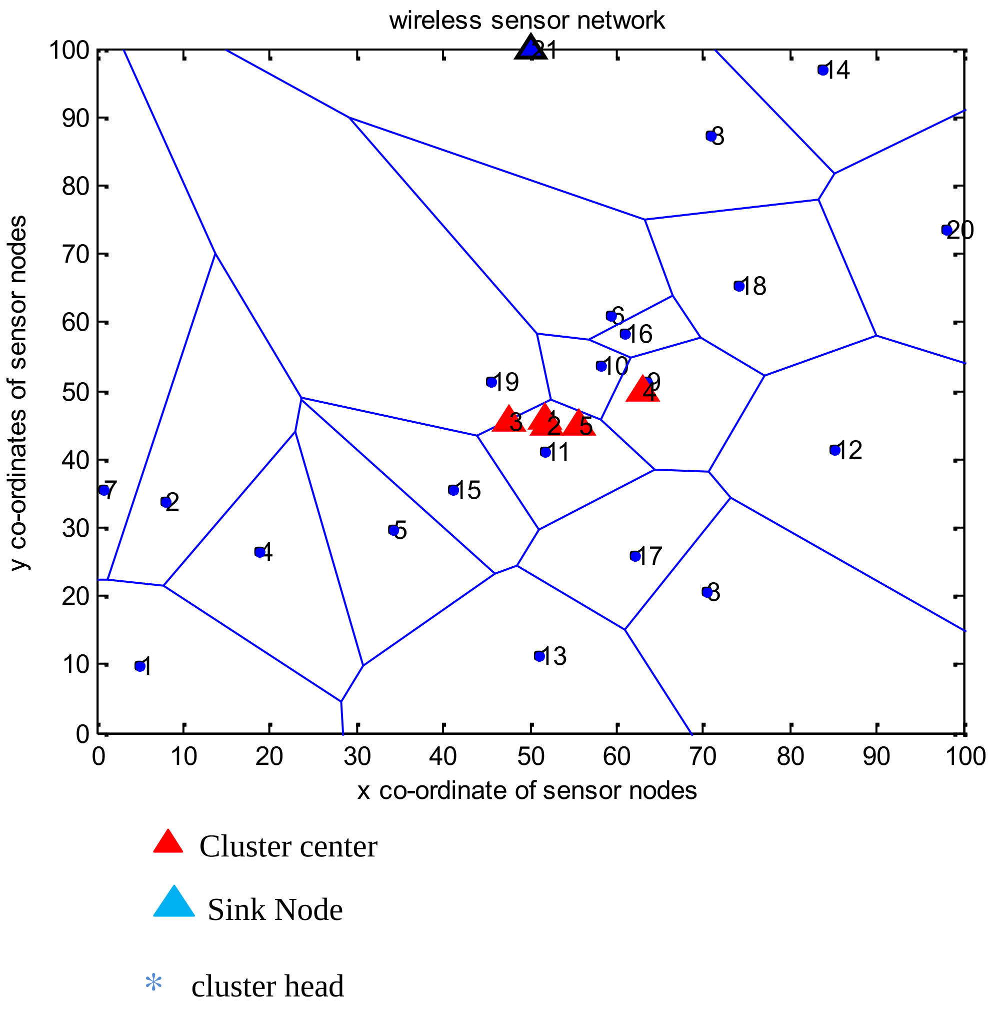


Figure (3.12): Location of first centers after applying FCM

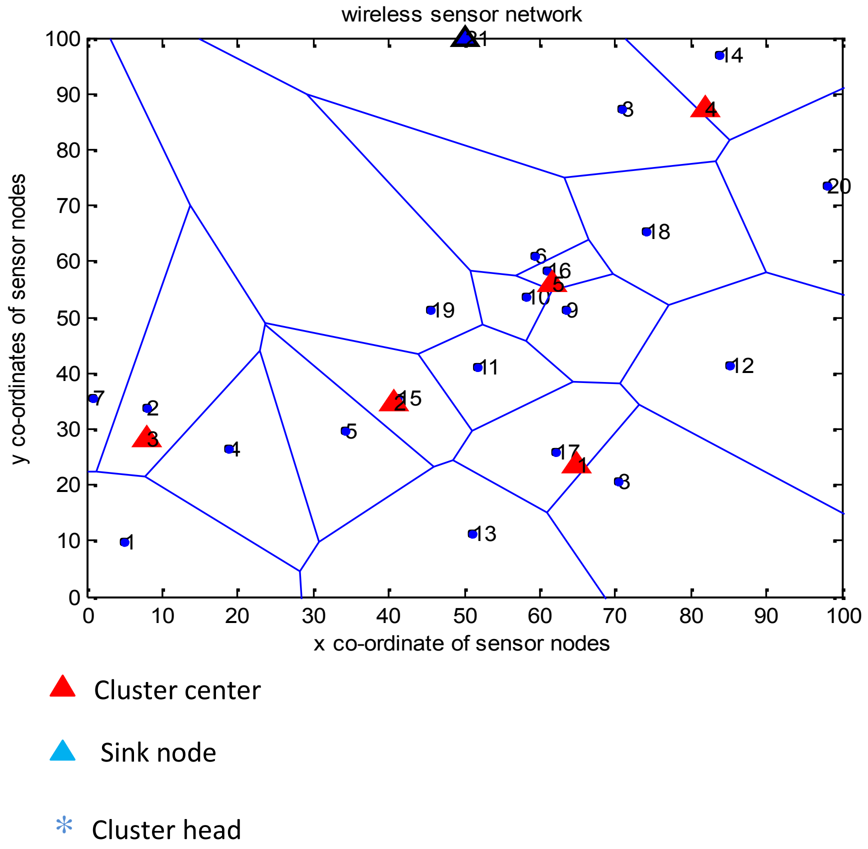


Figure (3.13): The last location for centers

It can be noted from Figure (3.13) that each of the last centers lies in one voronoi cell. The centers are in cells **(14, 16, 17, 15, 2)** .The selected cluster head should be the sensor that represents these cells as shown in Figure(3.13).

The sensor node in each voronoi cells is assigned to the nearest cluster head (voronoi cell). The algorithm has the following distributed: the first cluster of cluster head [voronoi cell 17] has the following members (voronoi cells 3, 12 and 13). The second cluster of cluster head [voronoi cell 15] has the following members (voronoi cells 5 and 11). The third cluster of cluster head [voronoi cell 2] has the following members (voronoi cells 1, 4 and 7). The fourth cluster of cluster head [voronoi cell 14] has the following members (voronoi cells 8 and 20). The fifth cluster of cluster head [voronoi cell 16] has the following members (voronoi cells 6,9, 10, 18 and 19) as shown in Figure (3.14).

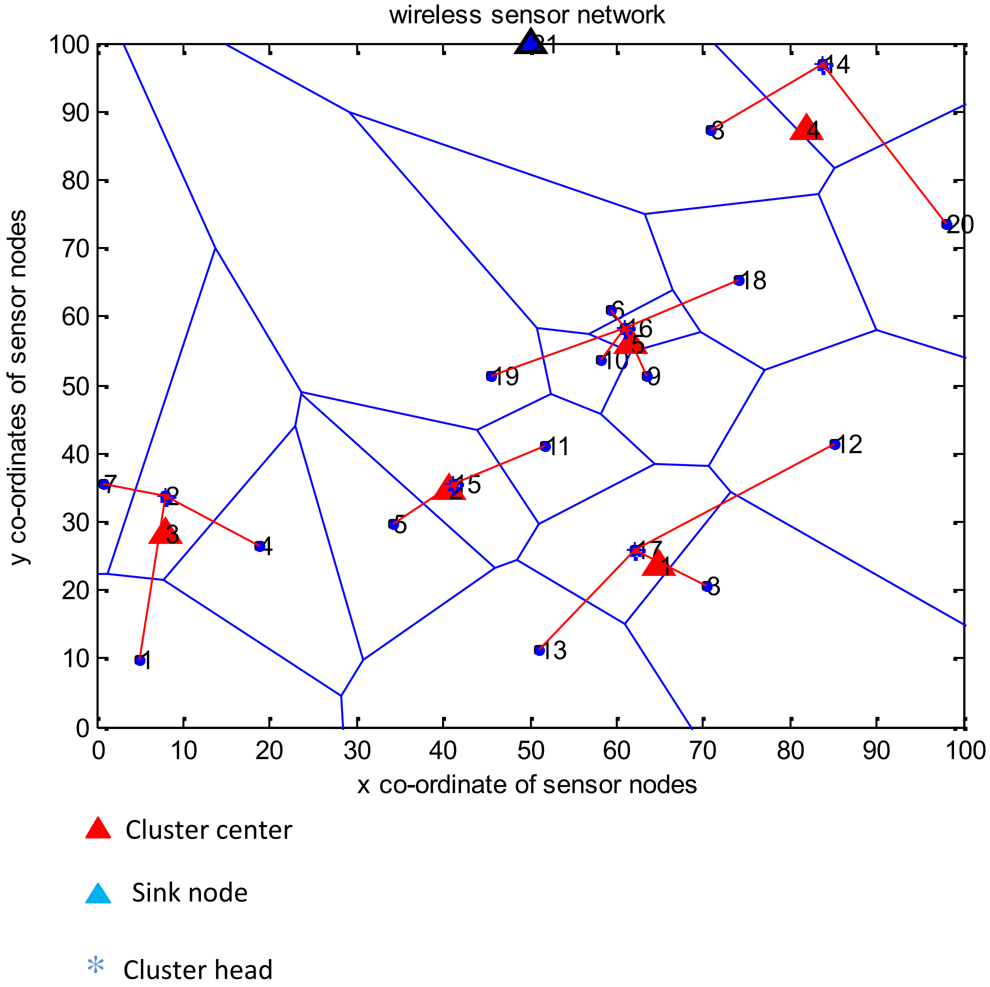


Figure (3.14): Each cluster head and its members for the first round

The flowchart of the setup phase steps of the modified VFCA can be shown in Figure (3.15).

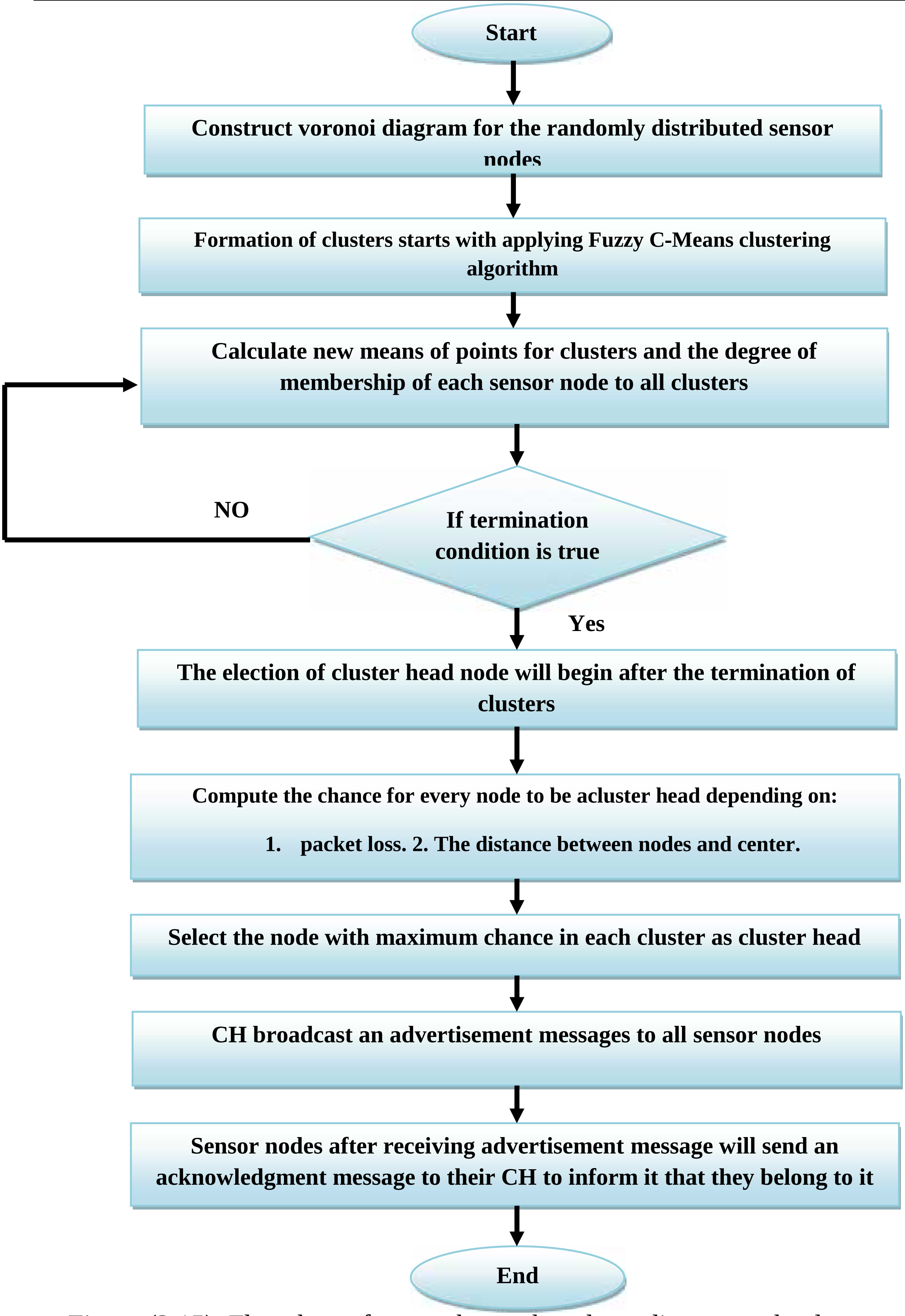


Figure (3.15): Flowchart of setup phase when depending on packet loss value and distance

C. The steady-state phase is same as in section 3.3.1 (C) .Each node (which is represents voronoi cell) sends its sensed data to its cluster head and the cluster head aggregate the received data. This for the first round. The cluster head after receiving data from its members check if there is packet lost from its buffer as in Eq.(3.10)

$$\mathbf{Pl = BUF - P} \qquad \ldots(3.10)$$

Where:
Pl: packet loss value.
BUF: size of the buffer.
P: number of received packets.

Each time the cluster head received sensed data from theris members, the cluster head subtract received data packets from its buffer size. To see if there is a space in its buffer for the receiving packets or not, If it is find that some of the received packets was lost, it should calculate the value of the packets that lost. Then the network should be re-clustered again in the second round, and chose the new cluster head nodes with low packet loss value and nearest to the final centers of FCM clustering. Figure (3.16) shows the flowchart of data transmission.

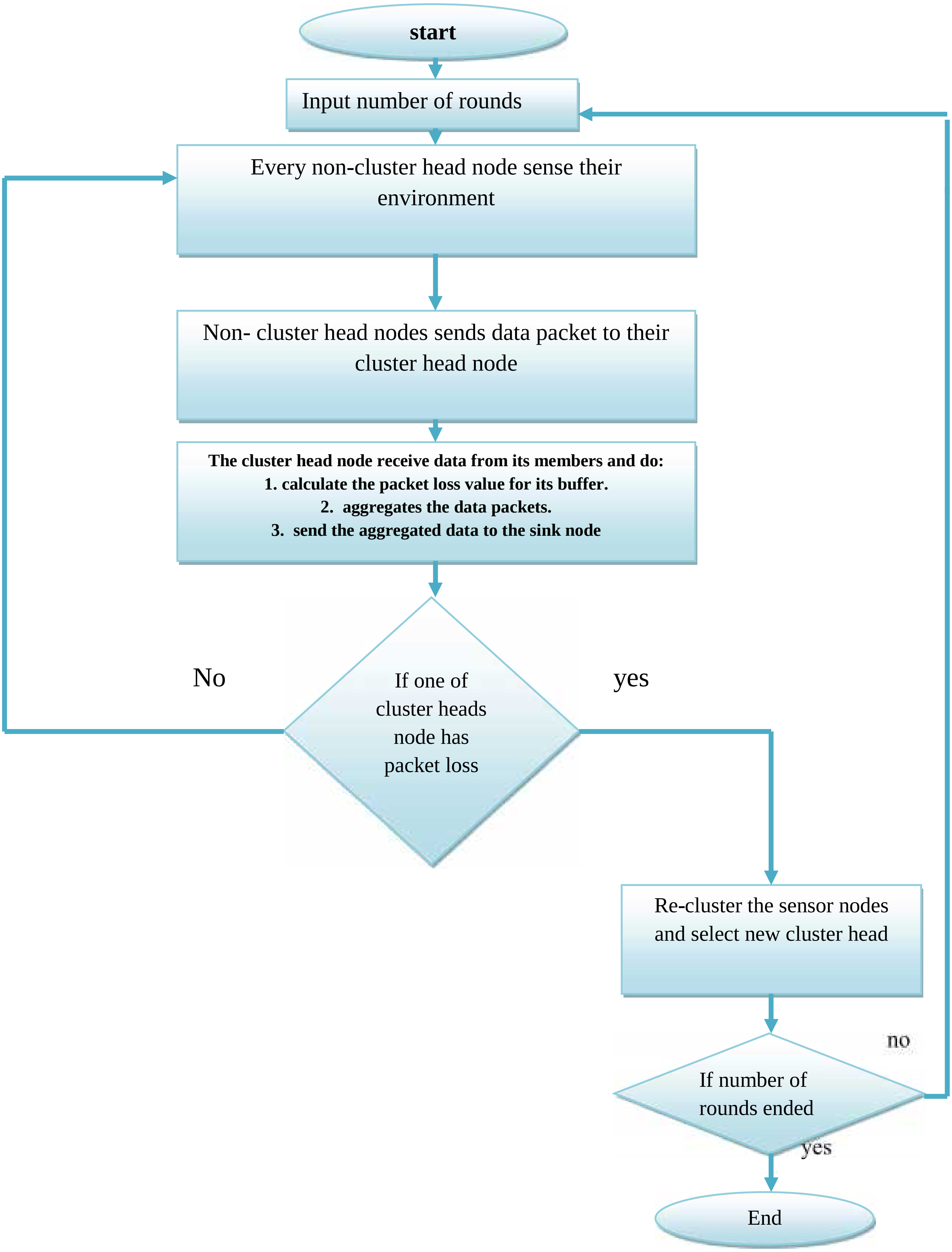


Figure (3.16): Flowchart of data transmission when depending on packet loss value and distance

CHAPTER FOUR

Performance Evaluation

Chapter Four
Performance Evaluation

4.1 Introduction

After modeling the modified VFCA that is illustrated previously, the implementation of the modified algorithm is explained to test the effectiveness of the algorithm and the performance of the network. In the modified algorithm, data aggregation in wireless sensor network has been implemented in Matlab 2010 simulator. The comparative analysis of the modified VFCA with LEACH protocol and then with K-Means clustering algorithm is implemented. The evaluation metrics of the modified algorithm including network lifetime, average energy consumption, total number of packets at sink buffer, sink buffer utilization, packet loss value, running time, buffer utilization and the number of the received data packets are measured.

4.2 Performance Metric for Evaluation

To evaluate the performance of the modified VFCA in the wireless sensor network, some performance matrices are computed. These performance metrics are:

- ***Network Lifetime:*** The time duration between the network initialization and the expiry of the last live nodes in the network.

- ***Average Energy Consumption (Ea):*** The average energy consumption is the average difference between the initial level of energy and the current level of energy that is left in each node in each round. Eq. (4.1) shows how to calculate the average energy conception for the network [39].

$$E_a = \frac{\sum_{K=1}^{N} (E_{ik} - E_{ck})}{N} \qquad \ldots(4.1)$$

Where:

E_{ik} = The initial energy level of a node.

E_{ck} = The current energy level of a node.

N = Number of nodes in the simulation.

- ***Total Number of packets:*** The total number of packets that are successfully sent from cluster head node to the sink node. And from nodes to their CH.
- ***Buffer Utilization (BU)*:** The buffer utilization is defined as the ratio of the packet which is occupied at the sink's buffer to the buffer length as described in Eq. (4.2).

$$BU = \frac{P_{total}}{BU_{sink}} \qquad \ldots(4.2)$$

Where:

BU: Buffer Utilization.

P_{total}: total packets received at sink buffer.

BU_{sink}: size of the sink buffer.

Buffer Utilization must be approximately equal to one. BU is very important in the traffic at the sink node. If its value approximately equal to one, then the sink node has no congestion. This is because the process of data aggregation, which decrease the redundant data arrived to the sink node, and decrease the congestion that may be occurs.

- ***Packet loss value:*** This represents the difference between the size of the cluster head buffer and the number of received packets at the cluster head.

- ***Running time:*** Represent the total time taken by sensor nodes to apply the clustering and data aggregation processes.

4.3 Simulation Setup and Results

In this section the simulation of the modified VFCA in the network environment and comparison with LEACH protocol in WSN are presented. Simulation is achieved with n-sensor nodes that are randomly distributed within a (100x100) m region.

The simulations run with the parameters mentioned in Table (4.1). To evaluate the performance of the modified VFCA, the number of sensor nodes should be inserted .For example 100-stationary sensor nodes are randomly placed in a sensed area also number of clusters should be inserted, for example 5 - clusters. Figure (4.1) illustrates the model of the 100-nodes simulation network after applying voronoi diagram and then FCM clustering for the first round.

Table (4.1): The simulation parameters

Parameter	Value
Network size	100mx100m
Number of nodes	100
Number of sinks	1
Behavior of nodes	Static
Base Station position	[100,100]
Number of clusters	5
Iteration steps	1000
Termination condition	0.00001
Buffer size of nodes	35 packet
Buffer size of sink	100 packet
E =Initial energy for each node	2J [39]
E_{CH}=Initial energy for each cluster head node	2J [39]
E_{elec}	50nJ/bit [39]
m	2 [17, 26]

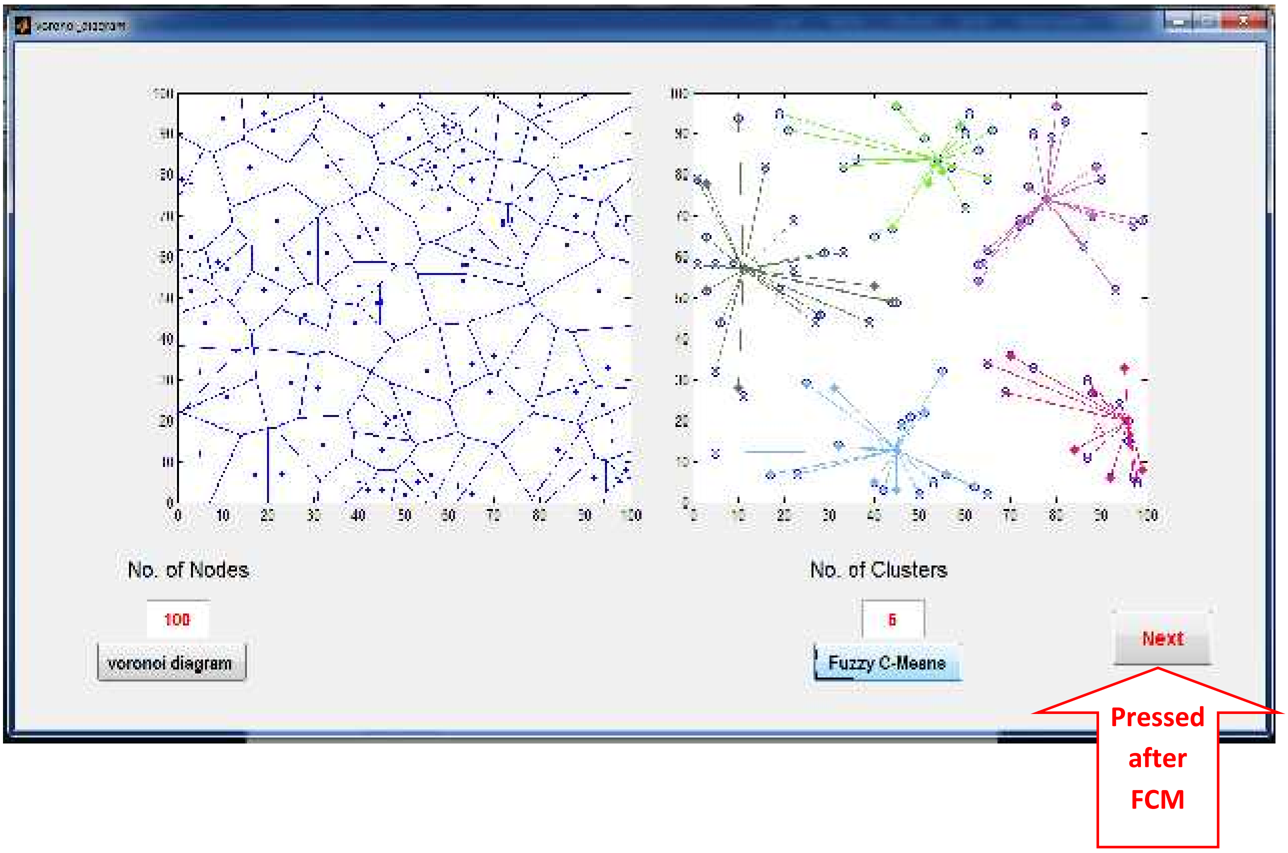


Figure (4.1): Sensor Nodes after Applying Voronoi Diagram and FCM

The running time taken to construct the voronoi diagram can be shown in Figure (4.2). From the figure one can see that voronoi diagram takes less time for constructing. This time is increasing in low rate when increased the number of nodes are increased.

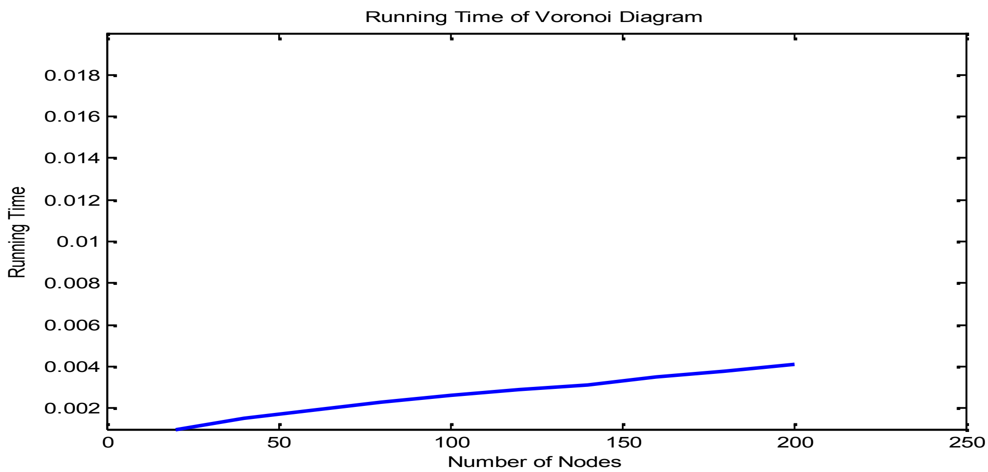


Figure (4.2): Running Time of Voronoi Diagram VS Number of Nodes

The running time taken by FCM for 100 sensor nodes divided to different number of clusters can be shown in Figure (4.3). From the figure it can be seen that FCM take minimum time to divide the voronoi cells to clusters and this time increasing in low rate with increased the number of clusters.

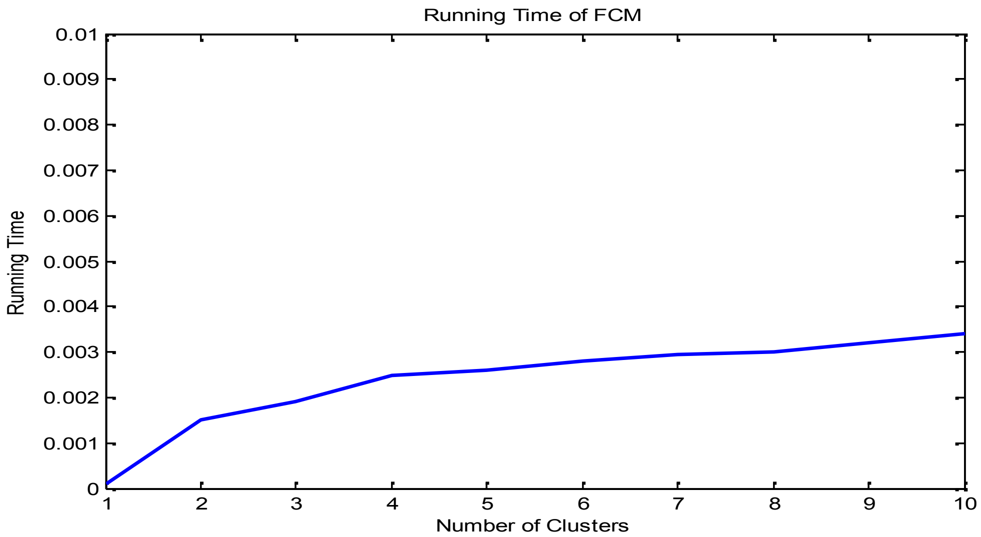


Figure (4.3): Running Time of FCM VS Number of Clusters

From Figure (4.3), the number of the inserted nodes are equal to 100, and the simulation is repeated by applying FCM, with different number of clusters. At the beginning the number of clusters equal to one. If the size of node buffer is equal to 35 this may lead to loss in the received data packets at CH buffer. And when the number of clusters are increased, the lost packet decrease and reach to zero for eight clusters and above. This is because when increasing number of clusters the members of each cluster decrease, then the congestion in CH buffer is decreased too. Figure (4.4) shows the state of CH buffer when increasing number of clusters from 1 to 10 for 100 sensor nodes.

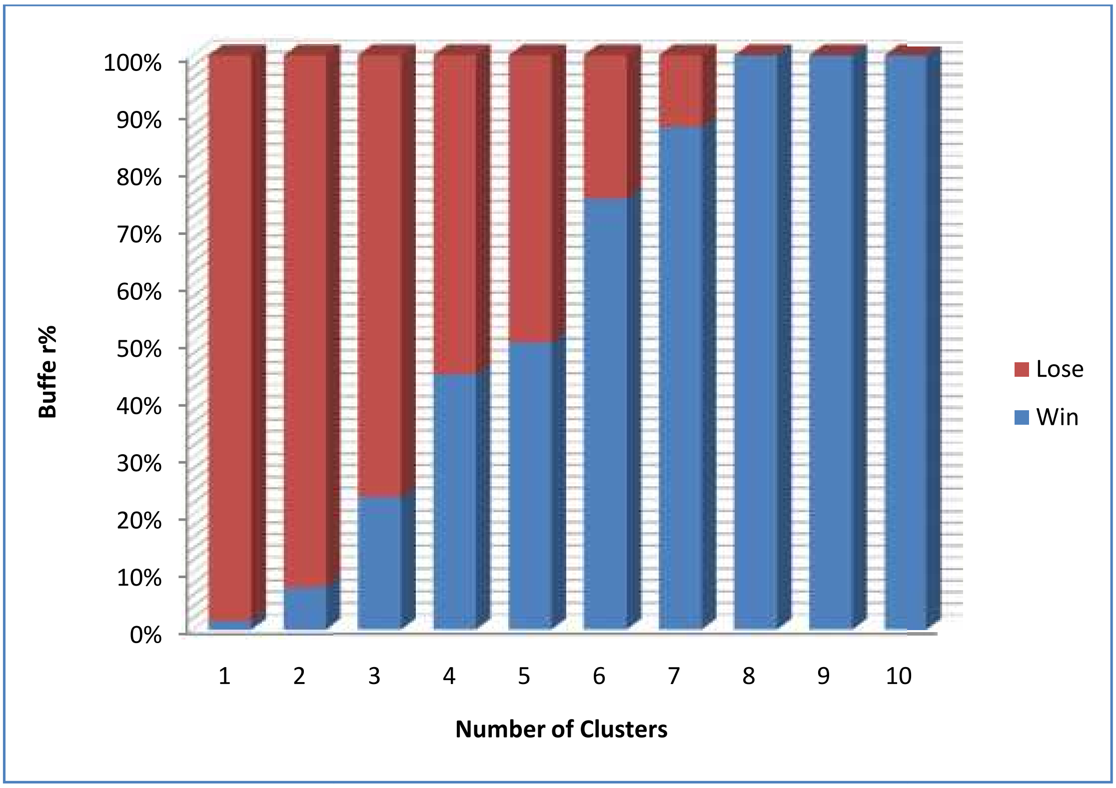


Figure (4.4): Percentage of Packets in Cluster Head Buffer VS Number of Clusters

The election of the cluster head node in the first round is depends on the distance of nodes from centers Figures (4.5, 4.6, 4.7, 4.8, 4.9) shows each cluster with its selected cluster head and the distance from each node to its cluster for the network shown in Figure (4.1).

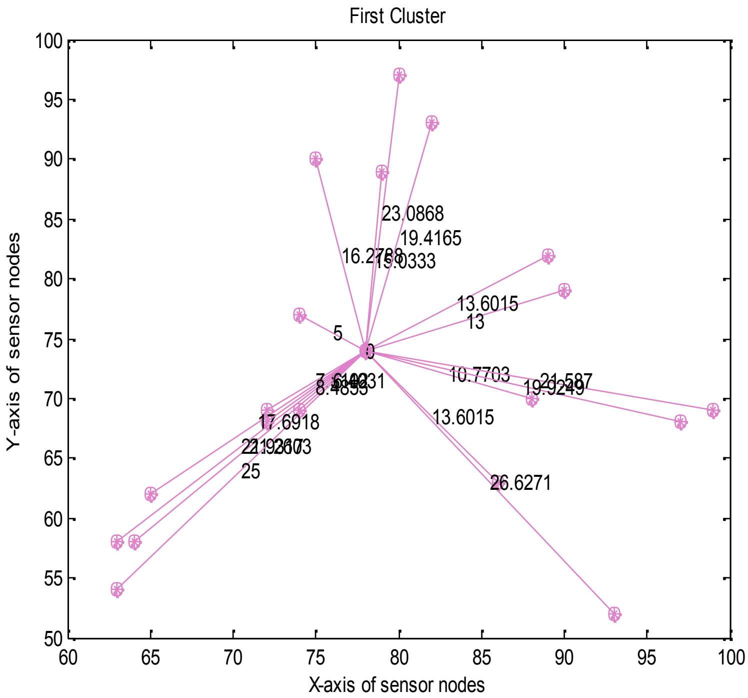


Figure (4.5): First Cluster for First Round

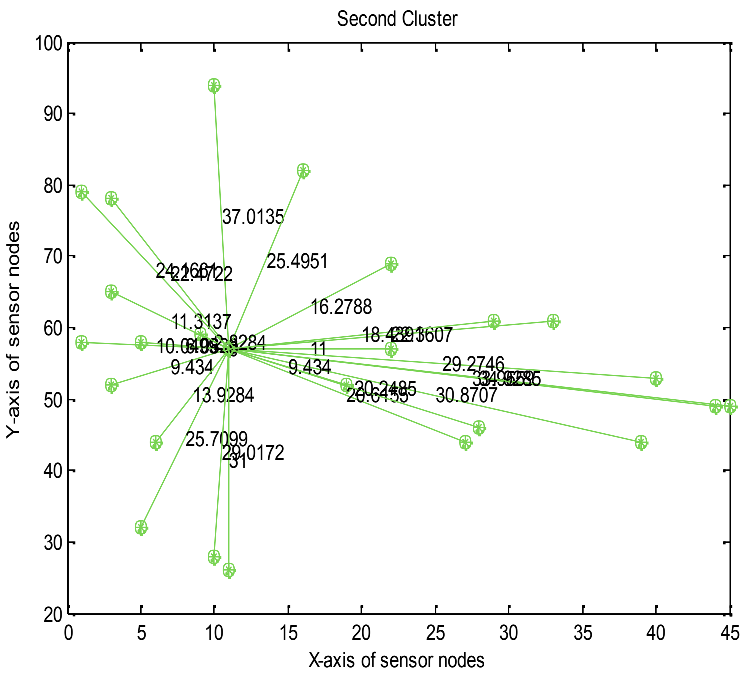


Figure (4.6): Second Cluster for First Round

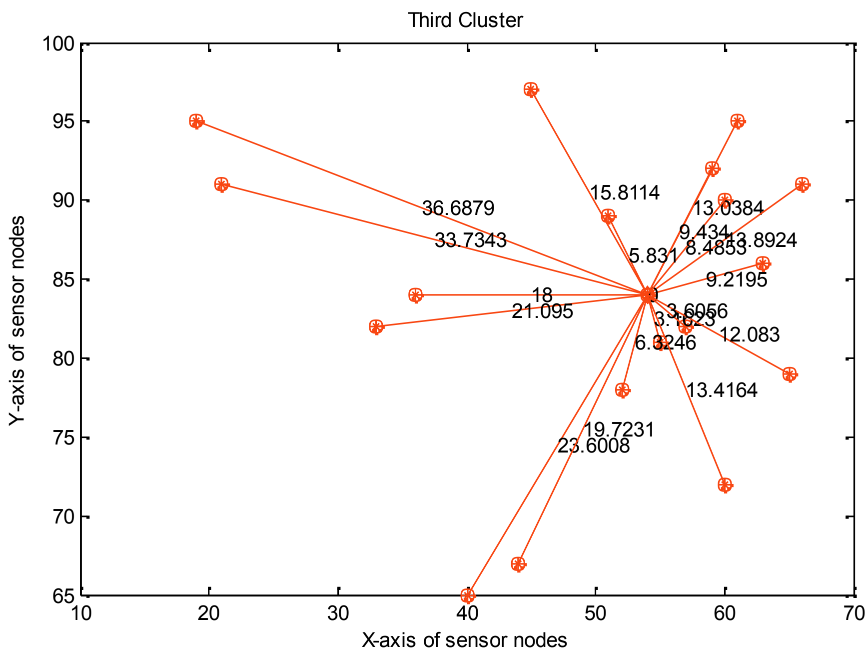


Figure (4.7): Third Cluster for First Round

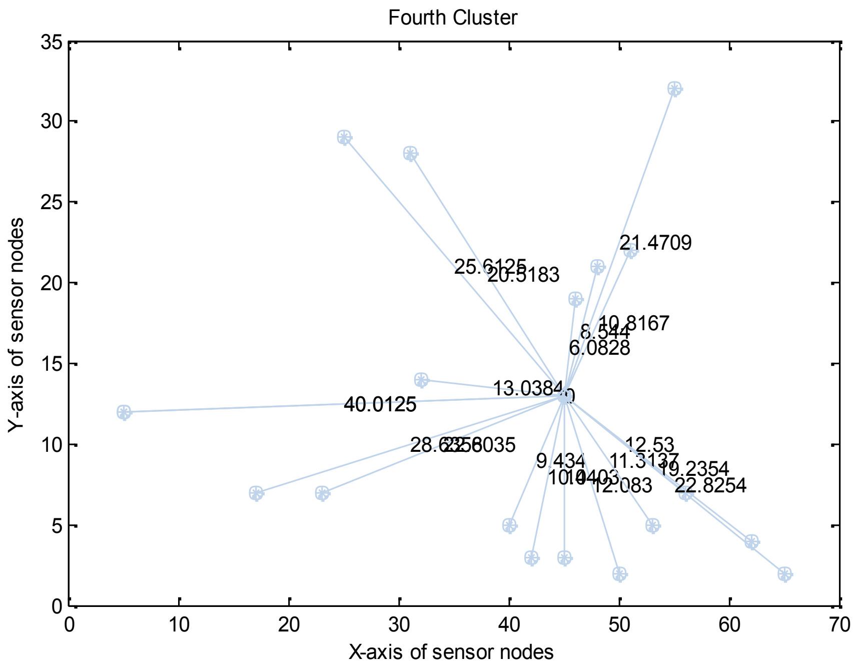


Figure (4.8): Fourth Cluster for First Round

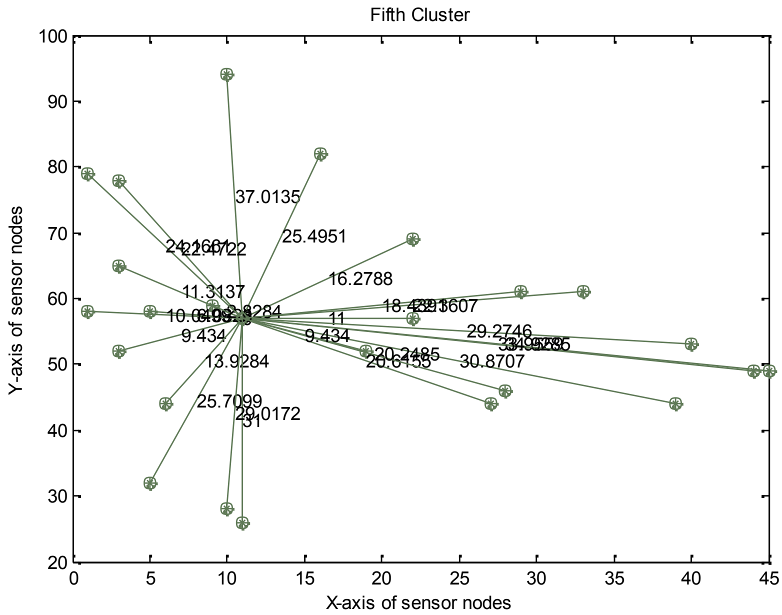


Figure (4.9): Fifth Cluster for First Round

The next button illustrated in Figure (4.1) and second round button illustrated in Figure (4.10) should be pressed, to see the information about each cluster. These information include the distance between each node in the cluster and the cluster head, the sensed data for each node in each cluster and the energy for each node in the cluster. All these information are shown in Figure (4.11).

Figure (4.10): Represent the Button to Run the Second and Third Rounds

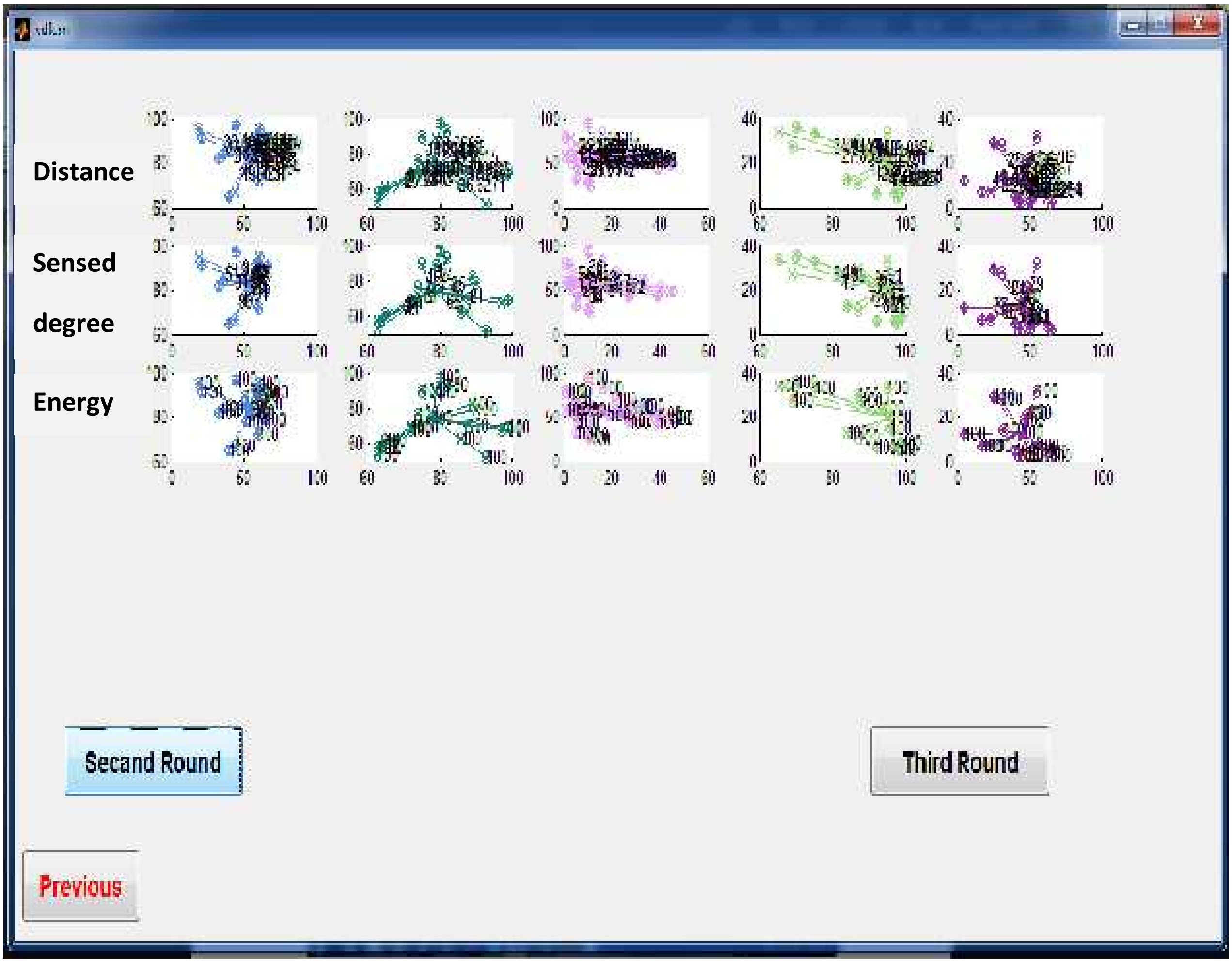


Figure (4.11): Information for Each Node in Each Cluster for First Round

When one press the second round, new five clusters will be plotted, with new cluster heads. If the cluster heads in the previous round are die, then new information about their distances, energy and sensed data are appeared. The same thing happen, when press the button third round, new clusters are created with new cluster heads and their information (distance, sensed data, energy). Due to the role of modified VFCA in this network, an optimal cluster head node will be used at each new round, depending on the division of the voronoi cells that cover all the sensed area to clusters, using FCM and. The process of cluster head election depends on the highest node energy, and the process of comparing the sensed data with threshold value at sensor nodes, which lead to decrease the traffic at CH buffer, also decrease the energy dissipated in receiving these data that is less than threshold, if one not using threshold value at CH. This may be lead to enhance the Performance of the applying the modified VFCA to the WSN from the hand of running time of the network, the energy dissipated, and the network lifetime to better than LEACH protocol as in the following.

4.3.1 Network Lifetime

The lifetime of the network for the modified VFCA and LEACH protocol in terms of alive nodes with the number of rounds is shown in Figure (4.12).

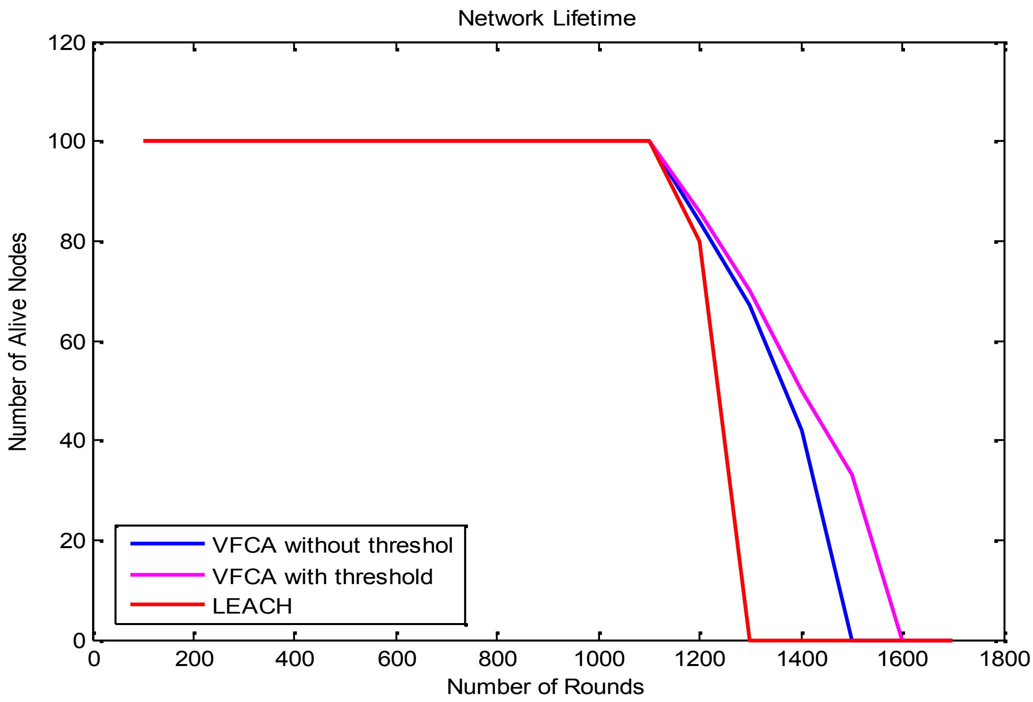


Figure (4.12): Network Lifetime

As compared with LEACH, the modified VFCA has an improvement over the stability period. As it is clear from Figure (4.12), the first node dies in LEACH protocol at round 932 and last node dies at round 1312, whereas in modified VFCA without threshold, the first dead node is at round 977 and last node die at round 1520. In addition, when applying VFCA with threshold value at each node in the network, the lifetime becomes longer than the case of using VFCA without threshold. This shows an improvement due to the use of the voronoi diagram. This helps the network to cover all the area, and reduce the transmission distance, which lead to save energy. Using threshold at each node may lead to decrease the traffic at CHs and decrease the energy consumption for CHs to received packets. Also, by using Fuzzy C-Means clustering (FCM) with voronoi diagram reduced the transmission distance. The modified VFCA chooses the best node as the cluster head node depending on the cluster node with the highest energy and this will lead to increase the network lifetime.

4.3.2 Average Energy Consumption

For any routing protocol, reducing energy consumption is an important issue so that the network stays alive for longer period or for more number of rounds. Figure (4.13) shows the average energy dissipation for all nodes with respect to the number of rounds. The average energy consumption of the modified VFCA with threshold is lower than the average energy consumption of VFCA without threshold and LEACH protocol. Nodes in the modified VFCA with threshold deplete their energy in very slow rate as compared to VFCA without threshold, because when using threshold not all the nodes send their sensed data to its CH. In the two cases of modified VFCA with and without threshold, the nodes deplete their energy in slow rate as compared to LEACH protocol.

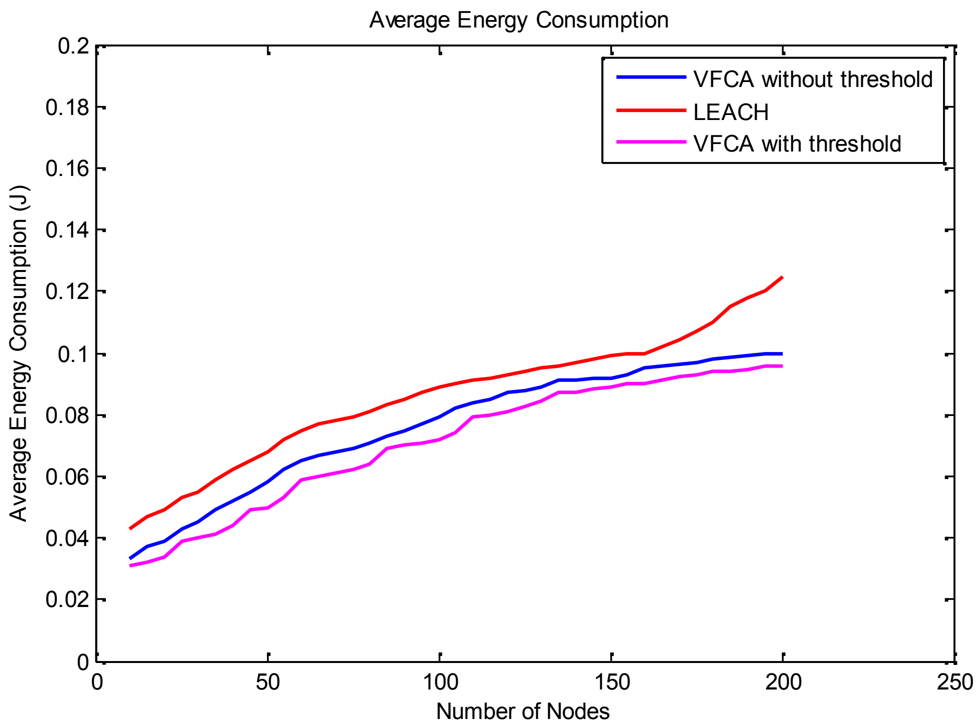


Figure (4.13): Average Energy Consumption for the Network

4.4 Performance of the modified VFCA with K-Means Algorithm

The simulations run with the parameters mentioned in Table (4.1). To evaluate the performance of the modified VFCA, 20-stationary sensor nodes are randomly placed in a sensed area with one sink node. Figure (4.14) illustrates the model of the 20-nodes simulation network. The number of elected cluster heads from all nodes in the network are chosen randomly.

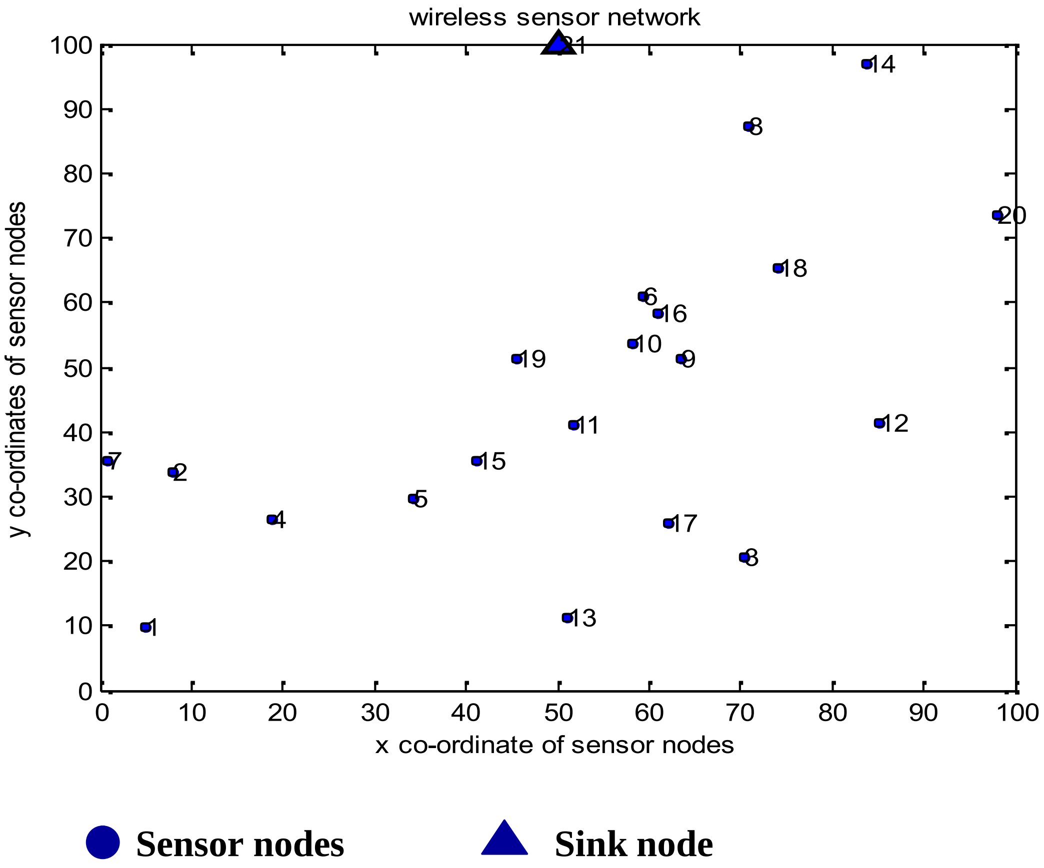


Figure (4.14):The Nodes Distribution over the Sensed Area

In WSN each node in an environment sense data and it should forward it to the sink node .This may lead to transmit redundant data from the nodes that are closed to each other and also may cause congestion in the buffer of the sink. In the modified VFCA the nodes can sent its sensed data to its cluster head, which is aggregate them and send the aggregated one to the sink node. In the modified VFCA the role of CH node rotates between all sensor nodes in the network. If the selected cluster head has packet lost from its buffer because the congestion of traffic in its buffer. The cluster head send the packets that are in its buffer, and all other cluster heads also send the aggregated data in their buffers. Then the process of clustering repeated, to chose new cluster head nodes depending on the value of packet loss and the distance between sensor nodes and the centers that get them from FCM clustering algorithm.

4.4.1 Total Number of Packets:

The total number of packets can be computed according to the packets reached to the buffer of the sink node and to the buffer of cluster head nodes.

- Total Number of Packets at Sink Node:

Figure (4.15) shows the network model that is used for implementing varying the number of cluster heads for 400 nodes. Figure (4.16) illustrates the comparisons between the modified VFCA and K-Means algorithm in terms of the total number of packets received at the sink node in the network, when varying the number of clusters in the network (5-10-15-20-25) clusters.

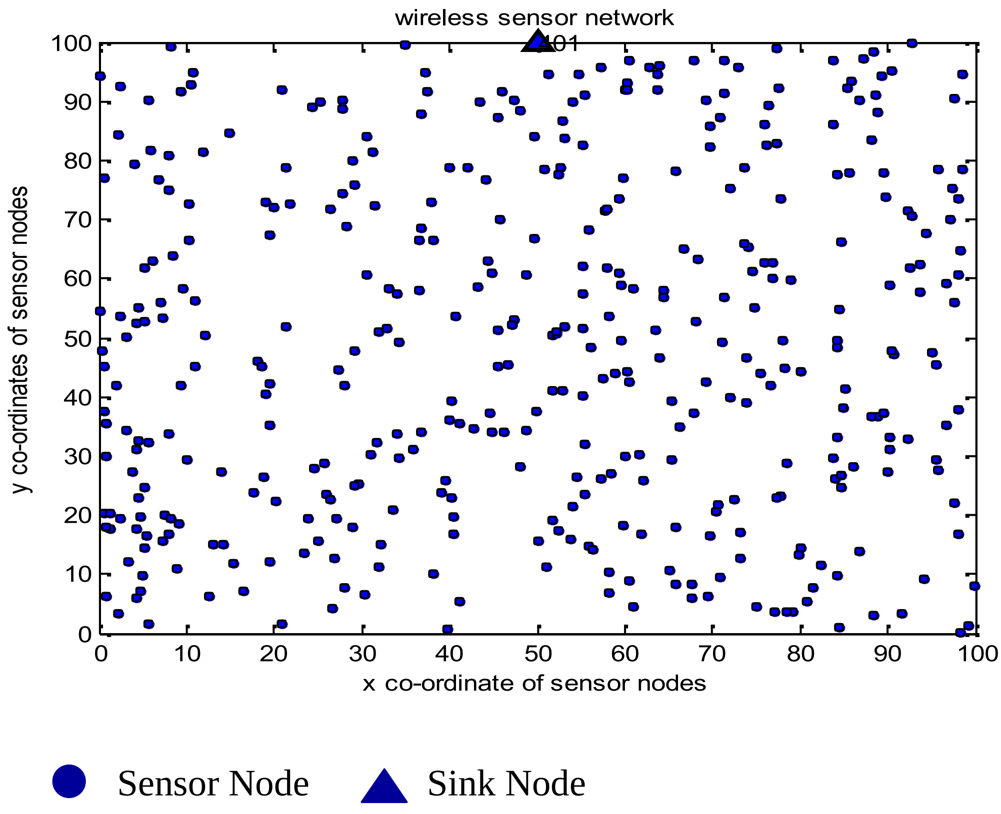


Figure (4.15):The 400 Sensor Nodes Distribution Over The Sensed Area

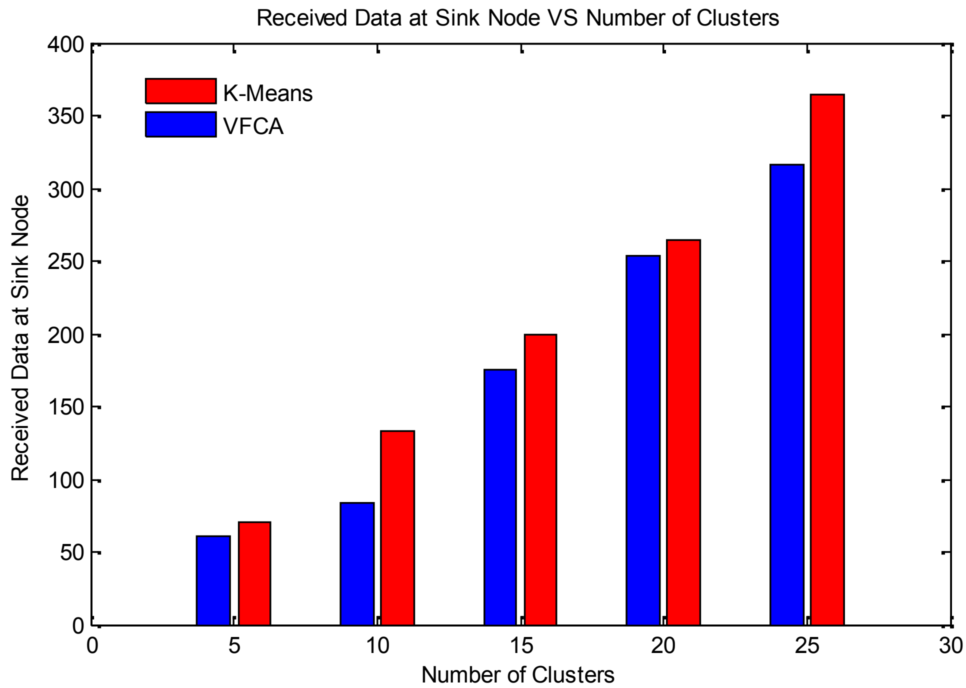


Figure (4.16): Received Data at Sink Node VS Number of Clusters in the Network

It can be observed from Figure (4.16) that the number of packets arrived at sink node increased when increasing the number of clusters in the network and fixing the number of nodes to 400 sensor nodes. This is because every time when the number of clusters increased then the number of data aggregated in each cluster head increased too. As shown in Figure (4.16) when the number of clusters equal to five. Then only the five nodes that represent CHs should send the packets of their aggregated data to the sink node. This means that the sink node received packets from five CHs which is equal to (61-packets). And when number of clusters are increased to 10 the sink node received aggregated packets from ten CHs and these ten CHs may be sure have packets more than the case of five CHs. The case of ten CHs number of received packets equal to (84-packets) .Every time the number of cluster heads is increased the number of received packets at the sink node will increased as shown in table (4.2).

Table (4.2): Received Packets at Sink Node by Varying Number of Clusters in the Network

Number of Clusters	Number of Received Packets at Sink Node (VFCA)	Number of Received Packets at Sink Node (K-Means)
5	61	70
10	84	133
15	175	200
20	254	264
25	316	365

From Figure (4.16) one can conclude, that the modified VFCA divides the area into cells and this will lead to optimization in distribution and aggregation of data from the network. Then the sink node may reach the data that need it from the all sensed area without losses. In K-Means algorithm ,although the sink node receive more data than modified VFCA, when increasing the number of clusters, but this may lead to congestion at the sink node, and losses some of the important data, where as in the modified VFCA the congestion and losses do not occur. Therefore, the VFCA is better than K-Means algorithm.

4.4.2 Buffer Utilization (BU)

The buffer utilization of sink node can be computed according to the buffer of sink node when increasing number of nodes and fixing number of clusters once and increasing number of clusters and fixing number of nodes in the other once.

a. (BU) When Increasing Number of Nodes And Fixing Number of Clusters:

Figure (4.17) denotes the Buffer Utilization, after applying Eq.(4.2) ,of the sink node by increasing number of nodes in the network and fixing number of clusters to 5. It can be seen from Figure(4.17) when number of nodes increase the buffer utilization increased, because when increasing number of nodes and fixing the number of clusters, this lead to increase the number of nodes in each cluster, and then when cluster head aggregate the packets received from its members, the sink received values from only five nodes represent data of its members. When the network contains 20 nodes the numbers of data packets approximately fill the sink buffer and when increasing the number of nodes in the network, the number of packets decreased.

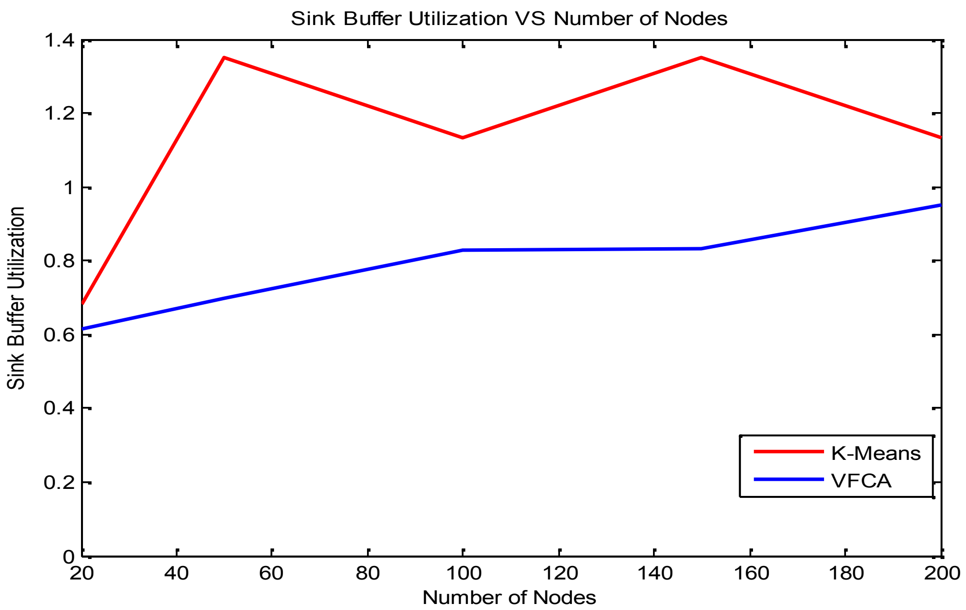


Figure (4.17): Buffer Utilization of Sink Node VS Number of Nodes

The best value of buffer utilization should be less than or equal to one but not greater than one. From the Figure (4.17) it can be seen that the buffer utilization for K-Means algorithm begin smaller than one when number of nodes equal to 20-nodes, and when the number of nodes increased the value of BU increased to value greater than one, which means that the sink buffer lost some on its received packets. But the value of BU when apply modified VFCA does not arise greater than one. This means that the modified VFCA is better than K-Means algorithm, because the modified VFCA managing the buffer accurately so that no losing in packets are happened.

Table (4.3) shows the values of buffer utilization in the sink node with respect to the number of nodes in the network.

Table (4.3):Buffer Utilization in Sink Node When Changing Number of Nodes in the Network

Number of nodes	Sink Buffer Utilization (VFCA)	Sink Buffer Utilization (K-Means)
20	0.6167	0.6833
50	0.7	1.35
100	0.83	1.133
150	0.8334	1.35
200	0.95	1.133

b. (BU) When Increasing Number of Clusters And Fixing Number of Sensor Nodes:

Figure (4.18) denotes the Buffer Utilization of the sink node by increasing number clusters in the network and fixing number of sensor nodes to 400. One can see from Figure.(4.18) when the number of clusters increase the buffer utilization approaches to one because when increasing number of clusters the number of cluster heads sending their data packets to sink node will be increased and this lead to increase the number of data packets arrived at sink node and then approximately all space in the CH buffer will be filled by data packets then when apply Eq.(4.2) the result approaches to one every time the number of nodes in the network increased.

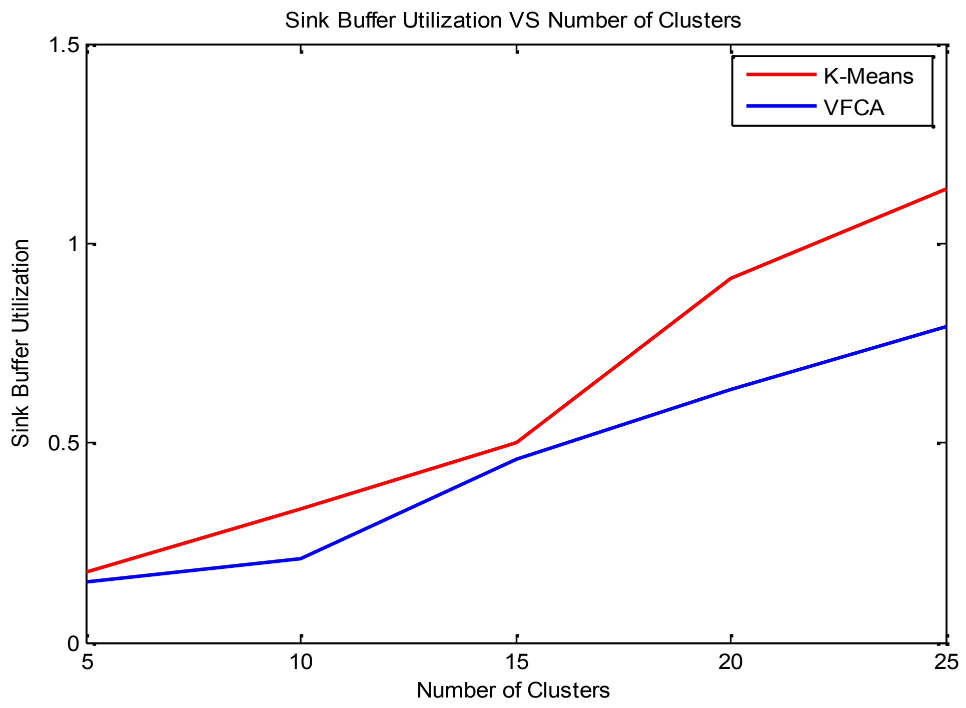


Figure (4.18): Buffer Utilization of Sink VS Number of Clusters in the Network

From the Figure(4.18) it can be seen that the buffer utilization for K-Means algorithm begin smaller than one, when number of clusters equal to 5-cluster in the network and when the number of clusters increased, the value of BU increased too, and when the number of clusters equal to 25 clusters the value of buffer utilization becomes greater than one. The same think happen when applying the modified VFCA but the value of BU dose not arise greater than one. The behavior of the modified VFCA is better than k-Means algorithm. This is because the modified VFCA managing the buffer of sink more efficient than the K-Means algorithm.

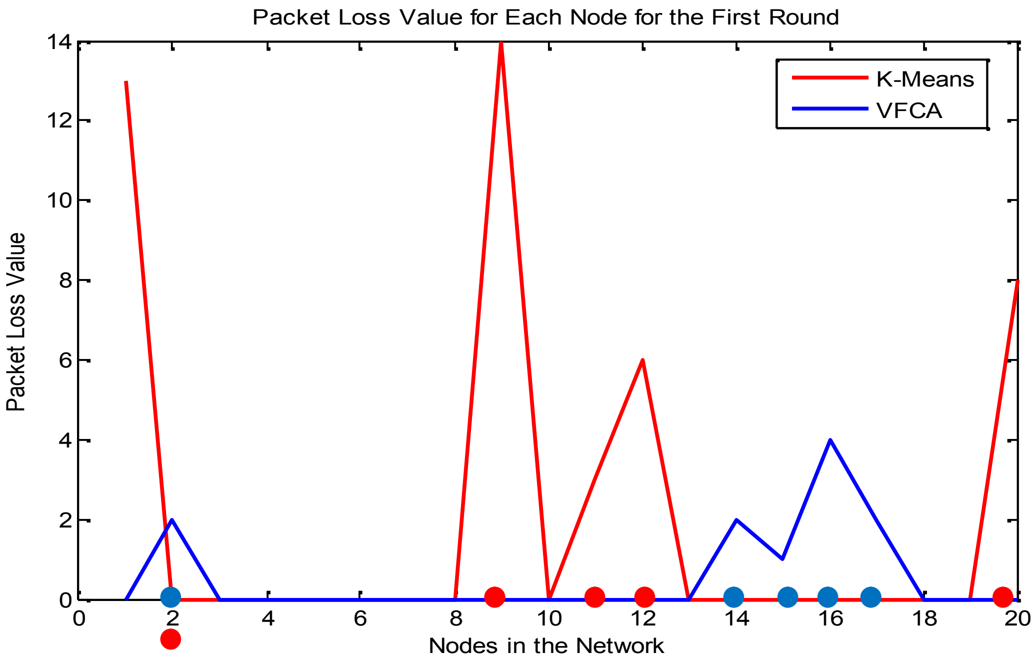
Table (4.4) shows the values of buffer utilization of the sink with respect to the number of clusters in the network.

Table (4.4):Buffer utilization of the Sink When Changing Number of Clusters in the Network

Number of clusters	Sink Buffer Utilization (VFCA)	Sink Buffer Utilization (K-Means)
5	0.1525	*0.176*
10	0.21	*0.3325*
15	0.4575	*0.5*
20	0.635	*0.9125*
25	0.79	*1.1375*

4.4.3 Packet loss value:

Figure (4.19) illustrates packet loss value for each node in the network that consists of 20 sensor nodes divided to 20 voronoi cells and these cells divided to five clusters for the first round. One can see from the figure that only cluster head nodes has packet lost from its buffer because the CH received data from its members and these data may be huge lead to packet loss from CH buffer.Figure (4.19) shows the values of packet lost from each cluster head node in the network that consists of 20 node and divided to five clusters. Table (4.5) shows the cluster head nodes, number of received data at each CH and packet loss values for both VFCA and K-Means algorithm for the first round.



● Cluster heads for VFCA

● Cluster heads for K-Means

Figure (4.19): Packet Loss Value for Each Node in the Network for the First Round

Table (4.5): Packet Loss Value for Each Cluster Head Node for the First Round

	Cluster head nodes	**Packet loss Value**
K-Means	Node 2 - cluster head of first cluster	13
	Node 9 - cluster head of second cluster	14
	Node 11 - cluster head of third cluster	3
	Node 12 - cluster head of fourth cluster	6
	Node 19 - cluster head of fifth cluster	8

Modified VFCA	Node 17 - cluster head of first cluster	2
	Node 15 - cluster head of second cluster	2
	Node 2 - cluster head of third cluster	1
	Node 14 - cluster head of fourth cluster	4
	Node 16 - cluster head of fifth cluster	2

4.4.4 Running Time:

Figure (4.20) shows the running time comparison of modified VFCA with K-means algorithm applying for the network in Figure (4.14). The number of nodes is changed at each time of execution and evaluates the time in both algorithms, the number of clusters constant for both algorithms to find the running time. The number of cluster heads equal to 5. Figure(4.20) shows that the running time of VFCA less than running time of K-Means algorithm. This is because the method of computing the membership functions in the modified VFCA which is repeated in a single voronoi cell, so that the execution of this function is just in the cell and not in all nodes in the cell, and hence the running time will be reduced.

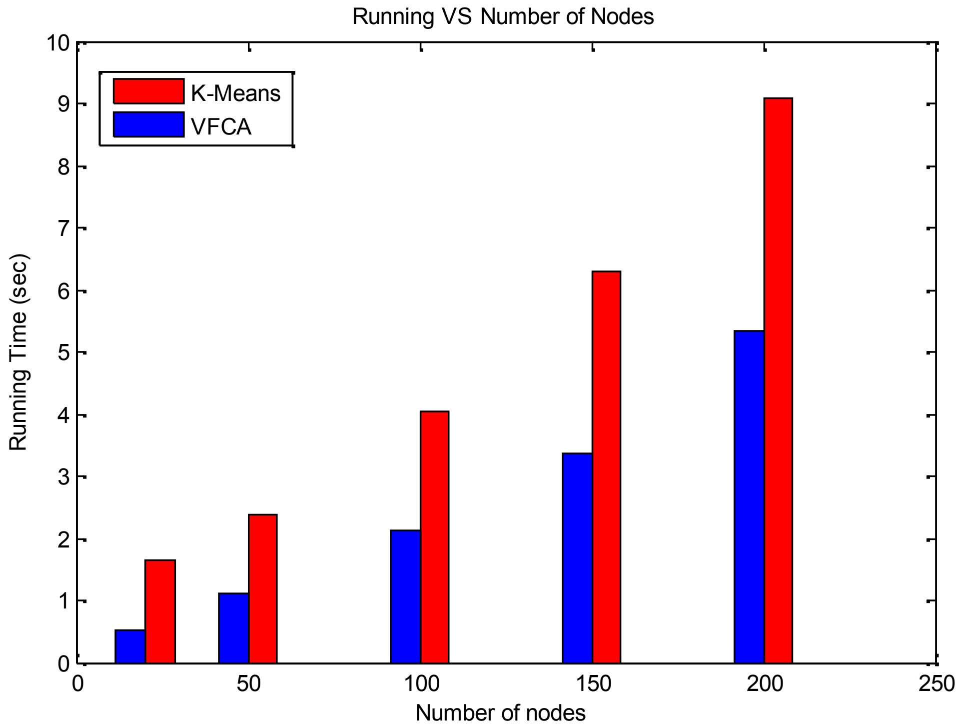


Figure (4.20):Running Time VS Number of Nodes

4.5 An Overall Comparison Between the data aggregation algorithms

Table (4.6) illustrates an overall comparison between modified VFCA, VF algorithm [14], VBGA [15] for different kinds of criteria.

Table (4.6): An over all comparision

Features	*VF algorithm [14]*	*VBGA [15]*	*Modified VFCA*
Initial energy level	Homogenous	Homogenous	Homogenous
Parameters to select CH	Distance and quality of servece parameters	Distance and energy	Energy, packet loss value, and distance
Clustering technique	FCM clustering	Genetic Algorithm	FCM clustering

Compare the sensed data with threshold value	No	No	Yes
Aplying Data Aggregation	Yes	Yes	Yes
Data transmission	Nodes send any sensed data to the CH,then CH send it to the sink node	Nodes send any sensed data to the CH,then CH send it to the sink node	Nodes send only the data that is greater than the threshold value to the CH, then CH aggregate them and send it to the sink node
Buffer improvement	No	No	Yes: by redusing the redundancy in data and sending less number of packets beacause the process of comparing with threshold
Energy efficincy	Good	Good	Very good
Congestion at sink buffer	Occur	Occur	Don’t accur

CHAPTER FIVE

Conclusions and Suggestions for Future Work

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5.1 Conclusions

The work carried out in this thesis proposed an efficient data aggregation algorithm for wireless sensor network. This has been done by developing a wireless sensor network. At first the voronoi diagram are applied for each node in wireless sensor network. Consequently cluster head is selected by fuzzy clustering algorithm. Every node in wireless sensor network sends its sensed data to its cluster head. The data aggregation process is done in each cluster head by taking the maximum values of sensed data. The aggregated value is send to the sink node by the cluster head.

Several points are concluded throughout the modeling of the modified algorithm are explained as follows

❖ The modified VFCA is simulated for clustering and aggregating the data. With (distance and energy) as parameters to select cluster heads. This algorithm is simulated and compared with LEACH protocol. The following points are concluded:

- The modified algorithm increased the number of packets that sending from cluster head nodes to the sink node. And on the other hand decrease the redundant data by ignores the similar sensed data .And this will lead to decrease the traffic on the buffer of both sink node and cluster head nodes.
- The modified algorithm using FCM clustering with Voronoi diagram, decreased the rate of energy consumption and increased the total number

of packets that are successfully transmitted as compared with LEACH protocol.

- The modified algorithm increased the network lifetime as compared with LEACH protocol.
- The improvement of the modified algorithm with and without threshold in terms of network lifetime and average energy consumption are greater than LEACH protocol.

❖ The simulation of the modified VFCA with (distance and packet loss) as parameters to select cluster heads is also introduced. This algorithm is simulated and compared with K-Means algorithm.

- The modified algorithm increased the number of packets sending from cluster head to the sink node. And decrease the redundant data, by ignoring the same sensed data and this will decrease the traffic on the buffer of both sink node and cluster head nodes. While in K-Means the number of packets sending to sink node more than the modified VFCA but may lead to congestion.
- From the results, it can be seen that VFCA approach reduced the number of lost packets in the whole network significantly greater than the K-Means. This is evident in calculating the packet loss parameter.
- From the results, it can be seen that VFCA decreasing the running time as comparison with the running time in K-Means algorithm.
- From results, it can be seen that the modified VFCA improved buffer utilization as compared with K-Means.

5.2 Suggestions for Future Work

Some points might be taken into account for further research and there are some of these points that can be taken into consideration to improve the performance of the system. These points are as follows:

- Applying Particle Swarm Optimization in an algorithm to evidence packets to the sink node safely.
- Using another case of wireless network, for example, can using multiple sink nodes in the network.
- Apply the proposed algorithm for mobile wireless sensor network. Mobility can prolong the network lifetime by continuously relocating the mobile base station or mobile sensor nodes and it can extend the coverage of the network by moving the mobile nodes to uncovered area.
- Calculate the rate for the number of iterations for each time to get the maximum value of the sensed data from cluster nodes, if the maximum value will be repeated from the same node for huge number of rounds. This can prove that the cluster head receive data only from that node and not received data from other cluster members. This process can help to reduce the energy consumption for cluster head node to receive sensed data and aggregate them, also decrease the congestion in the buffer of cluster head node. All these may lead to increase the network lifetime.

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الخلاصة

تجميع البيانات هو النهج الأساسي في شبكات الاستشعار اللاسلكية (WSN)، وذلك لأجل تقليل عدد الإرسال من عقد الاستشعار، وبالتالي التقليل من الاستهلاك الكلي للطاقة في الشبكة. اعتمد هذا العمل على تقنيات تجميع البيانات عن طريق خوارزمية معدلة على أساس *خوارزمية التجميع الـ FCM , مع مخطط الرسم البياني voronoi*. من خلال *الخوارزمية المعدلة (VFCA)*. في الخوارزمية المعدلة، المنطقة المراقبة تقسم إلى عدد من الخلايا تسمى *voronoi cells* من خلال تطبيق مخطط *voronoi*، على المنطقة المراد مراقبتها. يتم تقسيم هذه الخلايا إلى مجاميع باستخدام طريقة التجميع (*FCM*) لتقليل المسافة التي تقطعها المعلومة للوصول إلى الهدف وتقليل إرسال البيانات المكررة من العقد المتجاورة. استخدمت ثلاثة معايير لعملية اختيار رؤساء المجاميع وهي: *الطاقة، بعد المسافة بين رئيس المجموعة والعقد المجاورة له ، و قيم الخسارة من مخزن العقدة*. علاوة على ذلك، يعمل تجميع البيانات عند كل رئيس مجموعة على تقليل كمية البيانات المنقولة خلال الشبكة وهذا يؤدي إلى تمديد عمر الشبكة وتقليل حركة المرور التي قد تتراكم في المخزن الخاص بالـ *Sink Node*. رئيس كل مجموعة يجمع البيانات من أجهزة الاستشعار المنتمية اليه ويحولها إلى *الـ(Sink)*.

أظهرت نتائج المحاكاة لدراسة مقارنة بين الخوارزمية المعدلة *VFC* **والبروتوكول** *LEACH* أن *VFCA* المعدلة هي أكثر كفاءة من البروتوكول *LEACH* من حيث عمر الشبكة ومن حيث متوسط تبديد ومعدل استهلاك الطاقة في *VFCA* معدله أقل من معدل *LEACH*.

وتبين دراسة أُخرى للمقارنة بين الخوارزمية المعدلة VFCA و*K-Means* أن *VFCA* المعدلة هي أكثر كفاءة من *K-Means* من حيث الحزم المرسلة للعقدة المسؤولة عن **للشبكة** (*Sink*). و من حيث قيم الخسارة من مخزن كل عقدة تبين إن الـ *VFCA* المعدلة أفضل من **الـ** *K-Means* ، ومن حيث والوقت المستغرق لإتمام العملية عندما تتم مقارنتها مع **الـ** *K-Means* حيث إن الوقت في حالة تطبيق الخوارزمية المعدلة اقل من الـ *K-Means*.

تم تطوير عملية المحاكاة والاختبار باستخدام برنامج *MATLAB R2010a* في كمبيوتر بوجود الخصائص التالية: *ويندوز 7 (32-bit نظام التشغيل)، كور i7، ذاكرة الوصول* العشوائي *4GB، القرص الثابت 1TB*.

وزارة التعليم العالي والبحث العلمي

جامعة بغداد

كلية الهندسة

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رسالة

مقدمة إلى كلية الهندسة في جامعة بغداد

كجزء من متطلبات نيل درجة ماجستير علوم

في هندسة الإلكترونيك والاتصالات / هندسة الحاسبات

من قبل

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بإشراف

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