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Robust Cluster-based Routing Protocol for Internet of Things

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Dedication

To The sake of Allah, my Creator and my Master,

To My great teacher and messenger, Mohammed (May Allah bless and grant him), who taught us the purpose of life,

To My great parents, who never stop giving of themselves in countless ways, who leads me through from the darkness of life through the light of their love to be the person I'm today

To My beloved sisters; the symbol of love and giving,

To My friends, Family, work and master colleague, who encouraged and supported me, I dedicate this research.

Moath M. Haji

Declaration:

I Certify that this thesis submitted for the degree of Master, is the result of my own research, except where otherwise acknowledged, and that this Thesis study (or any part of the same) has not been submitted for a higher degree to any other university or institution.

Signed...

Moath Mohi Aldeen Orabi Haji

Date: 1/8/2018

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I would like to take this opportunity to say warm thanks to all my beloved friends, collogueseither on work or in university, who have been so supportive along the way of doing my thesis.

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Abstract

Internet of Things (IoT) is a network of physical objects, vehicles, buildings and other elements - integrated with electronic devices, software, sensors, and a network connection that allow these objects to collect and share data. IoT technologies allow things to be sensed and controlled remotely across the existing network infrastructure.

In recent years, the IoT technology has been widely used to describe advanced solutions with different devices connected to the Internet. Despite the fact that the IoT technology is relatively new, the idea of monitoring and controlling devices through computers and networks has been used for several decades by using Wireless Sensor Networks (WSN), but it was limited within the network and it wasn’t as wide as IoT technology.

WSN has been used for sensing in a smaller scale, where it was only controlled by local users. Many researchers have proposed to take the advantages of WSN in sensing process toward the new technology of IoT by providing the internet connectivity for such networks. However, there will be some limitations and challenges to be solved for the success of such transition. The major challenge for such networks is to extend the network lifetime as much as possible.

In order to extend network lifetime for such networks, we have to utilize the energy consumption for sensors as much as possible. Many researches showed that the majority of energy is consumed in the communication process.

In this thesis we proposed a new algorithm based on the Energy-aware routing algorithm called Minimum Residual Hop Capacity (MRHC).Then, we integrated the new algorithm with one of the most commonly used protocol called Low Energy Adaptive Cluster Hierarchal (LEACH).Our new proposed protocol which we called **Robust Cluster-based Routing Protocol (RCRP)** proved its capability to save energy through communication process, and its ability to extend network lifetime with a slightly improvement on the amount of data delivered to the Base Station (BS). As the network lifetime of the new protocol increased by 24% compared to the typical LEACH, and the amount of data delivered to the BS is increased by 38%.

بروتوكول التوجيه المتين القائم على نظام التجمع لإنترنت الأشياء

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الملخص

إنترنت الأشياء (IoT) عبارة عن شبكة من الكائنات -المادية والمركبات والمباني وعناصر أخرى - المتكاملة مع الأجهزة الإلكترونية والبرامج وأجهزة الاستشعار و شبكة اتصال تسمح لهذه الكائنات بجمع البيانات ومشاركتها. و أيضا تسمح تقنيات إنترنت الأشياء باستشعار الأشياء والتحكم فيها عن بعد عبر البنية التحتية للشبكة الحالية.

في السنوات الأخيرة، تم استخدام تكنولوجيا انترنت الأشياء (IoT) على نطاق واسع لتقديم الحلول المتقدمة بإستخدام أجهزة مختلفة متصلة بالإنترنت. على الرغم من حقيقة أن تقنية إنترنت الأشياء جديدة نسبياً، فقد تم استخدام فكرة المراقبة والتحكم في الأجهزة من خلال أجهزة الكمبيوتر والشبكات لعدة عقود باستخدام شبكات الإستشعار اللاسلكية(WSN)، ولكنها كانت محدودة داخل الشبكة ولم تكن واسعة كما هو الحال في إنترنت الأشياء(IoT).

لقد تم استخدام شبكات الإستشعار اللاسلكية WSN للاستشعار على نطاق أصغر، حيث تم التحكم بها فقط من قبل المستخدمين المحليين. وقد اقترح العديد من الباحثين الاستفادة من مزايا WSN في عملية الاستشعار نحو التكنولوجيا الجديدة لإنترنت الأشياء (IoT) من خلال توفير الاتصال بشبكة الإنترنت لهذه الشبكات.

ومع ذلك، سيكون هناك بعض القيود والتحديات التي يتعين حلها من أجل نجاح هذا الإنتقال. يتمثل التحدي الرئيسي لهذه الشبكات في إطالة عمر الشبكة(lifetime) قدر الإمكان. من أجل إطالة عمر الشبكة في شبكات الاستشعار اللاسلكية، يتعين علينا الإستخدامالأمثللطاقة أجهزة الاستشعار قدر الإمكان. حيث أظهرت العديد من الأبحاث أن معظم الطاقة تستهلك في عملية الاتصال.

في هذه الأطروحة ، اقترحنا خوارزمية جديدة تعتمد على التوجيه المدرك للطاقة والتي تسمى الحد الأدنى من قدرة القفزة المتبقية (MRHC). ثم قمنا بدمج الخوارزمية الجديدة مع واحد من أكثر البروتوكولات استخدامًا يسمى بروتوكول الـمجموعة الهرمية منخفضة الطاقة المتلائمة (LEACH) .البروتوكول المقترح RCRPأثبتقدرته على توفير الطاقة خلال عملية الاتصال. وأثبت قدرته أيضاً على إطالة عمر الشبكة مع تحسن في كمية البيانات التي تم تسليمها إلى المحطة الأساسية .حيث ان عمر الشبكة في البروتوكول المقترح قد زاد بنسبة 24% بالمقارنة مع (LEACH) و مع زيادة كذلك في كمية البيانات التي تم تسليمها للمحطة الأساسية بنسبة 38%.

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Acronyms

IoT	Internet of Things
RFID	Radio-Frequency Identification
6LoWPAN	IPv6Low Power Personal Area Network
NFC	Near-Field Communication
LAN	Local Area Network
PAN	Personal Area Network
3G	Mobile 3rd Generation
4G	Mobile 4th Generation
GSM	Global System for Mobile
GPSR	General Packet Radio Service
UWB	Ultra-Wideband
ITS	Intelligent transportation system
WSN	Wireless Sensor Network
LEACH	Low-energy adaptive clustering hierarchy
TEEN	Threshold Sensitive Energy Efficient Sensor Network Protocol
APTEEN	Adaptive TEEN
PEGASIS	Power Efficient Gathering in Sensor Information Systems
GAF	Geographic Adaptive Fidelity
GEAR	Geographic and Energy-Aware Routing
SPIN	Sensor Protocols for Information via Negotiation
SPIN-BC	SPIN –Broadcast
SPIN-RL	SPIN-Reliable
SPIN-EC	SPIN- Energy Conservation
SPIN-PP	SPIN- Point to Point
ADV	Advertisement Message
REQ	Request Message
DD	Directed Diffusion
CH	Cluster Head
BS	Base Station
GIS	Geographical Information System
MTAB	Maximum Total Available Battery Capacity
MTPR	Minimum Total Transmission Power Routing
MBCR	Minimum Battery Cost Routing
MMBCR	Min–Max Battery Cost Routing
MRPC	Maximum Residual Packet Capacity
MRHC	Maximum Residual Hop Capacity
TDMA	Time Division Multiple Access

Chapter One

Introduction

1.1. Background

1.2. Motivation

1.3. Objective

1.4. Problem Statement

1.5. Research Methodology

1.6. Thesis Contribution

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1.8. Thesis Structure

Chapter One

Introduction

1.1.Background

A Wireless Sensor Network (WSN) is a type of wireless Ad Hoc network that contain a large number of low-cost sensor devices spread over an area, where sensors report readings to a data collection destination (sink) or Base Station (BS), periodically or based on demand. Their data can be as simple as measurements of physical parameters, such as temperature, pressure, relative humidity, etc. to as complex as multimedia content, as in recent years. WSN was used for variety of applications, many researches were done in WSN in different aspect. However the interest in the WSN researches increased in the recent few years when a new technology was proposed called the Internet of Things (IoT).

IoThas been defined in many terms and aspect which all can be summarize in general way by making energy thing “object” such as table, watch, light, etc. connected to the Internet. As the IoT depends mostly on making decisions based on sensed values and parameters, many researches proposed new developments in WSNs to achieve the IoT concept.

In this Chapter we show the motivation for going toward WSN, and the objective of our research.We will also introduce the main problem we have solved in this research and how others tried to solve it through different techniques and algorithm and how our protocol solved the problem with a slightly better results. In the last section, we will show a brief description about what each chapter within this thesis has covered.

1.2.Motivation

It is expected that the IoT will be the leading technology according to Forbes [41], where the IoT market and the number of things are currently growing in a rapid way. The development in such technology and its related technologies such as WSN is essential.

As the WSN is the most effective and reliable networks to make the sensing of environment in order to achieve the concept of IoT,researches showed that there are many techniques to integrate WSN into IoT. However, such integrating needs to take into account that the new network will still have the same limitation and drawbacks that WSN is already facing that still need to be solved or minimized.

In WSN, the main metric is the network lifetime, which is a vital issue in designing such networks. Lifetime relies on different factors: First, the covered area, where the wider the area node covers the more power consumed, hence the network life time is much less. Second factor that influence network lifetime as we will discuss in the next chapters is network topology, flat or hierarchal. Finally, the most effected factor is the routing protocol used in communications and data transmission through the network.

Many researches were done to improve the existing protocols or to propose new ones. In this thesis, we aim to propose a new algorithm that can be applied on one of the existing cluster-based routing protocol, to prolong network lifetime as much as possible relying on one of the energy aware routing algorithms.

1.3.Objective

The main objective of doing in this work to propose a new energy aware algorithm that take into account hop by hop decisions rather than path decisions, where residual energy and the expected energy dissipation for transmission to the next hop is considered. Later we will apply this algorithm to single hop cluster-based protocol. In this way we will reduce the energy dissipated in communication within cluster and hence prolong network lifetime for an energy efficient WSN.

1.4.Problem Statement

We are getting into a new era, where everything will be connected to the internet.This type of connection will be either wireless or wired. Wired connection has been used for decades but the upcoming technology of IoT means that every object will be connected to the Internet anywhere and anytime, such requirements requirebetter solution the ordinary wired connection,WSN is the most efficient solution to satisfy the IoT concept.Even that WSN satisfied the IoT concept and it's the main solution to achieve the concept of IoT, it has manyconstrains and drawbacks that are considered as obstacle in the way to develop the IoT networks.

One of the most common issues for the WSN is the network lifetime, as many researches have discussed where the energy dissipates in such networks, many of them showed that the most dissipation on the network happens during the communication process more than any other process. However, as many of the sensors are battery powered and in some of them batteries can’t be replaced or recharged we have to find a solution to extend network lifetime. In this thesis, we have proposed a new algorithm based on residual energy and transmission cost to forward data in a cluster-based protocol to solve the lifetime issue, and to utilize the battery usage within a network as much as possible.

1.5.Research Methodology

In this thesis, the research depends on studying previous works regarding cluster-based protocols, and checking their performance and the desired metrics. Then, comparing these results with the new proposed protocol for the same desired metrics.

We have used the network simulator (NS-2), as it’s an open source software and many researches for WSN were implemented using this software. Besides, it provides online support and documentation as it’s a free software.

1.6.Thesis Contribution

IoT is one of the leading technologies, many researches have connected it to WSN, where the purpose of such network is to monitor and sense some parameters within an area of interest. It consists of many low-cost sensors. Beside, their memory capacity limitations, these low-cost sensors are limited in computation, communication capability and are usually battery-powered devices. Hence, network lifetime is affected and limited, where many applications have these sensor will not be charged or replaced. Hence:

i. We have analyzed and implemented some of the well-known WSN routing protocols mainly LEACH, static clustering and LEACH-C.
ii. We have proposed a new energy-aware algorithm called Maximum Residual Hop Capacity (MRHC).
iii. We have include in the new algorithm two main metrics the residual energy on the receiving node and the expected energy dissipation for forwarding data to the receiving node on a hop by hop base.
iv. We have developed a new routing protocol by integrating the new algorithm into the LEACH protocol. The new protocol called Robust Cluster-based Routing Protocol (RCRP).
v. We have implemented the new protocol (RCRP) and compared the results with the original LEACH, Static Clustering and LEACH-C.

1.7.Literature Review

WSN is one of the widely used technology for the IoT, where a large number of low-cost battery powered sensors are distributed over an area of interest to monitor and observe a range of parameters that could vary from normal environmental parameters to medical or military parameters. However, as the WSN sensors in some applications their battery can’t be replaced or charged, the energy and network lifetime have been the most critical metric that has to be considered and analyzed.

Joanna Kulik et al. [8]proposed a new routing protocol that would extend network lifetime to be longer when compared to original routing techniques such as flooding, the proposed protocol called Sensor Protocols for Information via Negotiation (SPIN),where the nodes negotiate before sending data to each other. Thus, reducing the amount of data transmission within the network.

ChalermekIntanagonwiwat et al. [51]proposed another flat routing protocol called Direct Diffusion, where this protocol solved some of SPIN issues and increased network life time. As the routing process occurs in four phases: interest propagation, gradient establishment, data propagation and reinforcement**.**The initiator of the communication is the base station unlike SPIN protocol.

YaXu et al.[52] proposed another network structure as the location-based protocols consume more energy as all nodes are treated as peer to peer, a new network topology was proposed later based on the location of each node.The authors proposed a protocol calledGeographic Adaptive Fidelity(GAF), where in this protocol the network is divided using a virtual gird into regions, where each region contains a number of nodes which are considered equally cost. This protocol solved some issues of the previous routing protocol had.

Yan Yu et al. [53] proposed another well-known location based routing protocol called Geographic and Energy-Aware Routing (GEAR).In this protocol the data is sent to the destination node area, then the nodes start forwarding the data until it reach the desired node.

Wendi B. Heinzelman et al. [15] proposed a new network topology based on thehierarchical network structure.The proposed a new cluster-based routing protocol called Low-energy Adaptive clustering Hierarchy- Centralized (LEACH), where the network has 2-level of nodes, where the network will be divided into many clusters , and the communication with the base station will be done through an intermediate node called Cluster-Head (CH) , the same authors in [16] have introduced another protocol as an improvement to the LEACH, called LEACH-C, where it differ in the CH selection process as the CH will be selected by the Base Station (BS) according to a pre-knowledge about networks nodes positions. Even though the LEACH was better regarding lifetime, LEACH-C had a better throughput.

Li Qing et al. [50] proposed a new clustering protocol called distributed energy efficient clustering (DEEC) that takes into account both initial and residual energies of each node in CH selection process. This protocol computes the optimal lifetime for the network and predicts the energy for each node based on this computation.

Stephanie Lmdsey et al.[12] proposed another hierarchical protocol, but unlike the LEACH and LEACH-C, it's chain-based the new protocol calledPower-Efficient Gathering in Sensor Information Systems(PEGASIS), where the network nodes form a chain starting from the Base station, this protocol introduces an enhancement regarding network lifetime but with an extensive time delay.

AratiManjeshwar et al. [13] proposed another hierarchical cluster-based protocol called TEEN, where the network has 3-level cluster and the data are not sent periodically. This protocol increased the network lifetime but it's good forspecific applications. Later the same authors[14] proposed an enhancement to this protocol a new protocol called it Adaptive TEEN (APTEEN).

As these protocols are application specific, where some of them are better in a specific applications but the same protocol will be worst in others. In this thesis we have proposed a new algorithm and integrated it into the LEACH protocol to improve network lifetime for IoT application based on WSN.

1.8.Thesis Structure

We have organized this thesis by diving it into six chapters which contain: Introduction, Internet of Things, Related Work, proposed work, simulation and results, and conclusion.

i. **Chapter One**: In chapter one we introduced the IoT and WSN in general in term of motivation, objective, problem statement, contribution, research methodology and literature review.

ii. **Chapter Two**: Literature review about IoT and WSN, and its architecture and technologies and we also proposed the techniques to integrate WSN towards IoT.

iii. **Chapter Three**: Literature review about routing protocol challenges, routing protocol classifications, and a comparison between the discussed protocols. We also discussed some of the energy aware algorithms for multi hop communications

iv. **Chapter Four:** In this chapter we proposed and discussed a new algorithm for multi hop communication based on residual batter and data transmission costs. And also discussed that the new RCRP.

v. **Chapter Five**: We introduced our protocol results and made a comparison with other protocols.

vi. **Chapter Six**: we provided the conclusion of this thesis and suggested some of future works.

Chapter Two

Internet of Things

Chapter Two

Internet of Things

2.1. Introduction

The term Internet of Things (IoT)has been defined in different ways, Bruno Dorsemaine et al.[31] have defined the IoT by taking into account the different types and elements of IoT as "A Group of infrastructures interconnecting connected objects and allowing their management, data mining and the access to the data they generate."

While Luca Mainetti et al. [27] define the IoT as "A worldwide network of uniquely addressable interconnected objects, based on standard communication protocols". On the other hand, Keyur K Pate et al. [30] define the internet of things as "A type of network to connect anything with the Internet based on stipulated protocols through information sensing equipment's to conduct information exchange and communications in order to achieve smart recognitions, positioning, tracing, monitoring, and administration."

Lu Tan et al. [34] adopted different definition for the internet of things. Firstly, they defined the IoT as "Things have identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environment, and user contexts".Also they suggested another definition "Interconnected objects having an active role in what might be called Future Internet", with the new technology of IoT a new dimension has been added to the communication an information technologies, we moved as in [34] to the three dimensions: "from anytime, anyplace connectivity for anyone, we will have connectivity for anything".

The definition of IoT differs depending on the way the author see it,but it always refers to the same concept making the Internet connectivity available to all objects around us in real life, in other word, connecting every object to the Internet.

As the researches in the near past focused on people to machine communications, in recent years with the start of the IoT revolution the direct communication between objects and elements within any network are vital, this type of communication is called as Machine to Machine (M2M). However making every object connecting to the Internet means that every object will have an IP address, but current IPv4 pool is about to be exhausted in many countries. With the tremendous number of object that are expected to be connected leads to the usage of the IPv6.

The main elements IoT technology [36] are: Identification, sensing, communication, computation, services and semantics. Figure 2.1 shows the IoT ecosystem network [46].

Figure 2.1: IoT Network [46].

2.2. IoT Architecture

The IoTarchitecture was proposed in different ways.SriSharanya et al. [29] illustrate the internet of thing consisting of three layers: Perception or sensing layer, Transmission/networkinglayer and the Application layer. In the perception layer the data is collected and processed from the physical world it consists of two parts, the old one includes the Radio-frequency Identification (RFID) label and sensor nodes,camera, and others. The new one is the distribution of many nodes in a given large area of interest.These nodes are used to collaborate and monitor the status of a set of parameters for the surrounding environments. After collecting data they will be transferred and forwarded to the next layer using one of short range communication technologies such as RFID, Bluetooth, Near-Field Communication (NFC), 6LoWPAN (Low Power Personal Area Network).The transmission layer is the layer that is responsible of transferring data between the perception and application layers for a large distance and, many of the communication technologies are used in this layer such as mobile broadband network (3G, 4G, and GPRS), Wi-Fi or wired communication technologies.In application layer, which is considered to be the top level layer, the data will be dealt and processed in order to provide services to the end users. This layer is customized and personalized upon end user needs. Figure 2.2 illustrate the main three layers in the IoT [29].

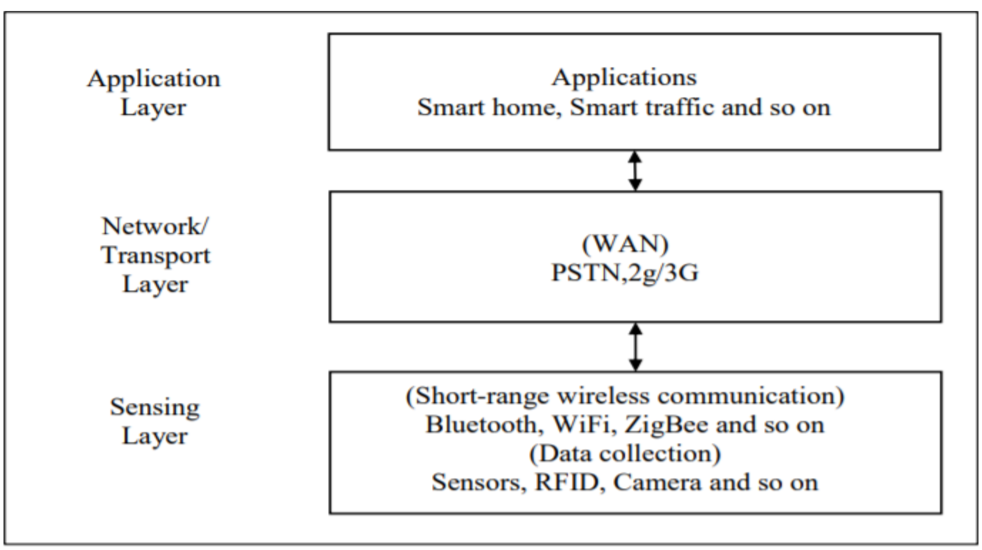


Figure 2.2: Typical IoTArchitecture [29].

There are many other architectures proposed for the IoT, the standard architecture is illustrated in Figure 2.2. However, as the IoT will connect billion of devices in the future, the layers in the IoT architecture have to be more flexible based on the application its used for. Rafiullah Khan et al.[35] introduced another architecture for the IoT. Besides the three main layers introduced in Figure 2.2, they added two more layers: business and middleware layers. This architecture illustrated is in Figure 2.3(**d)**.The Middleware Layeris responsible for the management of services and links the network layer to the databases, as it receives the data from the network layer then processes and deals with the stored data to make the right decision. Unlike the application layer that provides application management, this layer provides service specific management, it also contains the decision unit. The business layer, contains the business models, graphs, flowcharts and overall system management unit. In this layer the business models play a vital rule for the success of the IoT application, as it determines the further actions that will be taken in the future based on the analysis of the results.There are many other architectures that were proposed for the IoT based on the application and the flexibility needs for the overall system. Figure 2.3 Illustrates the different IoT architecture as proposed in [36]. The first architecture is illustrated in Figure 2.3(**a)** where there is another two layers added for middleware-based architecture that are used for the applications that require a middleware between two different independent systems such as WSN and IoT. Figure 2.3(**b)**,illustrates the Service-Oriented Architecture (SOA). The last Figure 2.3**(d),** illustrates the five layered architecture that was discussed before.

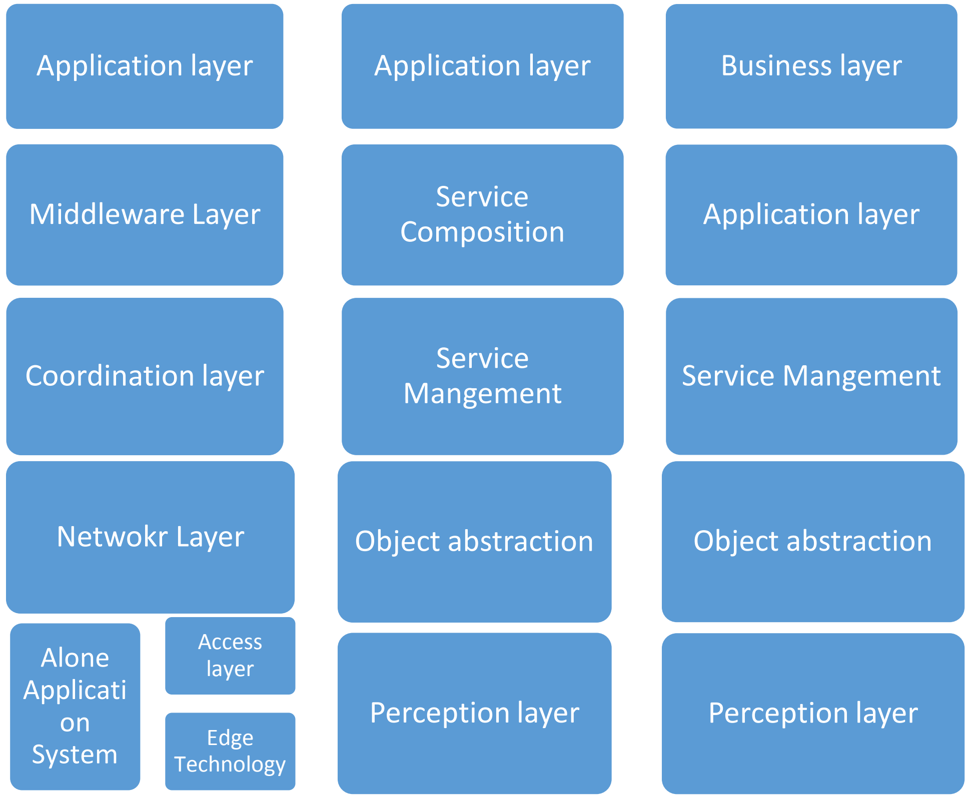


Figure 2.3: Architecture of theIoT: **a)** Middleware based **b)** SOA based **c)** Five layers [36].

There is no standard architecture for the IoT yet, each layer is used based on the researcher's needs or the level of flexibility they need in their application or service.

2.3. IoT Technologies

Keyur K Pate et al. [30] have divided the architecture of IoT technologies into four different layers as illustrated in details in Figure 2.4 [30] where the four layers are:

i. Sensing layer
ii. Network/communication layer
iii. Service support & application support layer (management)
iv. Application layer

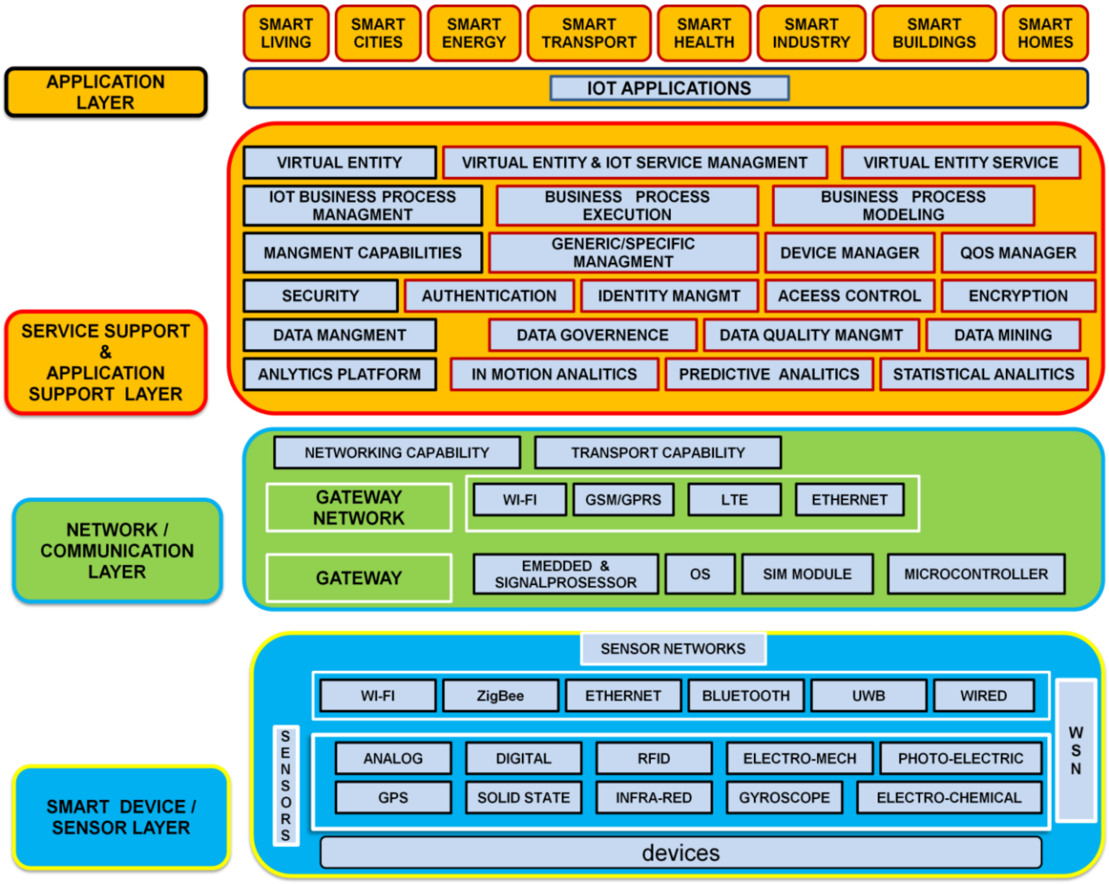


Figure 2.4: Architecture of IoT technologies [30].

2.3.1. Sensing layer

The lower level consists of intelligent objects integrated with sensors. Sensors allow you to connect to the physical and digital world, allowing you to collect and process information in real time. There are different types of sensors withdifferent objectives.

The sensors have the ability to take measurements such as temperature, air quality, speed, humidity, pressure, flow, movement, and electrical, etc. In some cases they may also have a degree of memory, allowing them to record a certain number of sensors and measurement that measure the physical property and convert it to a signal that the tool can understand. The sensors are assembled according to the unique purpose, such as environmental sensors, body sensors, home appliances and sensors, vehicle information technology, etc.

Most sensors require connectivity for sensor gates. These may be Local Area Network (LAN), such as Ethernet and Wi-Fi connection or Personal Area Network (PAN), such as ZigBee, Bluetooth and Ultra-Wideband (UWB). For sensors that do not require a connection to the sensor aggregation, their relationship can be obtained to servers / server applications that use a Wide Area Network (WAN), such as Global System for Mobile (GSM), General Packet Radio System(GPRS) and Long Term Evolution (LTE).

Low-power sensors and low data rates typically create networks, generally known as Wireless Sensor Networks (WSNs). WSN is gaining popularity, because it can absorb a lot of sensory nodes, while maintaining enough independent working time and coverage of large areas.

2.3.2. Network/communicationlayer

A huge amount of data will be produced by these small sensors, and this requires a reliable or high-performance wired or wireless infrastructure. Current networks, which are often associated with very different protocols, have been used to support Machine-to-Machine (M2M) networks and their applications.

With the requirements to serve a wider range of IoT services and applications, such as high speed transaction services, contextual applications, etc., many networks with different technologies and access protocols are needed to work with each other in heterogeneous configuration.

These networks can be in the form of private, public or hybrid models and are designed to support response time requirements, bandwidth or security,different gates (microcontrollers, microprocessors etc.) and gateway networks (WI-FI, GSM, GPRS, etc.)

2.3.3. Management service layer

The management service layer provides the ability to process information using analytics, security controls, process modeling, and device management. One of the main important functions of the service management level is the process modeling and process management of objects.

IoT provides communication and interaction between objects and systems together, provids information in the form of events or contextual data, such as product temperature, current location, and traffic data. Some of these events require filtering or routing for work analysis systems, such as periodic sensory data capture, while others require immediate response, such as emergency response to patient health. The data management and data filtering techniques are used in order to enable a more responsive IoT system.

2.3.4. Application layer

The IoT applications covers “smart” environment including but not limited to: Transportation, healthcare, environment, energy, retail, building, factory, cities, culture, tourism, agriculture and many others. Luigi Atzori et al. [37] and Daniele Miorandi et al. [38] showed the domains of IoT applications, and discussed some of applications in each domain. The IoT applications classified into different domains:

i. Transportation.
ii. Healthcare.
iii. Smart environment (home, office, plant).
iv. Personal and social.

Regarding the transportation we are heading to the new era of transportation under the name of Intelligent Transportation Systems (ITS), where the roadside and cars will have sensors in order to make the transportation easier, safer and more environmentally efficient , under the term of ITS there are many applications for the IoT. In the smart domain, there are many applications for the IoT such as: smart cities, smart home/building, smart business, smart energy systems, etc.

The application that will be used under the IoT technology are countless, and with the development of this technology many applications are expected to be found and used to facilitate people life and make it easier.

2.4. Wireless Sensor Network

The WSN network can be defined as a network of devices, referred to as a node, that can sense the environment and deliver information collected from an observer field (such as an area or a volume) through wireless links. Data, possibly through multiple hops or single hop, is redirected to the sink (sometimes referred to as a controller or monitor or base stations) that can be used to connect to a gateway [23].

2.3.5. SensorNode:

The sensor is a device that collects information from the environment in which it is located. The sensor node consists of four main subsystems: (i) the Sensing Subsystem, this subsystem is responsible of sensing and collecting data from the environment and converting the data from analog to digital signals,(ii) the processing subsystem that is responsible in processing and storing the gather information,(iii) the communication subsystem that is responsible of providing a communication channel between sensor nodes or a sensor and a sink; and finally (iv) the power supply subsystem that is responsible of providing the power to the sensor to do its given tasks [24]. Figure 2.5 shows the main subsystem for a node.

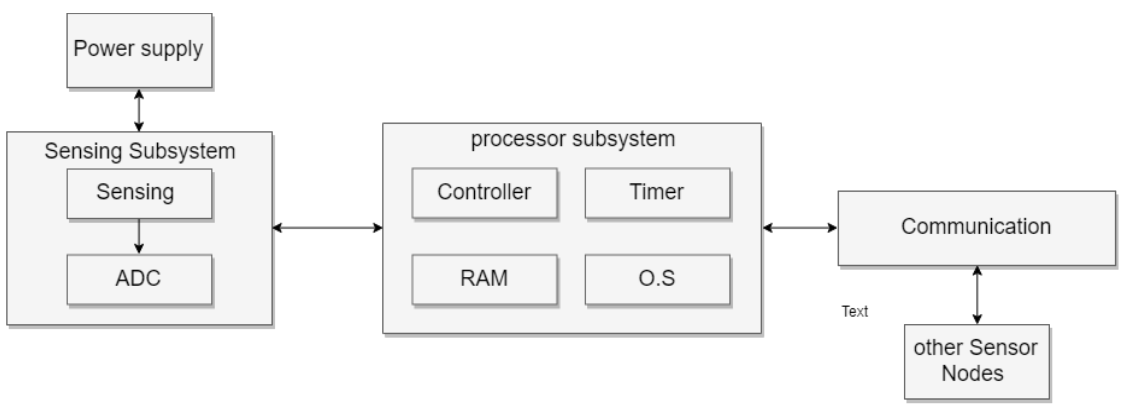


Figure 2.5: Sensor node'ssubsystem [24].

2.3.6. WSNArchitecture

The most commonly use Architecture for wireless sensor networks is the OSI model. As the network will have five layers: application, transport, network, data link, and physical layer. Figure 2.6 shows the WSN architecture [47].

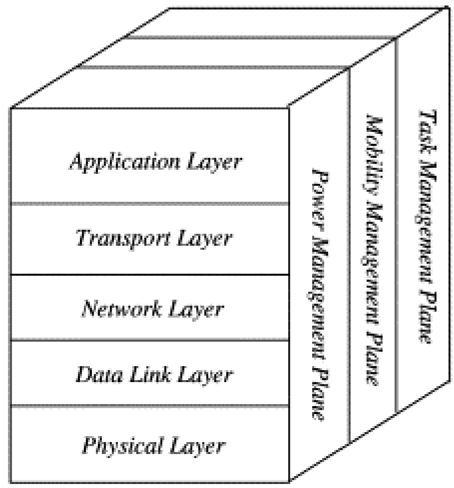


Figure 2.6: WSNarchitecture [47].

The application layer, is responsible for traffic management and it contains a number of software for the applications used in the WSN. The application will be discussed in the next section. The transport layer, main's function is to deliver congestion avoidance and to provide loss recover. It's required when the communication happens with other networks. The network layer, main function is network routing. However, in WSN there are many challenges for such protocols that will be discussed in the next sections in more details. The role of the routing protocols is to forward data to its destination choosing the optimal path to make the network last as much as possible. The data link layer, main responsibilities are multiplexing of data streams, data frame detection, error control and reliability assurance for point-to-point or point-to-multipoint. Finally, the Physical layer, is responsible of sending the steam of bits over a physical medium. In this thesis, our main work will be in the network layer in WSN to make the network last as much as possible and to maintain a higher amount of data to be delivered to the base station.

2.3.7. WSN Applications

There are many types of sensor nodes in WSN that include but not limited to: humidity, temperature, thermal, visual, infrared, radar, acoustic, magmatic, and motion. Due to the large number of sensors types in WSN a wide range of applications exist. We can classify these applications in terms of purpose of use into [24]: military, home, health, environmental, and industrial applications. Figure 2.7 shows the taxonomy of the WSN applications and some of well-known projects on each application area[24].

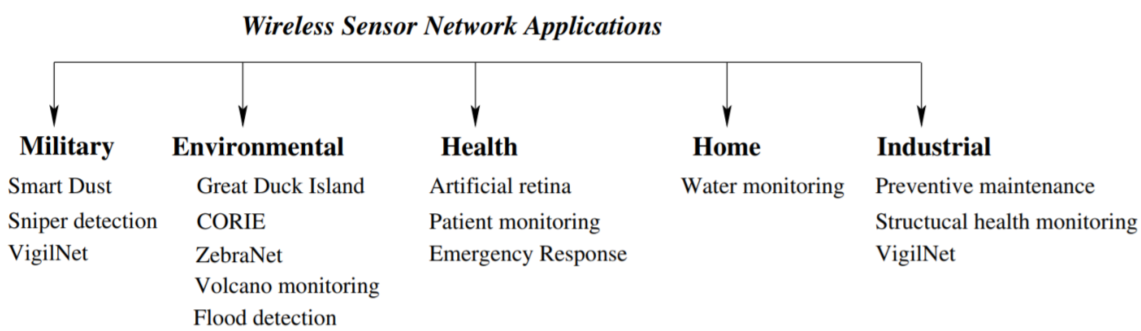


Figure 2.7: Taxonomy of WSN applications [24].

A. Military applications[24]:

WSN can be part of "command, control, communications, computing, intelligence, surveillance, reconnaissance and targeting (C4ISRT) systems", as in the battles it's too dangerous for soldiers to monitor the battle area continuously The WSN is used in order to monitor the battle field in order to take decisions based on the collected information such as motion, hazardous, infrastructure stability and other information. As we can see in Figure 3.2 there are many applications in the military including but not limited to smart dust, sniper detection and vigiNet. In the sniper detection application, the wireless sensor network uses acoustic sensors either stationary on the field or on the soldier arm that detect the position of the shooter based on sound detection. In addition to the mentioned application, the WSNs have been widely used in battlefield surveillance applications, where the detection of enemy movement will help to decrease their attacks. Moreover, WSNs are used for tracking of specific target, where the location of the target is detected by a group of sensors and it will be immediately reported to command station.

B. Environmental applications[24]:

The scientist used to monitor and observe the animal behavior, the environmental phenomenon and many of research fields.With the evolution of the WSN they can now get the results more accurate, less-cost and efficient way. The WSN has been used in variety of environmental applications such as but not limited to: animal tracking (e.g. bird's movement, small animal, and insects), environmental conditions such as humidity, temperature, pollution and others. Figure 2.7 illustrates several of the environmental projects. In the early flood detection project, the MIT made this project by deploying a large amount of low-cost sensors in a wide range area. This project consists of four types of sensors:

- Sensing node: It is responsible of collecting and gathering the required information such as: air temperature and water flow. The sensing of data will be over a period of minutes and will be reported using 900 MHz transceiver.

- Computation node: This node is responsible of receiving the data from the sensing nodes, these data will be used as input in a prediction model, where the data will be processed and based on the prediction model if the data are enough, the action will be taken, otherwise, they ask for more information to be collected.

- Government office interface nodes: This node likes interface for visualizing the network, and could be used for large scale prediction by taking the data from several locations.

- Community interface node: After getting the result and prediction the government office interface node will be connected to a several community interface node in order to inform these nodes interface about the final results.

This system is an example of environmental applications there is much more projects that were deployed as Great Duck island, ZebraNet and many others [24].

C. Health applications [24]:

As the monitoring of patients has been a critical task for the doctors all over the times, with the evolution of the technology many researches and projects have been done in order to develop the medical filed and applications. Health applications in WSN made the medical decision more accurate and helped the doctors to monitor their patient even when they are at their homes. As Figure 2.7 illustrated many of projects in the health and medical area, the University of Harvard has started a project called The CodeBlue [24] that focuses on the wearable sensors to monitor and observe patient vital signs throughout their daily lives. Many other projects where used in the medical filed.

D. Home applications [24]:

The scientists are always looking to deploy the technology to make our life much easier, as the technology advances the sensors were deployed in a variety of home objects such as but not limited to vacuum cleaner, DVD players, lights, microwave oven, refrigerators and many others. One of the projects that has been done as a home applications in the purpose of water monitoring is the Nonintrusive Autonomous Water Monitoring System (NAWMS) [24] , which was deployed as a WSN where the object of this project is to localize the wastage of the water usage, and to inform the owner how to make the usage of water more efficient.The concept of this application is to measure the vibration of water pipe, as the higher the vibration the higher the water flow, two types of nodes are used. the computation node which will be deployed on the water meter, and other vibration sensor nodes that are deployed on each pipe, the computation node will get the data from all other nodes and compare it with the reading on water meter, and according to the collected data, the computation node will calibrate automatically with the sensor nodes and determine the usage for each pipe in the network.

E. Industrial applications [24] :

As industrial filed has been always concerned on reducing the cost and increasing of accuracy and efficiency of their products, the technology has been always the answer and the best choice to achieve their goals. Even though, the biggest companies all over the world focus on the research and development fields beside deploying and getting the best of the latest technology. As the WSN has been the leading technology over the recent years, many projects where proposed for the industrial applications. The preventive maintenance project was one of the mostly used industrial applications, which aims to utilize the usage of the expensive equipment by deploying a large amount of sensor nodes over various pieces of the equipment that sense the vibration of these pieces. This project consists of three levels of nodes: first level, the nodes that are connected to collect the information (the vibration), every set of nodes form a cluster, each cluster has a gateway which represent the second level, that is responsible in collecting data from all other nodes, and sending them to the root node, which is connected to enterprise node that forms the third level. All these levels work collaboratively to monitor the equipment health and report any an expected fault to be fixed immediately.

2.5. WSN Toward IoT

As the concept of the IoT is to introduce a worldwide connectivity for objects over the world, the WSN play a vital rule in order to achieve the IoT concept. The authors in [30] have categorized the technologies that are used in IoT into three main groups:

i. Group one: The technology that contain devices with low power and microprocessor chips such as wireless sensor nodes and wireless sensor network for connectivity.
ii. Group two: The technologies that support sharing and address capacity such as Software Defined Radio and Cognitive Networks
iii. Group three: Management services such as intelligent decision making.

The authors in [28] have introduced the evolution over the past years of the used technologies in the IoT Table 2.1 summarizes a survey of the used technologies in the IoT.

Table 2.1: Survey of the IoT technologies

Year	IoT technology
2004	Smart sensor module using IEEE 1451 standards
2007	Smart sensor based on Web service technology
2009	Digital signal processor and field programmable gate array, Universal Serial Bus (USB) , Controller Area Network bus(CAN)
2011	Zigbee-based wireless sensor network ,WiFi-based wireless sensor network
2013	Zigbee-based wireless sensor network,IPv6 protocol
2014	RFIDs, Wireless Sensor Network (WSN), IPv6 and Zigbee

As we can see that the WSN is the main technology over the past few years. Even though some researchers consider that the IoT and WSN are two combined technology, where they both complete each other but each one of them could be used in standalone system. Johana A. Manrique et al. [22] made a brief contrasting between IoT and WSN in term of application requirements,they both have almost the same requirement. However, WSN is responsible of collecting and gather data to be processed after received by the base station and data will be handled and used by a local computer or a human to make the decision. However, such applications will work more efficiently and timely if we could access to the network externally. This could be done by using both IoT concept and the WSN's. In order to provide the connectivity to the existing WSN externally, the WSN has moved toward the IoT and it was fully integrated.

The WSN transition toward the IoT has some requirements and issues as [32] indicated in:

i. Addressing: As the term of internet is always related to the Internet Protocol (IP), such transition means that there is a tremendous amount of devices that will be connected to the Internet, but current IPv4 is about to be exhausted, and this requires the transition towards the new Internet Protocol IPv6. TeemuSavolainen et al. [45] introduced some strategies for the use of IPv6 into the IoT.

ii. Data availability: Once the node is dead, the data in the covered area by the sensor can't be obtained nor get historical data. However, the existence of a proxy or a gateway will solve these issues.

iii. Protocols and network specific issues: It's already known that WSN nodes are battery powered, and the services should be provided as long as possible. To solve this issue we have introduced a new cluster-based protocol that assure network will operate longer than usual and the cluster structure will facilitate the transition and to solve security issues as well.

In order to integrate WSN into IoT,Rodrigo Roman et al. [32] and DelphineChristin et al. [33] discussed the three main approaches to make such Integration:

In the first approach, sensor networks are not fully integrated into the Internet but they provide their applications and services using standard interfaces. This approach can be done by connecting both Internet and the WSN as two independent networks using a single gateway. **Figure** 2.8 illustrate this approach[33].

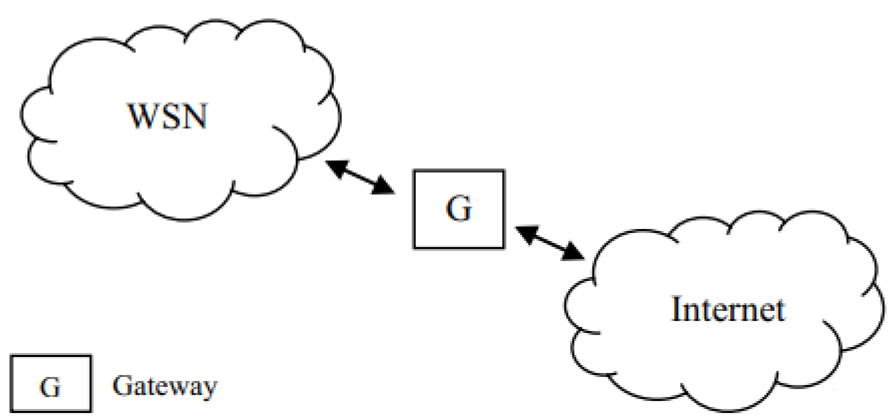


Figure 2.8: First Approach for WSN integration toward IoT [33].

In this approach the Base Station acts as an interface between WSN and the internet. The Sink (BS) is responsible for collecting and sorting of all information from its network nodes. In this approach, there will be no direct communication or connection between nodes and Internet .All incoming and outgoing information will be forward by the base station. As the sensors are completely independent from the Internet and will be using the standard algorithms and protocols rather than Internet protocol. The BS could offer the services to its node using standard mechanisms. This approach has the problem of bottle-neck

In the second approach,the level of integration takes advance step where some nodes are connected to the Internet and some others are still independent. The base station behave as an application layer gateway. In this approach the sensor nodes are able to directly communicate with other internet hosts but with the need to maintain a table to map the node addresses and IP addresses. This approach facilitates many applications to efficiently use the WSN as IoT networks,such as TinyRest.**Figure** 2.9 illustrates this approach[33].

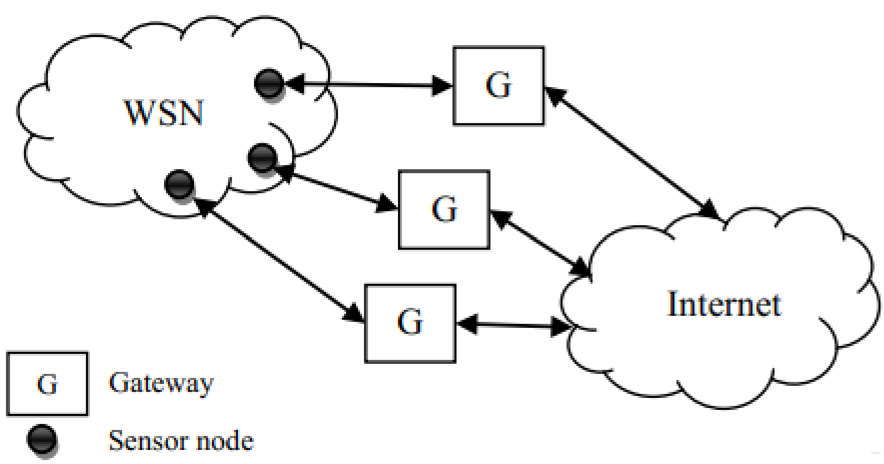


Figure 2.9: Second Approach for WSN integration toward IoT [33].

In the third approach, sensor nodes could communicate with each other's using TCP/IP. The main function of BS will be to forward packets between nodes and from nodes to itself as it will behave as a router or an access point. In this approach, the connection to the Internet will be offered to as a typical WLAN network where the nodes can connect to the Internet by a single hop connection. **Figure** 2.10 illustrates this approach[33].

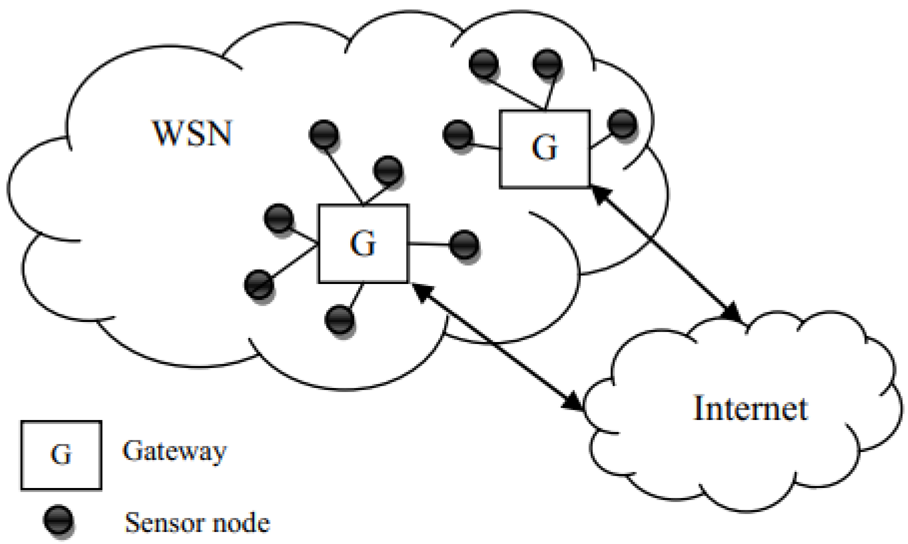


Figure 2.10: Third Approach for WSN integration toward IoT [33].

As we can see the three approaches vary in level of WSN dependency as the WSN in the first approach was fully independent from the internet and the other two have to be integrated into the Internet gradually, some researchers [33] [34] said that this approach still form the first phase due to the variety of applications and sensors used in the existing WSN networks. They believe that the transition has to be made fully and the network will be fully IP-Based in the future. However, the current approaches satisfy the needs that IoT technology offers. The software architecture will be the same for all of these approaches. However, the architecture for software in such network will be as illustrated in Figure 2.11 [44].

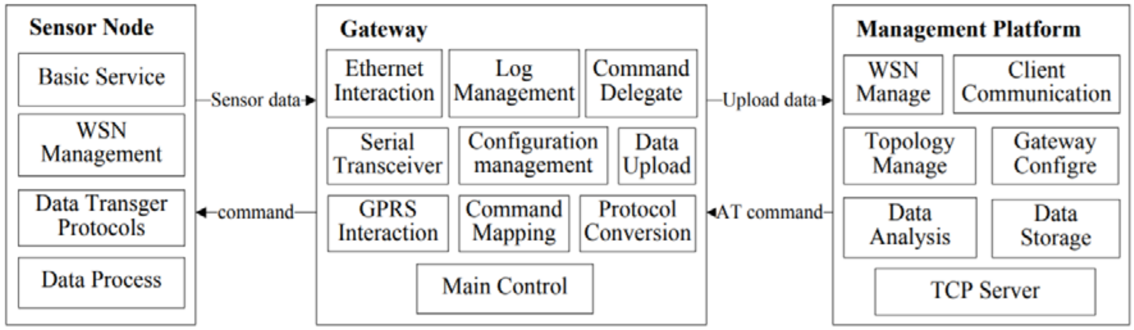


Figure 2.11: Software Architecture of IoT Gateway System [44].

2.6. Summary

In this chapter, we discussed many definitions regarding the IoT and the main concept was about making every object, anytime, anywhere connected to Internet.We also introduced the main component of IoT including perception, transmission/network and application layers. Also, we showed that there are many other architecture used by research in respect of the way they defined IoT and the used applications. We also introduced the main technologies used for each layer and the main applications.

As the recent researches showed that WSN is the mostly used technology in the sensing/perception in the IoT,we discussed WSN networks and showed the main challenges and system requirement for such networks and the main approaches for the integration toward IoT.

In this thesis, we will adapt the typical architecture as illustrated in Figure 2.2, our work will focuson the perception layer and the technology that will be used is WSN, and the integration of such network will be using first approach discussed in this chapter which makes the Internet connectivity through one gateway which will be the same as base station in our network. We will use the cluster structure in order to satisfy the IoT needs now and in the future, where we cloud use the other approaches.

In the following chapter we will discuss the main routing protocol for WSN, also we will discuss the energy aware algorithms.

Chapter Three

Related Work

Chapter Three

Related Work

3.1. Introduction

Wireless Sensor Networks refers to set of sensor nodes scattered over an area of interest to collect and gather data to be used for different type of applications. The term wireless refer to the technology used for the communications among these nodes. The WSN is currently widely used in several applications, with the new technology of internet of thing. This lead to a huge increase in the number of researches regarding WSN. WSN have the same architecture as OSI model. The design of such networks have many challenges and issues including lifetime issue, memory limitation, routing issues.

One of the most researches for WSN is the routing between these nodes, many classifications were proposed for the WSN, in term of network structure, there is different type of networks such as flat, hierarchy and location-based networks.

In this chapter we will discuss the main challenges for WSN and Routing protocols in term of network structure and the main routing protocols. In addition to, we will discuss the main energy aware algorithms.

3.2. Routing Protocols in WSNs

Routing techniques classified in WSN in different terms [7]. In the term of: routing Processing, Network architecture, Network Operations. In this thesis, we will focus on network structure protocols that rely on the architecture of network. Routing protocols in this category are distinguished on basis of nodes connections and technique they follow to transmit data packets from a source to a destination. This leads to the following types of classifications:

- Flat Protocols: The nodes are deployed evenly and have the same role i.e. each node is on the same level within the network. Flat protocols can be categorized as: proactive, interactive, and hybrid protocols.
- Hierarchical Protocols: In this category of protocols, the nodes fall into clusters, and the node with the maximum power becomes cluster head. The cluster head coordinates the actions inside and outside the block. The cluster head is responsible for collecting data from cluster nodes and eliminating redundancy between collected data in order to reduce the power requirements for transmitting data packets from the cluster head to the base station. Example of such category are LEACH, static clustering, TEEN, APTEEN, etc.
- Location based Protocols: Nodes are differed on basis of their location within the network. The distance between nodes is calculated based on the signal strength, the higher the signal, the closer the distance between them. Some protocols in this class allow the nodes to be in asleep mode, if no activity going on at the node Example are: GPSR and GEAR.

In this section we will discuss the main challenges and design issue in WSN, then we will discuss the routing protocol in terms of network structure as flat, hierarchical and location based protocols, and discuss the main routing protocols in each classification.

3.2.1. RoutingChallenges and Design Issues in WSNs[5]:

Even that WSNs share many commons with wired and ad hoc networks, they also have a number of unique properties that distinguish them from the existing networks. These unique characteristics offer new routing design requirements that go beyond wired and wireless Ad Hoc networks. These challenges can be assigned to multiple factors including but not limited to:

i. Energy capacity limitation: Since sensor nodes are powered by batteries, they have limited energy capacity. Energy isa big challenge for network designers in aggressive environments.
ii. Limited hardware resources: Beside, the limited energy capacity, sensor nodes have also limited capacity of processor and storage , therefore they can only

perform limited computational tasks. These constraints make many challenges in network protocol design for WSN.

iii. Data aggregation: Because the sensor nodes may generate significant repetitive data, similar packets from multiple nodes can be assembled and aggregated so that the number of transmissions is reduced. Data aggregation methods were used to achieve energy efficiency and improve data transfer in a number of routing protocols.

iv. Scalability: Routing protocols must be scalable in network size. In addition, sensors may not have the same capacity in terms of energy, processing, perception, and particularly communication. Thus, communication links between sensors may not be symmetric, in other words, a pair of sensors may not be able to have communication in both directions. This should be considered in the routing protocols.

There are more constrains and challenges that affect the design of routing protocols.We mentioned the main and major constrains. More details for routing challenges can be found in [6].

3.2.2. Classification of Routing Protocols in WSNs:

In designing of WSN routing protocols must take into account the challenges that mentioned in the previous section.To meet these challenges several routing protocol strategies have been proposed. One category of routing protocols uses a flat network structure where all nodes are at the same level (peers). The second category of routing protocols imposes hierarchal network to achieve energy efficiency, stability and scalability. The third category of routing protocols uses the location in which the sensor node is processed. Figure 3.1 summarizes the taxonomy of WSN protocols in term of network structure.

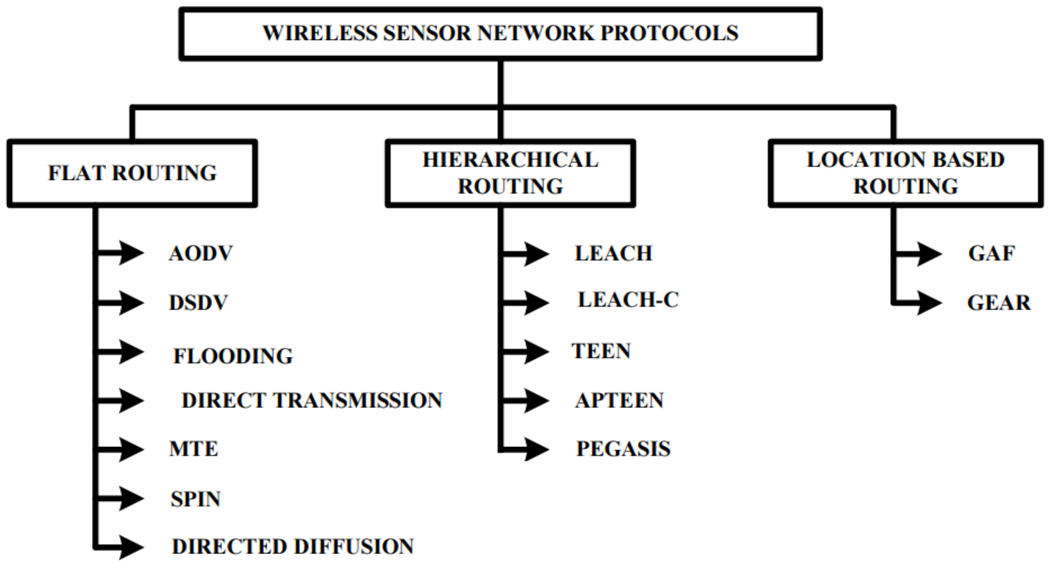


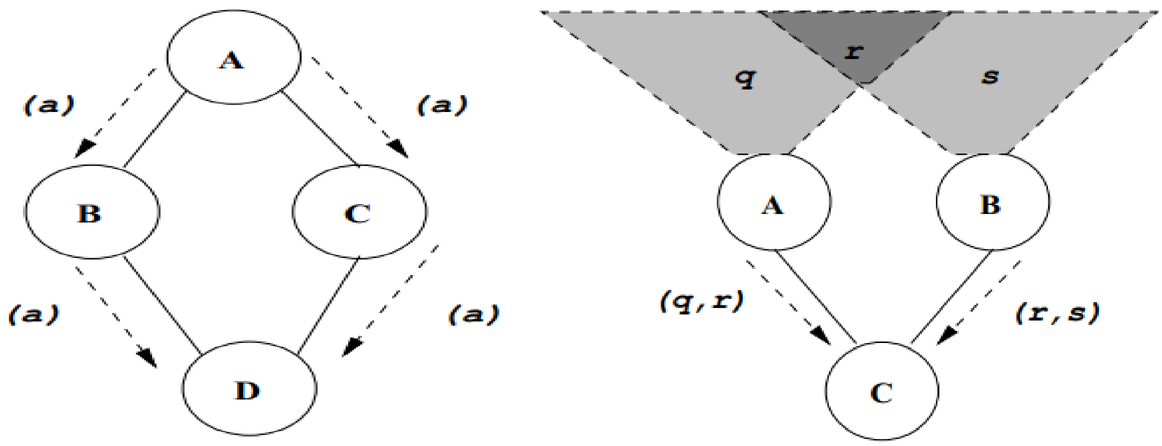
Figure 3.1: Taxonomy of WSN protocols in term of Network structure.

A. **Flat Routing Protocol**:

In flat routing all nodes are considered peers. A flat network architecture has many advantages, including minimal overhead to maintain the infrastructure and the discovery of multiple routes between communicating nodes for fault tolerance. In this section we will describe the main flat routing protocols:

a. **Sensor Protocols for Information via Negotiation** (SPIN)[8]:

As the flooding was used as classical technique to distribute data in sensor networks without the need for any routing mechanism or topology,there were many of problems caused due to the use of flooding technique. The main issue is that the network faced in this technique was the implosion and overlap problems. Figure 3.2 illustrates these two issues [8].



a) **b)**

Figure 3.2: **a**) Implosion problem **b**) Overlap problem [8].

As shown in Figure 3.2(a), the implosion problem, where the same data are delivered to the node **D** from two different routes. Resulting a waste of time, energy and bandwidth for duplicated data. Figure 3.2(b), shows another problem where there is an overlap on the covered area from both sensors **A** and **B** resulting in sending data that have the area r in common.

To overcome these problem, Joanna Kulik et al. [8] proposed a new protocol, they called it SPIN to improve the classical flooding protocols. SPIN protocols are resource aware and resource adaptive. Sensors that operate on SPIN protocols can calculate the power consumption needed to calculate, send and receive data over the network. Thus, they can make informed decisions to use their resources effectively. SPIN protocols are based on two main mechanisms: negotiations and resource adaptation. SPIN allows sensors to negotiate with each other before distributing data to avoid redundancy of the information within the network. SPIN proposed the concept of meta-data, where sensors use meta-data to describe the collected data. In other word, instead of sending the actual data, a meta-data are sent. The SPIN protocol has three main types of messages:

i. ADV message: New data advertisement message is sent by the node that has a new data to share, where it broadcasts advertisement messages to all neighbor nodes containing meta-data.
ii. REQ message: This message is sent by the interested sensors that get the ADV message and want to get the actual data

iii. Data message: This message is sent including the desired data and meta-data header to the nodes that requested for actual data.

The main two protocols in SPIN are SPIN-1, SPIN-2[8]. In SPIN-1, or SPIN-PP the operations are illustrated in Figure 3.3 [8]where the protocol starts once a node has a new data and wishes to share it, it will broadcast the ADV messages, the nodes that receive the ADV messages and wish to get the actual data will send a REQ message asking for the actual data, then data will be sent and shared. This process will be repeated by each node that has data until it cover the whole area of WSN.

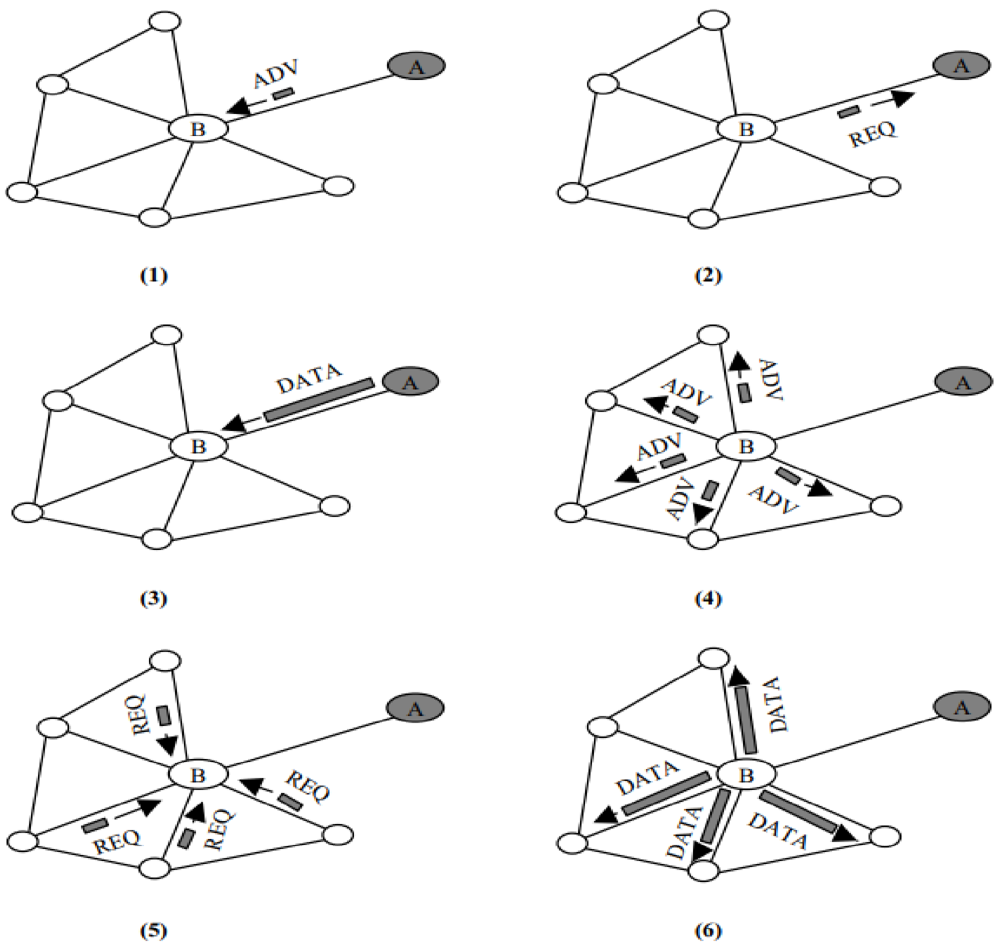


Figure 3.3: SPIN-PP Protocol [8].

As an improvement to the SPIN-1, a new protocol was proposed SPIN-2 (SPIN-EC), it has the same stages.In addition to that it takes into account the residual energy of nodes, as if the node has a low energy it will not participate in data dissipation. There are many other improvements in SPIN such as SPIN-BC and SPIN-RL [9-11].

b. **Directed Diffusion (DD)** [9] [25] [26]

In Directed Diffusion, the traffic flow initiated from the sink, unlike the SPIN protocol where the source node usually starts the ADV message, then the data start being transmitted over the network nodes till it reaches the destination (usually the sink). This protocol consists of four main elements:

i. Interests messages
ii. Data messages
iii. Gradient setup
iv. Reinforcements

In this protocol, the traffic flow starts based on sink demand, where the sink sends interests messages containing the desired type of data to be flooded over the network, this is called interests prorogation phase, the flood could be as normal mechanism or under a certain rules. Each node receives the interest message, stores it in interests cache, which contains the following information: i) **time stamp**is used to store the time the interest message was received, ii) **gradient** which represents the node name from which the interest message was received , iii) interval for sending updates and iv) duration for keeping interest messages. Once a node has data that matches the interest message, it starts to establish a gradients nodes, as there is no limit to the number of gradients that node can have.As a result the data could be send through multiple paths to reach the sink, once the sink receives the data it could reinforce one specific path through sending the interests through a specified node in the selected path, the path selection could be decided for the path that has the best data rate, the one that has the maximum residual energy, the number of neighbors or the source selects the node that data was firstly received from. Once the nodes specify the path will be reinforced and data will be sentfrom each node to the next hop till it reach the source to form a link and then data will be sent only over this path. Figure 3.4 illustrates the DD process [26].

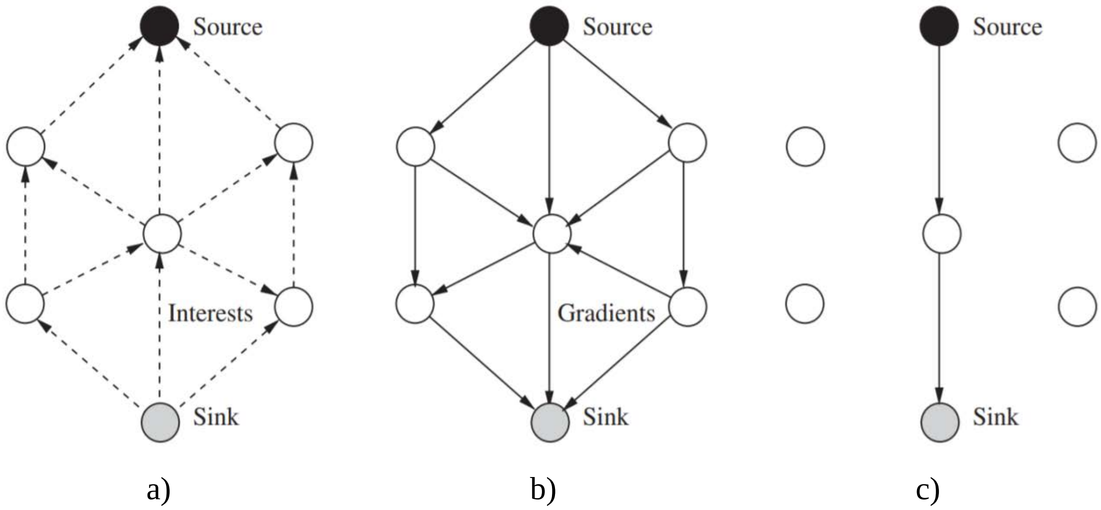


Figure 3.4:**a**)Interest Propagation**b**)Gradient Establishment**c)** Reinforcement and data delivery [26].

B. **Hierarchal Routing Protocols**

In hierarchal routing protocols, network nodes are organized in clusters in which a node with higher residual energy, will be a CH where theCH is responsible for coordinating activities within the cluster and forwarding information to the information sink (BS). Clustering has reduced energy consumption and extended the lifetime of the network in comparison with the flat and location-based routing protocols. In this section the main hierarchal routing protocols will be discussed:

a. **Static Clustering (Stat-Clus)** [43]:

Wendi B. Heinzelman [43]discussed a new hierarchy routing protocols called static clustering protocol. In this protocol,cluster heads are known prior to the network operation. These cluster heads send TDMA schedule to all nodes within cluster. And they remain fixed during the network lifetime. The collected data will be sent to CH which will forward it to the BS. Once all CHs are dead the network no longer operational.

However, what makes this protocol better than flooding or sending data directly is that CH collects data, aggregates it and eliminates redundant data before sending it to the BS. If the CH couldn't do the aggregation, then this protocol would be worse than sending data directly as it hasone singlepoint of failure.

b. **Low-Energy Adaptive Clustering Hierarchy (LEACH)[**15,16]:

It is the first and most popular energy-efficient hierarchical clustering algorithm for WSNs that was proposed for reducing power consumption.In LEACH, the nodes are divided into clusters where each cluster has a CH to aggregate data and report it back to the BS instead of sending it directly. This will reduce the possibility of collisions and the amount of data transmitted to the BS and make the network more scalable and robust. LEACH has two phases:

(i) **Setup phase** where CHs will be selected as each node will select a random number between 0 and 1, and if the number is greater than Threshold (n) it will be a CH otherwise it will be an ordinary node, and the nodes that have been selected as cluster heads before will not be elected once more.

$$\boldsymbol{Trsh(n)} = \begin{cases} \dfrac{\rho}{1-\rho*(r \bmod \frac{1}{\rho})} & \boldsymbol{if\ n \in N} \\ \mathbf{0} & \boldsymbol{othwerwise} \end{cases} \quad \textbf{(3.1)}$$

Where ρ is the desired percentage of cluster head, r is the round number, and N is the set of all nodes.

After the CHs are elected they will send advertisement requests and the network nodes will send join requests to desired CH and the clusters will be formed and CH will create a TDMA schedule for the current round. This phase has presented in [16] as flow chart in Figure 3.5.

(ii) **Steady state phase**, where the CH will send a TDMA schedule to cluster node where each node will send data on its TDMA slot and the CH will aggregate data and send themto the BS. There are many types of LEACH variants introduced in [19].

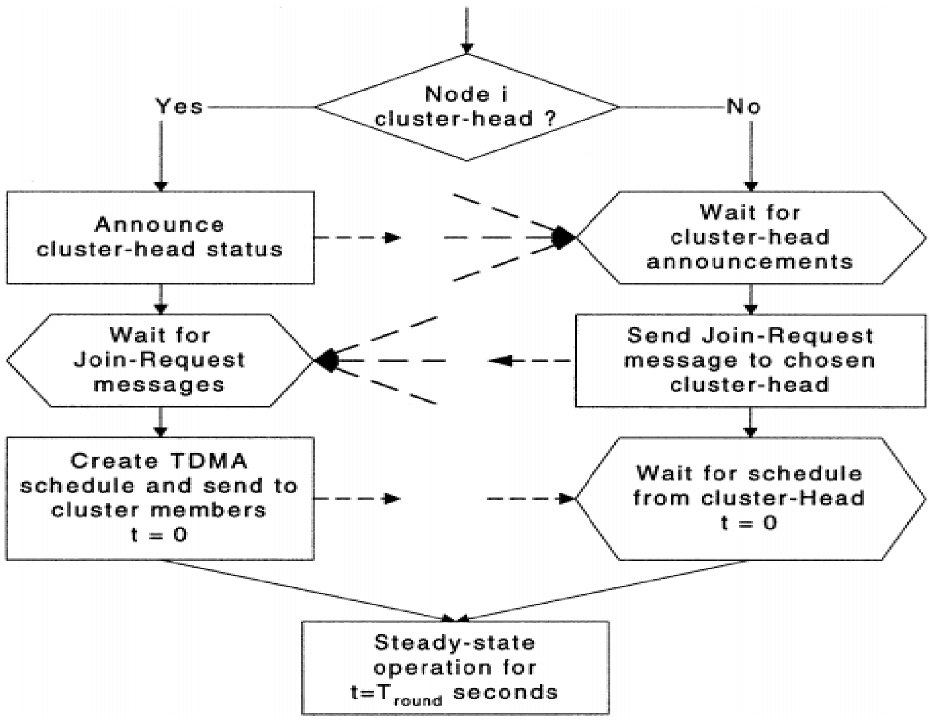


Figure 3.5: Flowchart of cluster formation algorithm for LEACH [16].

Wendi B. Heinzelman et al. [16] introduced a new routing protocol based on LEACH. They called it a centralized LEACH or LEACH-C. As LEACH protocol can't guarantee the place of CH, as there is possibility that CHwill be in the edge of cluster instead of the centerwhich results the further nodes to die due to the high distance. To make the protocol more reliable, the CH selection was improved in the new proposed protocol. Where each node within cluster sends its energy and location to the BS which computes the average energy for the network as any node having less than average energy can't be CH. Based on location and energy,BS broadcast, the CH ID to its cluster. All other phases and data transmission remain the same as LEACH. Figure 3.6 illustrates a comparison between LEACH, MTE (flat protocol) and direct transmission [48].

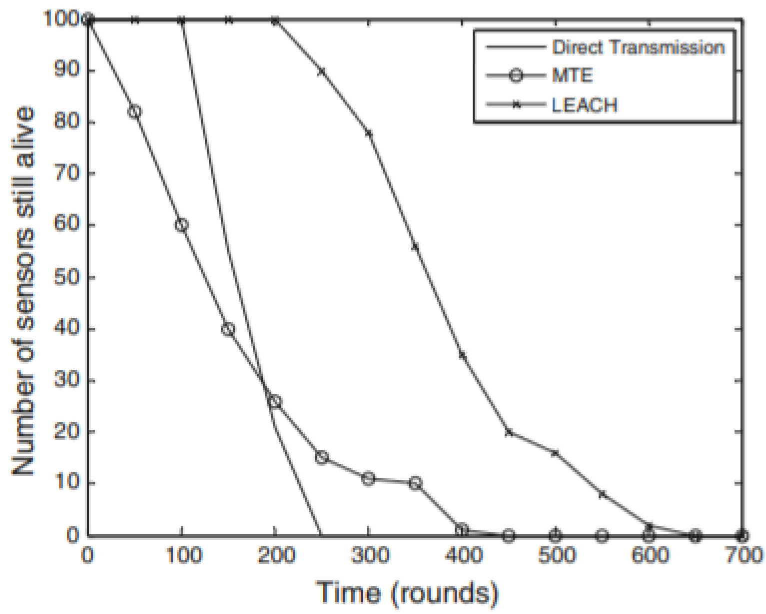


Figure 3.6: Comparison between LEACH , MTE and DT [48].

Figure 3.6 shows that LEACH protocol is better than MTE and Direct transmission in term of network lifetime as it last longer due to the clustering in LEACH protocol.

c. **Power Efficient Gathering in Sensor Information Systems (PEGASIS)** [12]:

Stephanie Lmdsey et al. [12] proposed a new hierarchal routing protocol, where they aim,firstly, to extend the network lifetime by distributing the energy consumption evenly over all nodes in the network;Second, to reduce the delay occurs in the other hierarchal WSN protocols where the data aggregated at specific node (usually CH) before being sent to the BS in this protocol the data sent directly to the base station. The authors assumed that nodes are deployed among an area of interest. Where, all nodes have a global knowledge about all other nodes locations.In the first round the nodes will form a chain starting from BS to the closest neighbor till all nodes in the network are included in the formed chain as illustrated in Figure 3.7.

$$n0 \rightarrow n1 \rightarrow n2 \leftarrow n3 \leftarrow n4$$
$$\downarrow$$
$$BS$$

Figure 3. 7: PEGASIS Chain.

Figure 3.8 illustrate a comparison between LEACH ad PEGASIS in term of network lifetime [48].

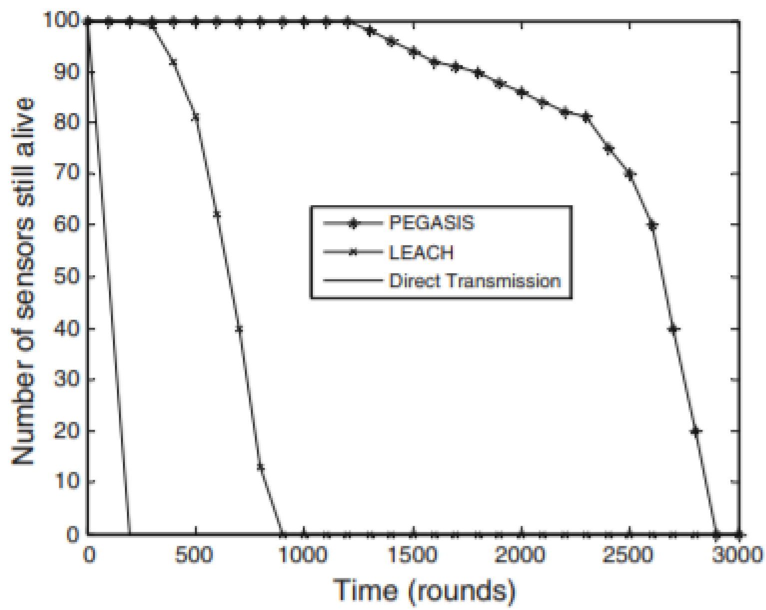


Figure 3.8: Comparison between LEACH , PEGASIS and DT[48].

Even though the experimental results the authors provided showed that PEGASIS outperforms LEACH in certain scenarios that(Figure 3.8) illustrated. However, if the data comes from the furthest node from BS that will cause a high energy consumption over the whole chain which will result that many nodes will die, hence, decreasing lifetime. PEGASIS protocol has a huge delay compared to all other hierarchal protocols.

d. **Distributed Energy Efficient Clustering (DEEC)**[50]:

Li Qing et al. [50] introduced a new cluster-based routing protocol, this protocol take into account both initial and residual energy of each node in cluster-head selection. However, this protocol does not assume a global knowledge of Energy for all nodes. It computes the optimal network lifetime, and predicts the residual energy for a specific round based on some equations. In this protocol, its two level heterogeneous network, where there are two types of nodes, normal and advance nodes. This protocol enhanced the network lifetime on contrast with LEACH protocol.

e. **Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN)** [13][25]:

It's a hierarchical routing protocol that combines sensors into clusters each controlled by cluster head. The sensors in the cluster report their sensitive data to their CH. Every CH sends the collected data to CH at a higher level until the data reaches the receiver. Thus, reducing the transmitting time and increasing lifetime. In the TEEN protocol, beside the attributes CH sends two different values to other nodes: Hard Threshold and Soft Threshold, where the sensed value of interest exceeds the hard threshold the data will be sent to the CH. While the data is being transmitted to the CH, the node keep collecting only the data in the area of interest and storing it. The collected data will be sent later if the change in the collected data exceeded the soft threshold or exceeded the hard threshold. Figure 3.9 illustrate the network topology in the TEEN protocol [25].

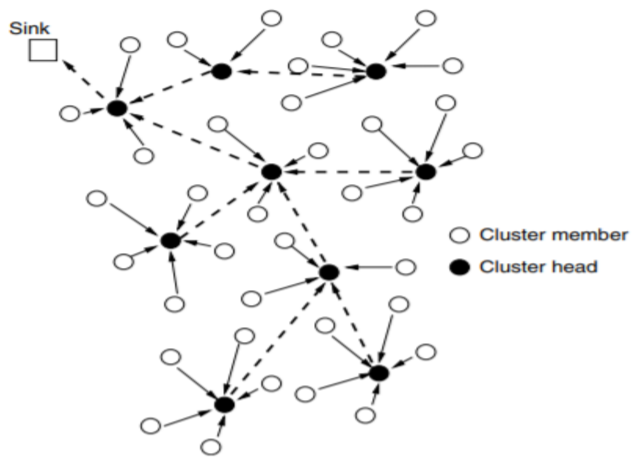


Figure 3.9: TEEN and APTEEN network architecture [25].

However, this protocol is not suitable for networks that require periodically update information, since the user may not get any data at all if the thresholds were not reached. However, the authors in [14] presented a new routing protocol to overcome this issue called APTEEN where the CH sends

i. Attributes
ii. TDMA schedule
iii. Soft and Hard Thresholds
iv. Max Count time (The maximum time period between two consecutive reports sent by the node)

So, it solves the periodically updates issue in TEEN protocol, where if the soft or hard thresholds never reached, or the node gets its time and had no data. The max count time will allow these nodes to send data, hence, solving the periodically update issue. Other hierarchal protocols can be seen in [10] [11] [9] [14]. Figure 3.10 illustrates a comparison between TEEN, APTEEN and LEACH protocol in term of network Lifetime [48].

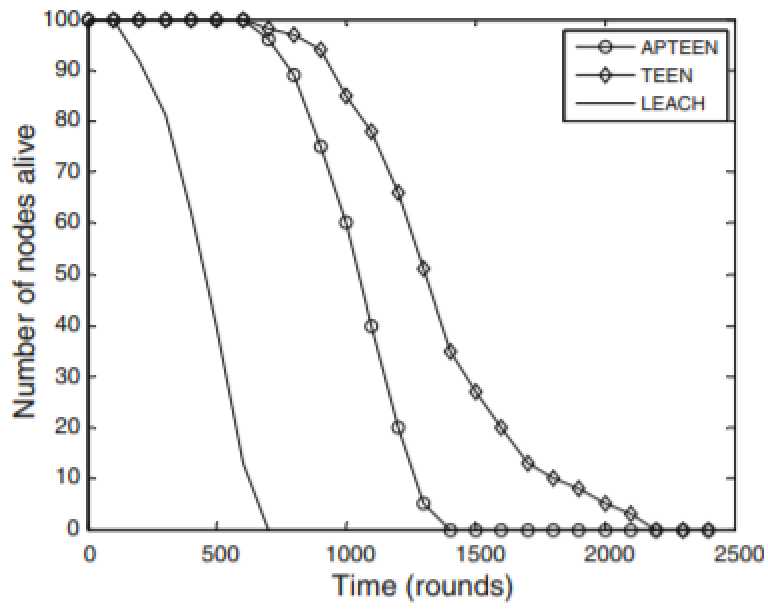


Figure 3.10: Comparison between TEEN, APTEEN and LEACH[48].

Figure 3.10 shows that TEEN outperforms both LEACH and APTEEN in termsof network lifetime as in TEEN that data is not periodically updated or sent to the CH, where in both APTEEN and LEACH there is a periodic update for data.

C. Location-Based Routing Protocols

In Location-based routing protocols the site is used to address the sensor node. A location-based directive is useful in applications where the node's location is related to the geographic coverage of the network by the query from the source node. Such a request may indicate a particular area in which the phenomenon of interest may occur or proximity to a particular point in the network environment.

a. **Geographic Adaptive Fidelity** (**GAF**) [9] [26] [52] :

It is an energy-aware routing protocol, which is proposed primarily for MANET, but it can also be used in WSN, as it contributes to energy saving. In GAF, the network is divided using a virtual gird into regions, where each region contain number of nodes which are considered equally cost. The regions size and gird are predetermined, thus each node knows to what region does it belong assuming it know its location. The nodes within region have three main states:

i. Discovery state: where the node try to discover the neighbors nodes in the gird.
ii. Active state: when the node is within routing process and the transmitter is on.
iii. Sleep state: the node goes to the sleeping state, and turn off its transmitter when it detect that other node is handling the forwarding process.

In case of MANET, each node provides the sink with the predicted period to leave the grid due to the mobility. Once the period is about to expire one of the sleeping node wake up to keep up the routing process.

b. **Geographic and Energy-Aware Routing (GEAR)** [26] [9] [53] :

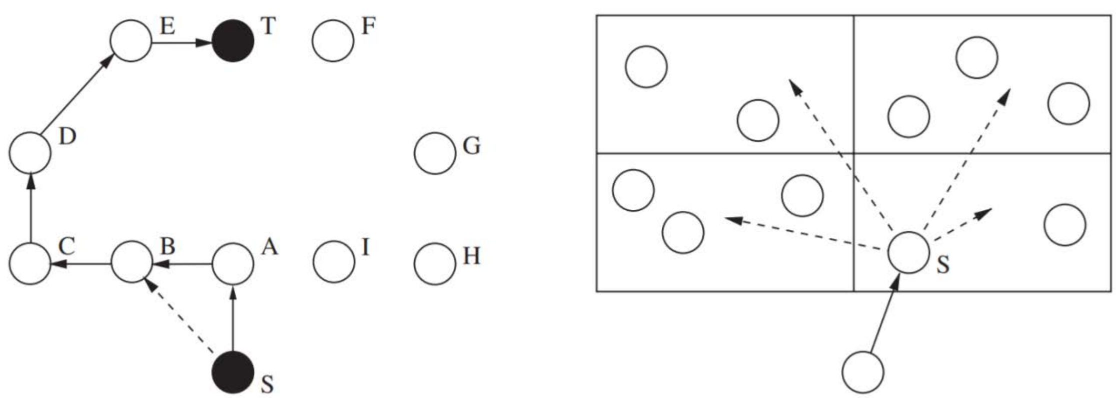
GEAR is one of the most commonly used location-based routing protocol, where it use GIS (Geographical Information System) to know the position of each node within the network. This protocol consists of two phases:

i. **Phase one**: Where data packets are sent to the target area. After receiving the packet, the node looks to one of the neighbors closest to the target area than itself.

Then neighbor will be selected as next hop. If there is more than one suitable node, there is a hole in it this case one of the nodes is selected for packet forwarding is based on the learning cost function.

ii. **Phase two**: Where the data packets are sent to all nodes within targeted area, using either flooding mechanism or recursive geographic forwarding, where the area is divided two four subarea and the packets are duplicated four times, and then the packet will be flooded within sub area and this process will be repeated until there is only one node within subareas. Figure 3.11(b) illustrates the recursive geographic forwarding [26].

In this protocol the cost of routing is calculated in two different ways: (i)the estimated cost, if there is no holes one is, which is the summation of the residual energy of nodes and the distance to the targeted area. (ii)learned cost , if there is holes , which is the cost of paths to avoid holes , if there is holes then the learned cost is higher otherwise it is identically the same. Figure 3.11(a) illustrate the routes learning in order to avoid holes [26].



a) **b)**

Figure 3.11: **a**) Routes learning in order to avoid holes **b**)Recursive geographic forwarding [26].

3.2.3. Comparison of Routing Protocols

Table 3.1 a comparison between the different routing protocols algorithms discussed in this chapter [9].

Table 3.1: ComparisonbetweenRoutingProtocols [9].

Protocols	Mobility	Power management	Network lifetime	Scalability	Resource awareness	Classification	Data aggregation	Query based	Multipath
LEACH	Fixed BS	Maximum	Very good	Good	Yes	Clustering	Yes	No	No
TEEN	Fixed BS	Maximum	Very good	Good	Yes	Reactive/Clustering	Yes	No	No
APTEEN	Fixed BS	Maximum	Very good	Good	Yes	Hybrid	Yes	No	No
PEGASIS	Fixed BS	Maximum	Very good	Good	Yes	Reactive/Clustering	Yes	No	No
SPIN	Supported	Limited	Good	Limited	Yes	Proactive/flat	Yes	Yes	Yes
DD	Limited	Limited	Good	Limited	Yes	Proactive/flat	Yes	Yes	Yes
GEAR	Limited	Limited	Good	Limited	Yes	Location	No	No	No
GAF	Limited	Limited	Good	Limited	Yes	Location	No	No	No

As shown in Table 3.1,Debnath Bhattacharyyaet al. [9] compared all the discussed protocols in this chapter in many terms and parameters, and as we can see that the flat protocols such as SPIN, DD are query based routing protocol, and they both reach the destination using multi-hop routing but the initiator of SPIN is the source while in DD the sink is the initiator of the forwarding process.

But in comparison with the location based routing protocol,they showed that they are similar regarding power management and lifetime with a slightly benefit for the GEAR as the flooding is occur only in the interested region. However, the clustered protocol we could see that they outperform the other protocols regarding power management and network life time, as the network is divided into clusters for TEEN, APTEEN and LEACH.

Regarding network lifetime APTEEN relies between LEACH and TEEN. However, TEEN protocol is not suitable for application that require periodically updates, LEACH and APTEEN offer this periodically updates. In other hands, the PEGASIS protocol is better than LEACH in certain condition and network topology. And the DEEC protocol is almost the same regarding network lifetime in comparison with LEACH. In this thesis we will take in consideration the network lifetime and the data received by base station as a metric for a new protocol we will introduce.

Figure 3.12 and Figure 3.13 shows the network lifetime for the main clustered protocol and the number of data packets received by base station respectively [49].

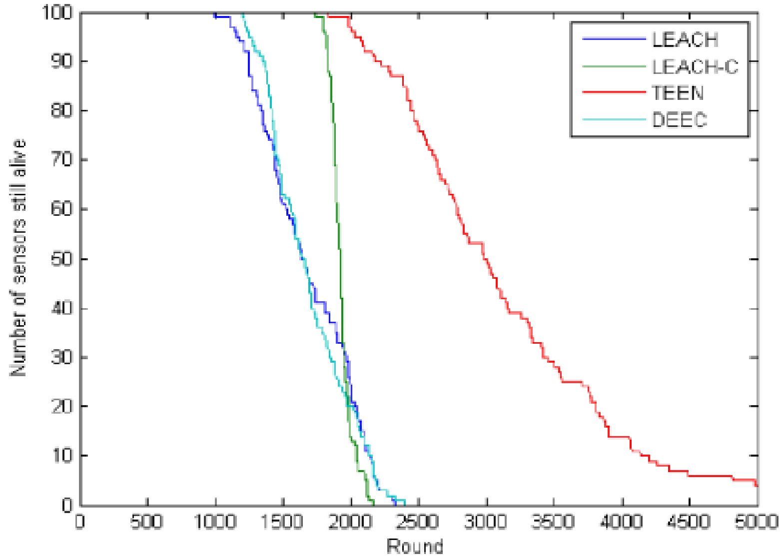


Figure 3.12: Comparison between network lifetime for the TEEN, DEEC, LEACH and LEACH-C protocols[49].

As we discussed earlier that PEGASIS is not suitable for IoT applications as it has a very high delay regarding data delivered to BS. On other Hand, as the simulation shows TEEN outperforms LEACH in terms of network lifetime, but it's not usable for periodically update applications which IoT mainly relies on. Figure 3.12 shows that LEACH, DEEC and LEACH-C have almost the same network lifetime.

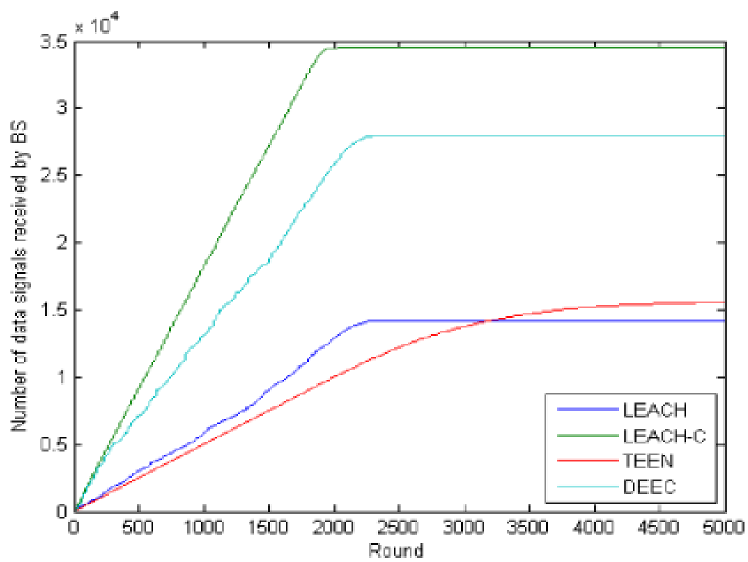


Figure 3.13: Number of data received by BS for TEEN, DEEC, LEACH and LEACH-C protocols[49].

As shown in Figure 3.13, LEACH-C has the maximum amount of data delivered for Base Station in comparison with DEEC, LEACH and TEEN. Even that TEEN has the best network lifetime among all these protocol but it also has the least amount of data delivered to the base stations.

3.3. Energy-Aware Algorithms:

As our purpose is to increase WSN's lifetime as much as possible, and in order to achieve this goal, the modification could be done in different layers: physical, data link and network layer. The network lifetime could be maximized in the physical layer but minimizing the usage of sensor elements such as CPU, memory and others. By controlling the transmission at its least level to maintain the links and reduce the possible interference. On other hand, the lifetime could be maximized as in [18] by introducing an efficient retransmission scheme. In the network layer, the network lifetime could be maximized by introducing a new energy efficient algorithm.

The conventional way in routing is using an energy unaware algorithm [19], where each link is assigned an identical cost. The first algorithm to be used in energy aware was Min-Energy routing [19].In this algorithm the path is selected in which a minimum packet transmission energy without taking into account the battery of the nodes. However,several algorithm were proposed for WSN to extend network lifetime by using energy based routing algorithms. These algorithms are illustrated by computing the total energy drain and dissipated to transmit a packet over each link from a source to a distention over multi-hop routes. And each one has introduced how the cost and energy is calculated and how the optimal route is chosen. In this section the following algorithms will be discussed:

i. Maximum Total Available Battery Capacity (MTAB)
ii. Minimum Total Transmission Power Routing (MTPR)
iii. Minimum Battery Cost Routing (MBCR)
iv. Min–Max Battery Cost Routing (MMBCR).
v. Conditional Max–Min Battery Capacity Routing (CMMBCR)
vi. Maximum Residual Packet Capacity (MRPC)
vii. Maximum Residual Hop Capacity (MRHC)

To illustrate and understand how these algorithms work we will present an example model from [17] as illustrated in Figure 3.14, where the source node will be A and the destination node will be H, the numbers on arrows will be the cost and the numbers over battery symbol indicate the current battery level.

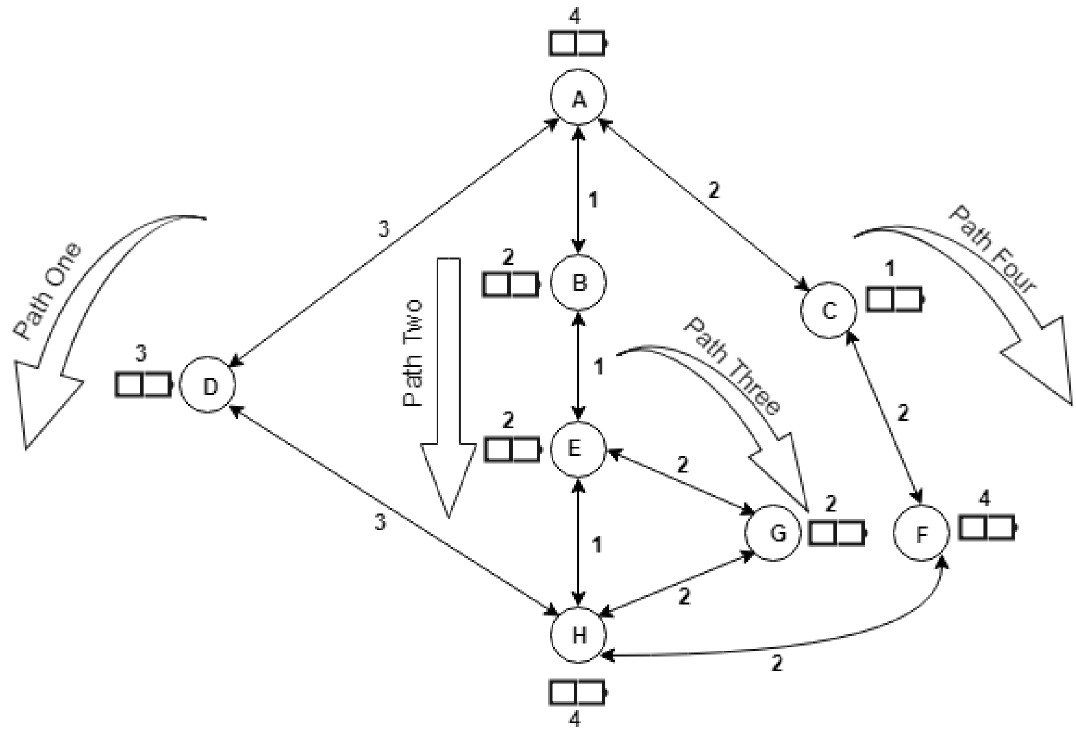


Figure 3.14: Example Model Network for Energy Aware [17].

Figure3.14 illustrate the possible paths to go from the source node A to the destination node H. However, in order to make it easier we also numbered each path to go from source to distention. Table 3.2 shows each path with the corresponding hops.

Table 3.2: Possible paths with corresponding hops.

Path Number	Corresponding Hops
One	A ➔ D ➔ H
Two	A ➔ B ➔ E ➔ H
Three	A ➔ B ➔ E ➔ G ➔ H
Four	A ➔ C ➔ F ➔ H

3.3.1. NetworkLifetime:

The time during which the network is operational, in other words, the time where the sensors are able to perform their tasks (starting with a certain amount of stored energy). However, it is not entirely clear when this time is over. Possible definitions are [17]:

i. The time when the first node dies: the time the first node fail to do its task or run out of energy or fails to operate.

ii. Network Half-Time: the time that half of the network node are out of energy or not able to perform their tasks.

iii. Time to partition: when the first partition is disconnected between two nodes or more. This could be as soon as the first node dies if the dead node in critical position or later if the node is not important.

iv. Time to loss of coverage: this metric is used when the spot is observed with many nodes, as if the spot of area of interest is observed with one node then the first definition is the same as this one, but in redundant deployment of node over the spotted area, the network lifetime will be when any spot is no longer observed by any node.

v. Time to failure of the first event notification: once any of events could not be delivered due to dead node or partition failure the network is said to be dead.

vi. Until all nodes die: the network is said to be dead once all nodes in the network are dead,or the remaining nodes are not able to communicate or report events.

3.3.2. Maximum Total Available Battery Capacity (MTAB) [17]:

In MTAB, the route with the maximum total available battery capacity in nodes within that route, without taking needless detour, is chosen. Mathematically: let us assume that the battery capacity at node iis denoted as B_i, and the routes to destination dare:

$$\boldsymbol{r_d = r_0 , r_1 , \ldots , r_{N-1}} \quad \textbf{(3.2)}$$

Wherer_d is the set of all possible routes to the destination, and N is the number of all possible routes.

Then the function of total available battery capacity P in path L is:

$$\boldsymbol{P_l = \sum B_i} \quad \textbf{(3.3)}$$

The optimal path will be the Max $P_i$in r_d. Table 3.3 illustrate how the optimal route was chosen in the example of Figure 3.14.

Table 3.3:MTAB algorithm.

Path Number	MTAB Value
One	3
Two	2+2
Three	2+2+2
Four	1+4

Path number three have a MTAB value of 6 which make it the max value among all other routes, however it will not be selected as there is extra needless hop (G), so eventually, the path number four will be selected.

3.3.3. Minimum Total Transmission Power Routing (MTPR) [18,17]:

This algorithm make a simple metric of the route where it calculate the total energy consumed within route to reach the destination. Mathematically: let consider a generic route as follow:

$$\boldsymbol{r_d = n_0 , n_1 , \dots , n_d} \qquad \textbf{(3.4)}$$

Where n_0 is the source node and n_d is the destination node, and the function:

$$\mathbf{P}(\boldsymbol{n_i , n_{i+1}}) \quad \textbf{(3.5)}$$

is the energy consumed in transmitting in one hop. Then the total transmitting power over a route L is calculated using:

$$\boldsymbol{P_l} = \sum \mathbf{P}(\boldsymbol{n_i , n_{i+1}}) \ \textbf{(3.6)}$$

The optimal route will be the route with **minimum P Value.** Table 3.4 illustrates how the optimal route is chosen in the example of Figure 3.14.

Table 3.4:MTPR algorithm.

Path Number	TPR Value
One	3+3
Two	1+1+1
Three	1+1+2+2
Four	2+2+2

As we see in the table the path with **Minimum TPR** value is the path number two,thus, it will be selected as optimal path.

3.3.4. Minimum Battery Cost Routing (MBCR) [18,17]:

This algorithm was proposed to overcome one of MTRP disadvantages where only the transmission power is considered and the batter capacity at the node is neglected during the route selections process, which will result to always select the route with minimum power transmission and the nodes at that route will die quickly. To overcome this issue, the remaining battery capacity of each node is considered to define the lifetime of each node. Mathematically: let the battery capacity at node I at time t be denoted as $B_i(t)$ then the battery cost function is

$$f_i(B_i) = \frac{1}{B_i(t)} \quad (3.7)$$

Then the cost of route **L** is:

$$P_l = \sum f_i(B_i) \quad (3.8)$$

Then the optimal route will be the route with the **minimum P value**. Table 3.5 illustrate how the optimal route is chosen in the example of Figure 3.14.

Table 3.5:MBCR algorithm.

Path Number	BCR Value
One	1/3
Two	1/2 + 1/2
Three	1/2 + 1/2 + 1/2
Four	1/1 + 1/4

As path numberone has the minimum value of BCR it will be selected as the optimal path. Where the nodes with Minimum BCR still may select a route containing nodes with small battery capacity, hence these nodes will die. The new algorithm called Min–Max Battery Cost Routing (MMBCR).

3.3.5. Min–Max Battery Cost Routing (MMBCR) [17,18]:

In MBCR, since only the total cost function of the battery is considered, we can select a path that has a node with a slightly remaining battery. To avoid excessive use of a particular nodes the cost function can be changed in order to avoid choosing the path with the nodes that have the smallest capacity of the battery among the nodes on all possible paths. MMBCR allows the nodes with large residual power to participate in the routing process over nodes with low power capacity. Mathematically: let the battery capacity at node I at time t be denoted as $B_i(t)$ then the battery cost function is

$$\boldsymbol{f_i(B_i) = \frac{1}{B_i(t)}} \quad \textbf{(3.9)}$$

Then the function R in route j will be as follow:

$$\boldsymbol{R_j(B_i) = \mathbf{Max}\, f_i(B_i)} \; \textbf{(3.10)}$$

Where **i** is the set of all nodes in route **j**. Then the optimal route is the path **L** that satisfies the following:

$$\boldsymbol{P_L = \mathbf{Min}\, R_j} \textbf{(3.11)}$$

Table 3.6 illustrates how the optimal route was chosen in the example of Figure 3.14.

Table 3.6:MMBCR algorithm.

Path Number	MBCR Value
One	1/3
Two	1/2
Three	1/2
Four	1

As path numberonehas the minimum value of MBCR it will be selected.

C.-K. Toh [18] proposed a new algorithm called Conditional Max–Min Battery Capacity Routing (CMMBCR), where if there are routes which all nodes having a battery level higher than a given threshold, then the route will be selected that requires the lowest energy per bit, otherwise, the MMBCR algorithm will be used.

3.3.6. Maximum Residual Packet Capacity (MRPC) [19]

As its difficult to know the optimal path unless the total packet stream is already known, and as the battery metric is not always the optimal metric to be considered,ArchanMisra et al.[19] introduced a new algorithm that selects the optimal path based on both the residual capacity and expected energy dissipated during the transmission of forwarded packets over a specific wireless link. In other words, this algorithm take into account all metric that are previously mentioned. Mathematically: let us consider the function of node-link metric be as:

$$\boldsymbol{f_{i,j} = \frac{B_i}{P_{i,j}}} \quad \textbf{(3.12)}$$

Where B_i is the battery level of node i and $P_{i,j}$is the transmission energy required by node i to transmit a packet over link(i, j). Then the maximal lifetime over a route L can be presented as:

$$\boldsymbol{M_l = Min\ (f_{i,j})}\textbf{(3.13)}$$

Then the desired route will be the route with the Max M_l value. Table 3.7 illustrates how the optimal route was chosen in the example of Figure 3.14.

Table 3.7:MRPC algorithm.

Path Number	RPC Value
One	3/3
Two	2/1
Three	2/2
Four	1/2

Then route two will be selected as optimal path. As it have the Max RPC value.

Another energy aware algorithm was proposed in [19]. CMRPC, it's a conditional version of MRPC which use the Min-Energy Algorithm as long as specific route is above a specific threshold,once a node is below that threshold it will switch to MRPC. Figure 3.15 [19] show a brief comparison between MRPC, CMRPC, Min-Energy, MMBCR and MBCR.

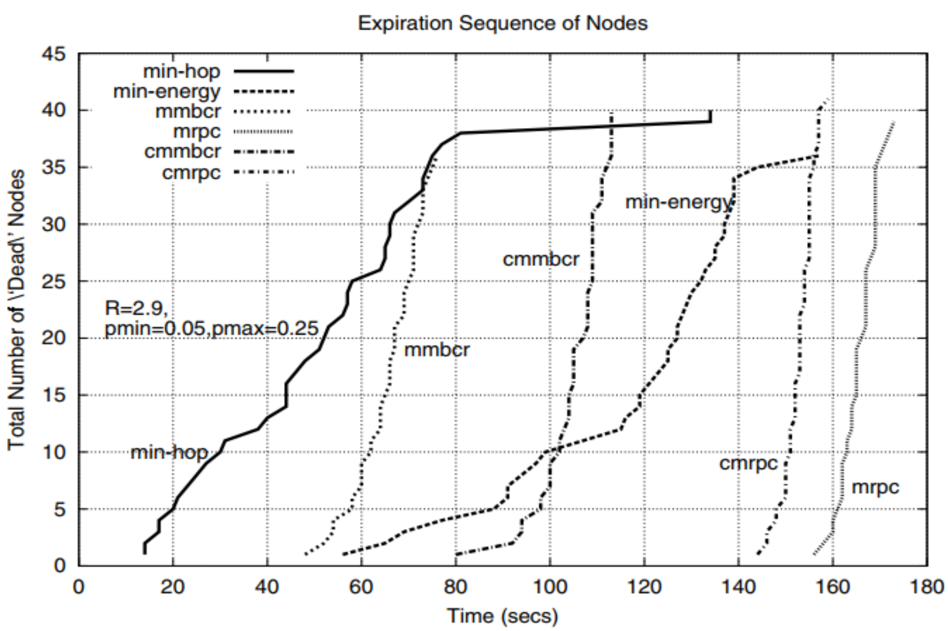


Figure 3.15: comparison between MRPC, CMRPC, Min-Energy, MMBCR and MBCR. [19].

3.3.7. Maximum Residual Hop Capacity (MRHC):

As the main issues on the previously mentioned protocols were in selecting a path which contains a node with low energy, and as that route will be the optimal in many scenarios, it will cause the death of that node. However, regarding the term clustering and as we said before in the previous part, we will use LEACH and LEACH-C protocols,which do not have links and the communication happens using one hop either inter or intra cluster. We have proposed a new energy aware algorithm that make the decision hop by hop instead of choosing paths which will make utilization of each node in the cluster. Hence increasing network lifetime.

In our proposed work, node B will be selected as the first hop to forward the data to the destination.

3.4. Summary

In this chapter we discussed the definition of WSN, as it could be defined as scattering a large number of low-cost sensor network over an area of interest to collect data to be used in specific applications. We also introduced the modules used in these sensor nodes. And later we discussed these networks architecture.

We focused on network layer, where we introduced the challenges and issues we face in routing for WSN. A classification of routing protocols was also introduced in terms of network structure. We have shown that, the main protocols in each category and we have made a brief comparison in table 3.1. The table summarizes the comparison between all discussed routing protocols and the figures showed a comparison between them, but as the WSN's routing protocols are application dependents we can't decide which protocol is better than the others in general, as it relies on the purpose of use. But for our case we have showed that LEACH and LEACH-C are the preferred ones to be used in IoT. We will be using LEACH and LEACH-C in our proposed work in this thesis. In the next part of this chapter, we will discuss the main energy aware algorithm and propose a new one to be used with the LEACH protocol.

We also discussed the main energy aware algorithm used to extend lifetime with taking in consideration many metric such as nodes battery and the routing cost. We discussed all of these algorithm and explained them in term of example to see how the optimal route will be selected in each.

However, ArchanMisra et al. in [19] showed that the MRPC last longer than the previously mentioned algorithms. And that MRPC protocol has a higher throughput than all other algorithm. Which makes the MRPC protocol is the best algorithm among all other mentioned in this chapter. On other hand, we mentioned our new proposed algorithm that use the same metric as MRPC but instead of taking the decision in term of paths, it will take hop by hop decision. Later to be integrated into LEACH in our proposed protocol that we called Robust Cluster-based Routing Protocol (RCRP) that will be used in routing in WSN to maintain a good lifetime for providing a better throughput for sensing in IoT applications.

Chapter Four:

Robust Cluster-based Routing Protocol (RCRP)

Chapter Four

Robust Cluster-based Routing Protocol (RCRP)

4.1 Introduction

As previouslymentioned, the hieratical protocols are better than flat and location based routing protocols, the LEACH protocol is the favorite among all hierarchal protocols where it is suitable, reliable and scalable unlike PEGASIS which outperform LEACH in termsof lifetime under certain conditions but it has some drawbacks if the data being sent come mostly from furthest node in the chain from the BS. Or TEEN routing protocol which is not suitable for IoT where most of the IoT application require frequently and periodically information updated. In our work, we introduce a new version of the LEACH protocol to overcome its drawback and to increase network life time as long as possible to be suitable and reliable over any circumstances that might occurs in the network.

As it's known that LEACH protocol is a one hop communication protocol either intra cluster or inter cluster. In our proposed model we modified the way the nodes communicate within a cluster, instead of sending data directly to the CH the data will be sent through nodes into cluster until it reaches the CH. In order to make the multi-hop communications more energy efficient we used the best energy aware algorithm presented in (4.2) and modified it to be suitable for use in LEACH protocol where there is no predefined links between nodes and CH, and the decision will be more accurate and better as it will be taken for each hop instead of all links. The modification where only in the intra clustercommunication. The CH selection and communication with base station remain the same.

4.2 Maximum Residual Hop Capacity (MRHC) Algorithm

4.2.1. Energy model

The energy model that was used is the same as presented in [15,16]. Figure 4.1 shows the radio energy dissipation model as the authors in [15,16] illustrated.

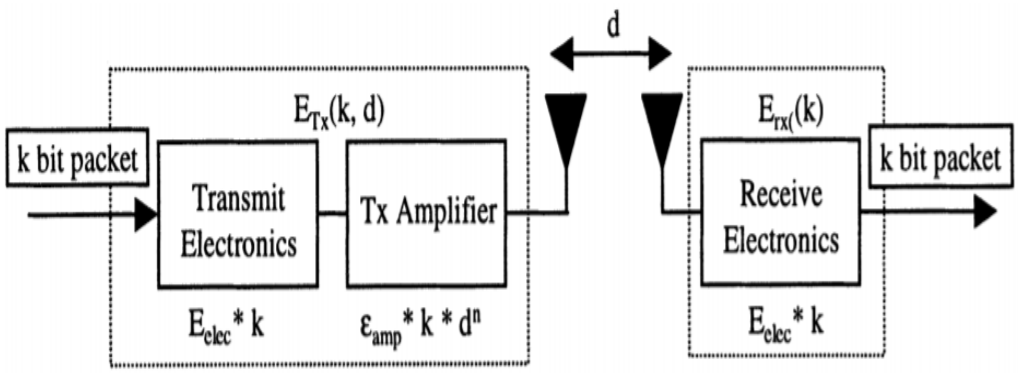


Figure 4.1: Radio energy dissipation model.

The dissipated energy while transmitting will be as following:

$$\boldsymbol{E_{Tx}(k, d) = E_{Tx-elec}(k) + E_{Tx-amp}(k, d)}$$

$$\boldsymbol{E_{Tx}(k, d) = E_{elec} * k + \epsilon_{amp} * k * d^2} \quad \textbf{(4.1)}$$

Where k is the number of bits, and d is the distance between sender and receiver, and the energy dissipated at the receiver side will be

$$\boldsymbol{E_{Rx}(k) = E_{Rx-elec}(k)}$$

$$\boldsymbol{E_{Rx}(k) = E_{elec} * k} \quad \textbf{(4.2)}$$

4.2.2. MRHC Algorithm

As in MBCR, the $f_{i,j} = \frac{B_i}{P_{i,j}}$ where $P_{i,j}$is the transmission energy required by node **i** to transmit a packet over link(i, j). In our proposed algorithm the decision will be made hop by hop so that$P_{i,j}$ represent the energy required for transmitting packet from one node to another via one hop communication and as illustrated in Equation (4.1).

The energy dissipation in transmission relies on two parameters**d** which is the distance between the sender and receiver and k which is the number of data bits, and as the bits are already the same but the distance varies, the $P_{i,j}$ will be replace in our algorithm by the distance between the source node and the next hope.

So the function $RHC = \frac{B_j}{dist_{i,j}}$ where B is the energy at the destination node and $dist_{i,j}$ is the distance between source and distention, the next hop will be the node in the same cluster that has the maximum RHC that satisfies the following condition:

i. **First**, the distance between source node and next hop is less than the distance between the source node and Cluster Head (CH).
ii. **Second**, the distance between source node and next hop is less than the distance between next hop and Cluster Head (CH).

If all nodes failed to satisfy these condition then the next hop will be CH, if no CH selected the next hop will be the BS. Mathematically:

Let us assume that the MRHC will be applied to all $n_j \in N$ Where,

N: is the set of all nodes within cluster

m: is the number of all nodes within cluster

CH is the Cluster Head

$n_i$is the source node

CHD is the distance between the n_i and **CH**,

D is the distance between $\boldsymbol{n_i}$ and $\boldsymbol{n_j}$,

NCHD is the distance between $\boldsymbol{n_j}$ and **CH**,

Next hop is the destination node.

The MRHC algorithm for a single next hop decision is illustrated in Figure 4.2.

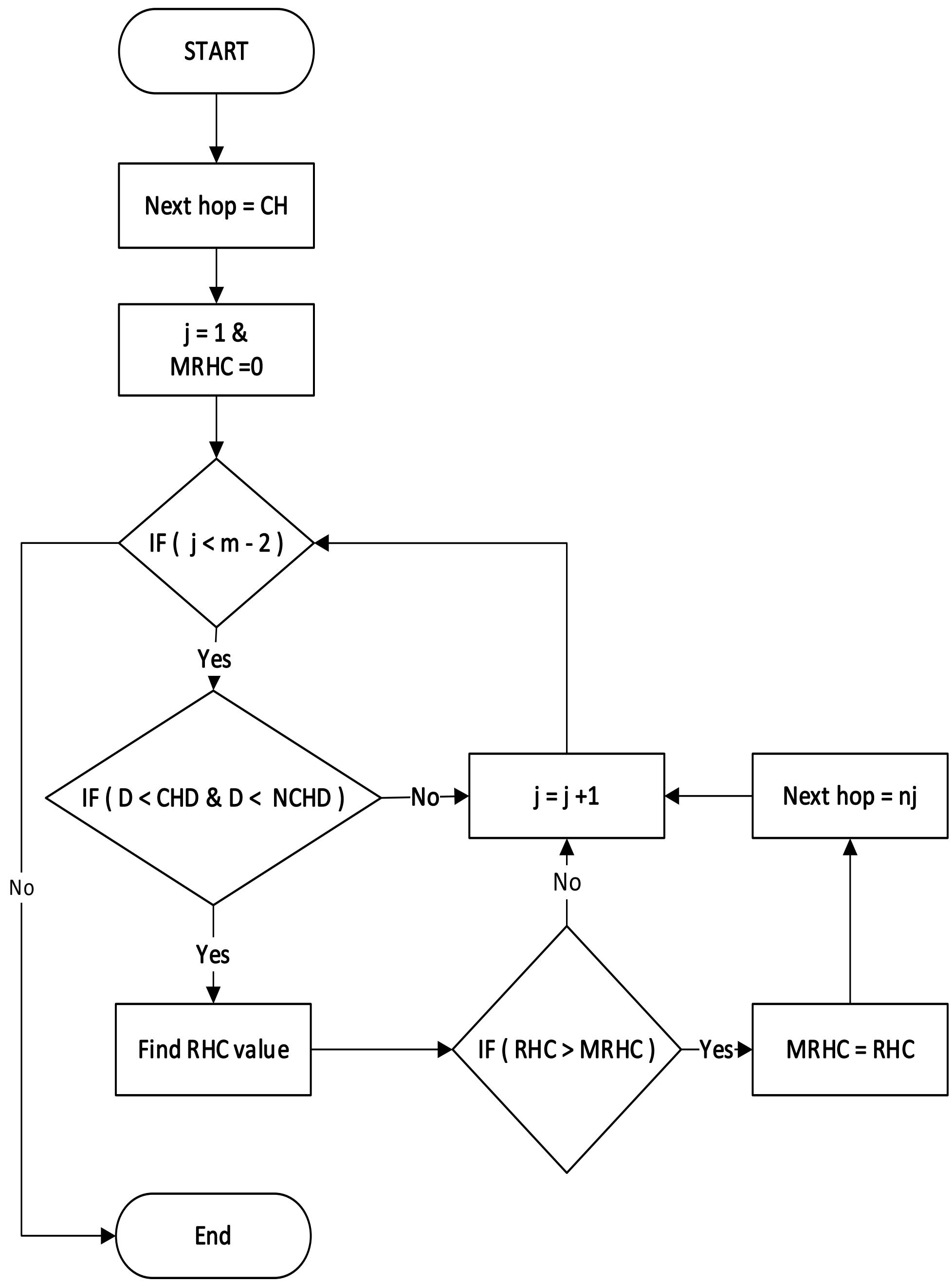


Figure 4.2: A flow chart of the suggested MRHC algorithm.

As shown in Figure 4.2 the usual next hop will be the CH within the cluster as it was before in single hop communication. However, in our new algorithm the default will remain the CH. The node will check the cost (distance) for all other nodes that are closer to the destination node than cluster head. And if the distance between other node and the CH is less than distance between CH and destination node. This process will be done for all nodes within cluster and any node satisfies these conditions and RHC will be calculated. The node with maximum RHC value will be elected as Next Hop and the data will be forwarded to. This process will be done and the number of hops are not predefined. Once the node is the closer to CH and there is not node that satisfies both or one condition the data will be sent to CH directly.

4.3 Robust Cluster-based Routing Protocol (RCRP)

Our new protocol will be changed in term of sending, to be multi hop routing intra cluster instead of single hop the decision will be based on the proposed algorithm. While the communication and routing outside cluster between cluster heads and Base Station and the election of cluster head will remain the same as normal LEACH protocol.

This protocol will contain of two main phases as LEACH protocol: i) Setup phase ii) Steady State Phase. The Network will contain of number of nodes deployed over an area of interest.

i. In the **first step** in this protocol each node within network will choose a random number between 0-1.

ii. In The **second Step**, after the Trsh is calculated as follow [15,16] :

$$\boldsymbol{Trsh(n)} = \begin{cases} \dfrac{\rho}{\mathrm{N} - \rho * (r\,mod\,\frac{\mathrm{N}}{\rho})} & \boldsymbol{if} \;\; \boldsymbol{n} \in \boldsymbol{N} \\ \mathbf{0} & \boldsymbol{othwerwise} \end{cases} \quad \textbf{(4.3)}$$

Where ρ is the desired percentage of cluster head, r is the round number, N is the set of all nodes in network.

Each node will compare its chosen value with the Trsh if the value is less the node will be CH otherwise it will remain as ordinary node.

iii. In The **third Step,** after the cluster heads are elected, they will send advertisement messages to all nodes within network, each ordinary node will send join request to one of the CHbased on the Received Signal Strength Indication (RSSI), then the CH will send the TDMA schedule for all nodes within its cluster. However, in this phase any node is elected as CH can't be elected until $\frac{1}{\rho}$ rounds.

iv. **Finally**, after the creation of clusters and the election of CH, the network starts to do the sensing for the required parameter and each node will send the data to the CH using our algorithm MRHC instead of direct transmission. Then the CH will send the data directly to the BS. The whole steps of the proposed protocol is summarized in the following pseudo code:

Step 1: Setup Phase
1. O_i choose r(0,1)
2. O_i compute Trsh
3. if (r $< Trsh$) The O_i become CH
4. else node will remain O
5. CH $\rightarrow$ N : id_H, Adv
6. O_i $\rightarrow$ CH : $id_{O_i}, id_H, Join\_Req$
7. CH $\rightarrow$ N : id_H , $(\cdots, < id_{O_i}, t_{O_i} >, \cdots), Join\_Req$
Step 2: Steady State Phase
1. O_i $\rightarrow$ CH : $MRHC(d_{O_i}, id_H)$
2. CH $\rightarrow Bs : (id_H, id_{Bs})$

Algorithm 4.1: RCRP Pseudo code.

Where CH is cluster head, O: ordinary node, BS: base station, N: set of all nodes, MRHC: maximum residual hop capacity algorithm, and $(\cdots, < id_{O_i}, t_{O_i} >, \cdots)$ is the TDMA schedule. Figure 4.2 Illustrates the RCRP flowchart. The sequence diagram for this protocol is illustrated in Figure 4.3 for a single hop decision to send data.

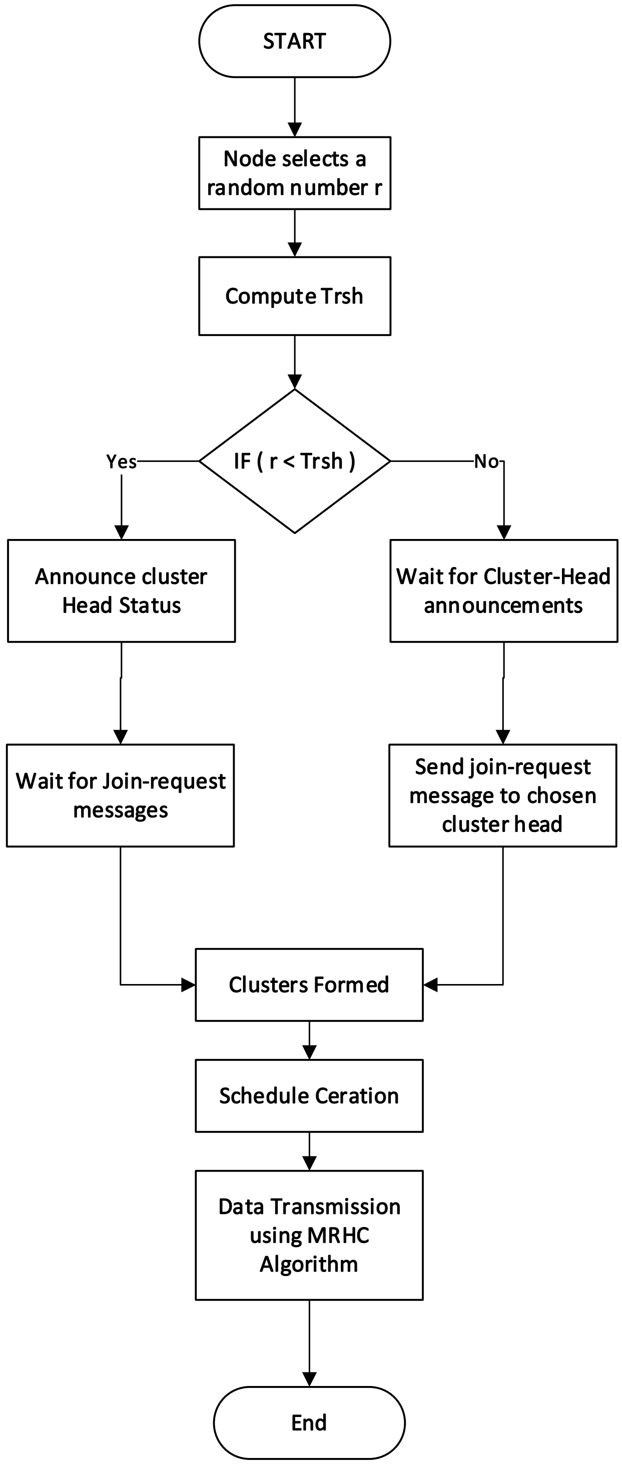


Figure 4.3: RCRPprotocolflow chart.

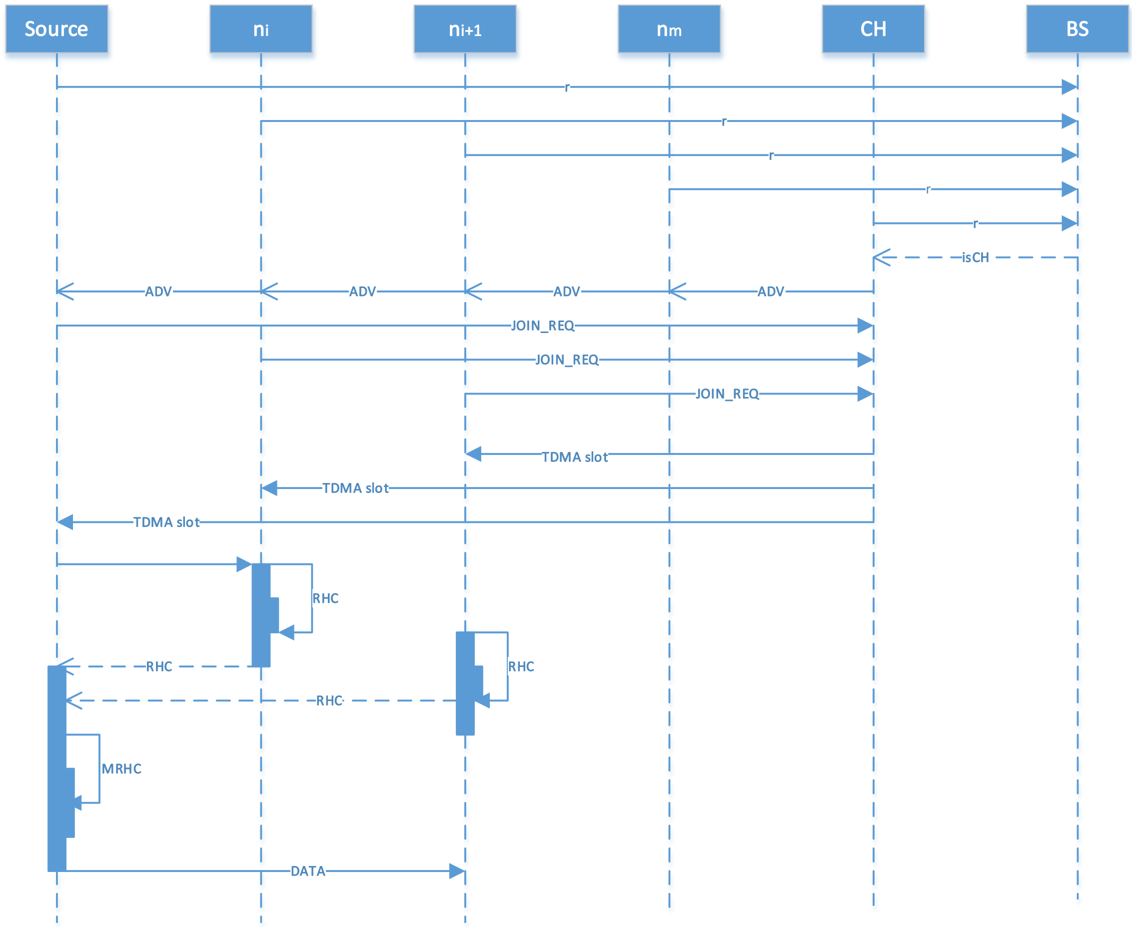


Figure 4.4: RCRPSequence Diagram Chart.

As Figure 4.3 shows the Flowchart for our new proposed protocol RCRP for each round. However, the CH selection process in the flowchart discussed the election when all nodes have the same initial Energy. When the residual energy is different for nodes the election will be based on the residual energy the CH will be the node with the minimum residual energy.

$$\boldsymbol{Trsh(t) = min\left(\frac{E_i(t)}{E_{Total}(t)} * \rho\right)} \textbf{(4.4)}$$

$$\boldsymbol{E_{Total}(t) = \sum_{i=1}^{N} E_i(t)} \textbf{(4.5)}$$

Where N is the set of all nodes in network.

4.4 Summary

In this chapter we have shown the basic energy model we will be using in our simulation, we also proposed a new energy aware algorithm that will be used and integrated in the LEACH protocol, we also have shown the pseudo code after integrating this algorithm in LEACH protocol.

In followingchapter we will simulate both LEACH and LEACH-C. Moreover, we will apply the new algorithm MRHC for LEACH protocols in communication process within cluster and we will show the result for RCRP, LEACH and LEACH-C.

Chapter Five

Simulation and Results

Chapter Five

Simulation and Results

5.1 Introduction

In this chapter we will give an overview of the used parameters for the tested protocols, we have implemented the new algorithm in the original LEACH protocol, we will compare the original LEACH with our new proposed and centralized LEACH (LEACH-C). As we mentioned before our ultimate goal is to increase the network lifetime as much as possible maintaining the same or even better data sent to the BS from the sensing area.

However in our simulation we assume that: each node always has data to send to the CH, also that the nodes are static, and that all nodes have same initial energy level. Even that initial energy we can make it randomly in our code. But for a better result and to get away from the randomness we proposed that all are equal and have the same initial energy.

5.2 Simulation Tool

The lab test of WSN are very costly and difficult. In addition to, that running experiment test for the WSN require a lot of time to be done, and can't isolate the network to test for example the effect of one parameter. As the WSN is usually tested for a large scale the Simulation would be the best way to test the behavior of the new protocol over a predefined or random networks.

In this Thesis, we used the NS-2 as a simulator [40, 41], it stands for network simulator version two. NS2 was firstly developed by 1989 using as real network simulator. Nowadays it is used to simulation for research and projects.

NS2is a discrete event Simulator what makes it more favorable that it is not specific to a certain type of networks, it could be used by many of network type as MANET, WSN, Ad-hoc networks and many others. It also contains a free no-commercial package for existing and standardized protocols.

NS2 is basically developed using C++ and Object-oriented extension of Tool Command Language (OTcl) as a front end. It also could be run in both Linux and Windows using (Cygwin). It’s widely used in many published papers in many decent journals.

For the previously mentioned purposes in addition to, that NS-2 support many protocols over different layers, and it’s a free simulation tools with online support and documentations which allow the code to be easily modified or changed, and for the continuous support and bug fix.

In this thesis, we used ns2.34 on ubuntu 10.04 LTS 32 bit operating system in VMware Workstation to simulated our new proposed protocol and compare it with other protocols.

5.3 Evaluation Metrics

As we discussed in Chapter Four regarding the network lifetime, there is many definition used for the network lifetime which are:

i. The Time when the first node die.
ii. Network Half-Time.
iii. Time to partition.
iv. Time to loss of coverage.
v. Time to failure of the first event notification.
vi. Until all nodes die.

In thiswork we would take the last parameter where we defined that network is dead once all nodes within network are dead and the amount of data delivered to the Base Station as another metric.

5.4 Simulation Parameters

The simulation was made based on MIT µAMPS NS2 extension for LEACH project [20].All simulation parameters are summarized in Table 5.1.

Table 5.1: Simulation parameters.

Parameter	Description
Area Dimensions	1000 m X 1000 m
Number of Nodes	100
Mac protocol	Mac/802.11
Initial Energy	2 Joules
Channel Type	Wireless Channel
Radio Propagation model	Two ray ground
Antennae model	Omni antenna
Energy model	Battery
Simulation time	To Die
Topology	Hierarchal, Random
Number of cluster heads	5
Routing protocol	LEACH , LEACH-C MRHC-LEACH , MRHC-LEACH-C , Static Clustering

5.5 Simulation Results

In this section we will show the results obtained under the previously mentioned parameter for Static Clustering, LEACH, LEACH-C and our proposed protocols MRHC-LEACH. As our main goal is to maximize the network lifetime, we will be checking the lifetime of each one of those protocols, and the amount of data delivered to the base station as another metric.

5.5.1 LEACH Simulations

In this section we will compare the network lifetime between original LEACH and another clustered protocol called Static Clustering protocol.

Regarding the used parameters the authors in [39] showed that the parameters used for the original LEACH in [15,16] are not always the best values. The chosen variables were good for certain network topologies. Where the optimal value of desired percentage of a CH is not always 5% and it will be changing depending on the average distance between CHs and BS.

Therefore, in our simulation we will use the same parameter as proposed in [15] [16] regarding the desired percentage of a cluster head (5%) and the BS location which will be (50,175). Table 5.2 shows a comparison between LEACH protocol the static clustering protocol.Where the values are the average value for different network topologies.

Table 5.2: Comparison between LEACH and Static Clustering protocols.

Time	LEACH	Static Clustering
	Number of Nodes Alive	
10	100	100
20	98	57
30	98	9
40	96	0
100	88	DEAD
150	82	DEAD
200	72	DEAD
250	68	DEAD
300	53	DEAD
350	36	DEAD
400	24	DEAD
450	11	DEAD
495	4	DEAD

As the table shows that LEACH protocol outperforms static clustering by a decent time. As static clustering the network is dead after 32 sec with same parameters applied. However, the LEACH protocol lasts till 495 seconds. Nothing changed but the communication protocol. If we take a look to the amount of data reached the sink (BS) for both for leach the data delivered till network dies was 40502 Bytes while for static clustering protocol it was only 3266 Bytes. Figure 5.1 shows the network lifetime for both protocols.

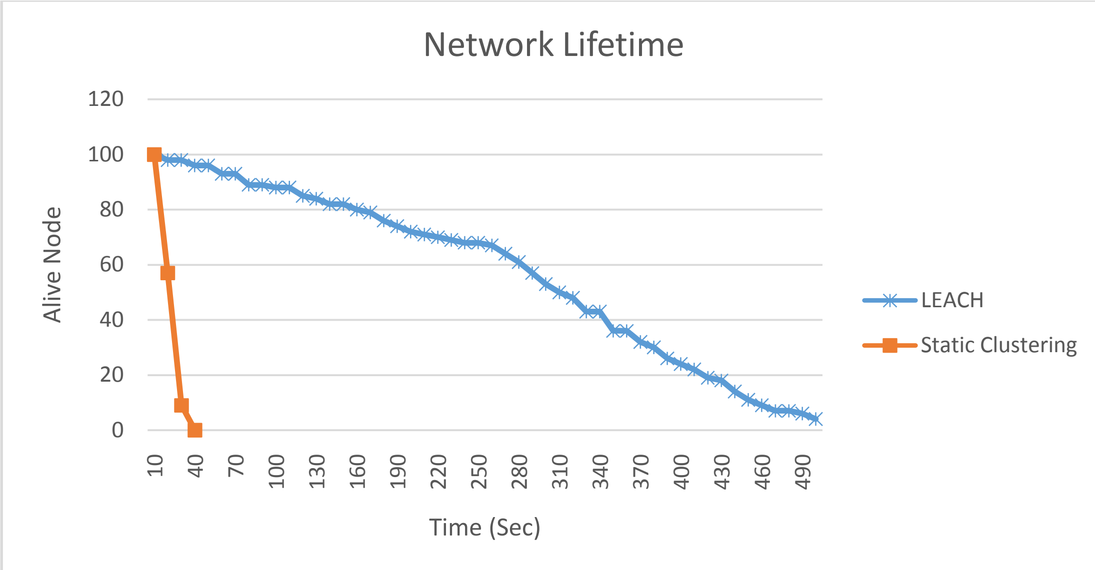


Figure 5.1: Comparison between LEACH and Static Clustering protocol.

5.5.2 LEACH-C Simulations

In this section we will compare the network lifetime between original LEACH and LEACH-C.The authors in [16] showed that LEACH-C the first node take longer time to dies compared to LEACH and that was the network lifetime definition but if we take the same metric that has been chosen for this thesis where the network lifetime is measured for the time that all nodes are dead both protocols are almost the same with a slightly difference for the LEACH protocol.

On the other hand, the amount of data delivered to the Sink (BS) LEACH-C is better compared to LEACH. We have simulated both protocols and the results for the number of alive nodes and data delivered to sink over network lifetime is summarized in table 5.3.Where the values are the average value for different network topologies.

Table 5.3: Comparison between LEACH and LEACH-C protocols.

Time	LEACH		LEACH-C	
	Alive Nodes	Data (Byte)	Alive Nodes	Data (Byte)
10	100	754	100	1511
20	98	1599	98	2982
30	98	2403	98	4493
40	96	3376	96	5999
50	96	4400	96	7515

60	93	5491	94	9024
70	93	6493	93	10505
80	89	7574	91	11871
90	89	8592	90	13269
100	88	9688	88	14581
110	88	10656	86	16076
120	85	11723	86	17495
130	84	12615	86	18965
140	82	13547	83	20385
150	82	14545	83	21839
160	80	15608	80	23269
170	79	16576	79	24684
180	76	17614	76	26021
190	74	18673	74	27400
200	72	19669	71	28735
210	71	20606	70	30114
220	70	21652	66	31407
230	69	22590	64	32751
240	68	23614	62	34030
250	68	24466	61	35339
260	67	25404	58	36546
270	64	26159	55	37764
280	61	26860	53	38863
290	57	27811	49	40039
300	53	28762	46	41094
310	50	29643	44	42290
320	48	30515	41	43370
330	43	31258	38	44348
340	43	32012	32	45149
350	36	32803	27	46143
360	36	33570	23	46910
370	32	34365	16	47511
380	30	35129	13	47932
390	26	35775	9	48354
400	24	36368	5	48624
410	22	37084	DEAD	DEAD
420	19	37718	DEAD	DEAD
430	18	38331	DEAD	DEAD
440	14	38917	DEAD	DEAD
450	11	39360	DEAD	DEAD
460	9	39728	DEAD	DEAD
470	7	39997	DEAD	DEAD
480	7	40229	DEAD	DEAD
490	6	40412	DEAD	DEAD
495	4	40502	DEAD	DEAD

As Table 5.3 shows that LEACH last longer than LEACH-C as it last for 495 second in LEACH protocol while it last less for LEACH-Cfor 400 seconds only. On other hand, the total data delivered for sink (BS) was 48 Kbytes in comparison it was only 40.5 Kbytes for LEACH. Figure5.2 & Figure 5.3 illustrate network lifetime and the total data for both protocols respectively.

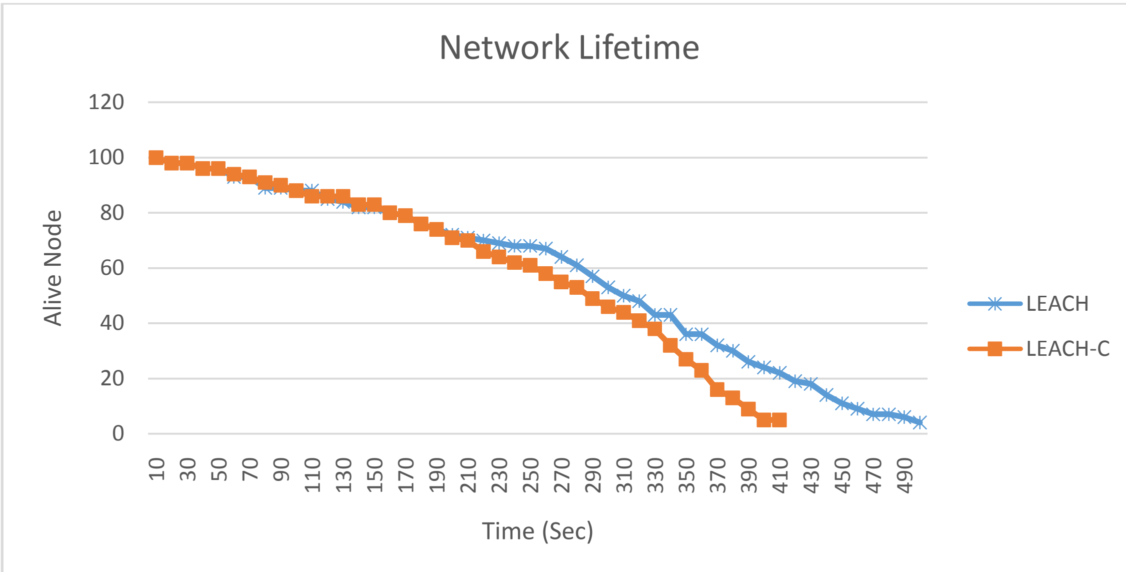


Figure5.2: Lifetime for both LEACH and LEACH-C protocols.

As we can see from Figure 6.2 that LEACH is better in term of life time in our metric as last node death. However, if we consider network lifetime as first dead node, LEACH-C would be better.

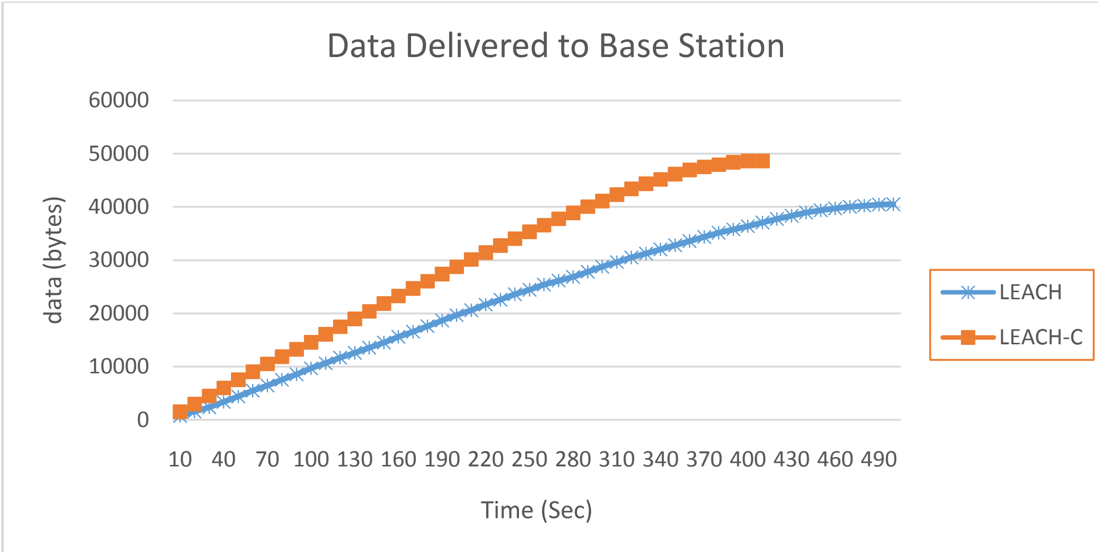


Figure 5.3: Data delivered to base station for both LEACH and LEACH-C protocols.

Due to the centralization of the CH in LEACH-C the amount of data received by Base station is higher in comparison with typical LEACH as Figure 5.3 Shows.

5.5.3 RCRP Protocols Simulations

In this section we will discussthe simulation results for the proposed protocol for different scenarios then we will we compare it with original version of LEACH.

The number of CH is one of the main factors that influence the performance of network in clustered protocol. However,as many researchers [15] [16] [39] said that the optimal number of clusters for LEACH to achieve the best performance is 5% of the nodes. We have analyzed RCRP protocol to check the optimal number of clusters to achieve the best performance. Figure 5.4 illustrates the network lifetime for RCRP protocol for with different number of clusters. We made the simulation under the same parameters for 100 nodes for different number of CH under one of the used network topologies, where the distance between nodes are higher to understand the effect on CHs number for the cases that RCRP get the best results. However, the relation between all curves are the same for all other topologies.

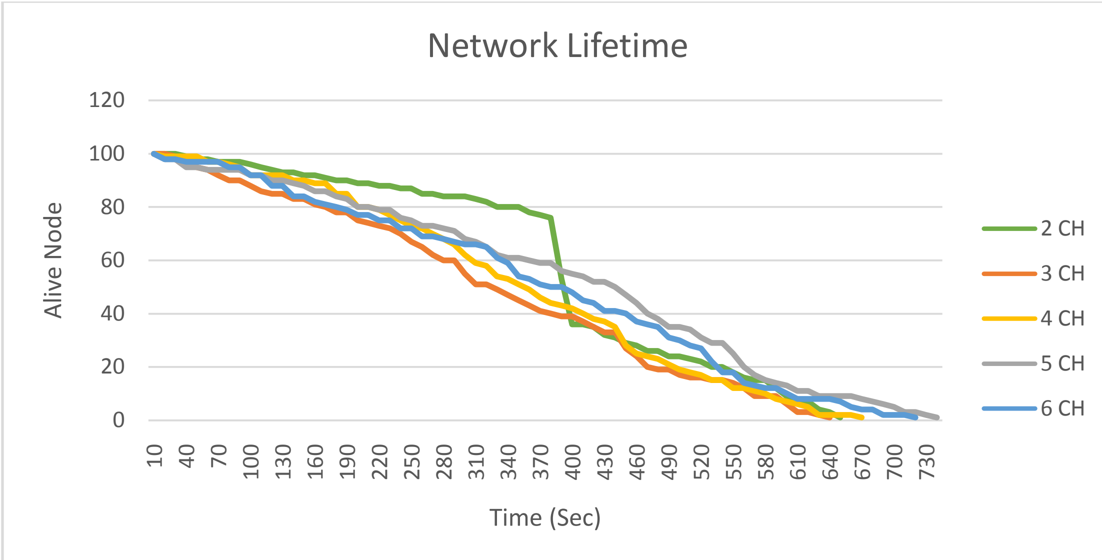


Figure 5.4: Network lifetime for different number of clusters.

Figure 5.4 shows that the network lifetime increases as the number of CHs increases until 5 CH where the network lifetime reach its maximum value, as we can see that in case we increase the CHs to 6 the network lifetime decreases compared to 5 CH. As a result, we can see that the best performance for our protocol under this network topology happens when the number of CH is 5% of the total number of nodes. In the following experiment we will use 5% of the total number of nodes.

Figure 5.5 shows the effect of increasing the number of nodes under the same simulation parameters except the number of CH's that wasn't fixed but, was the same percentage of the total number of nodes 5%.these results for a certain network topology. However, the relation between all curves are the same for all other topologies.

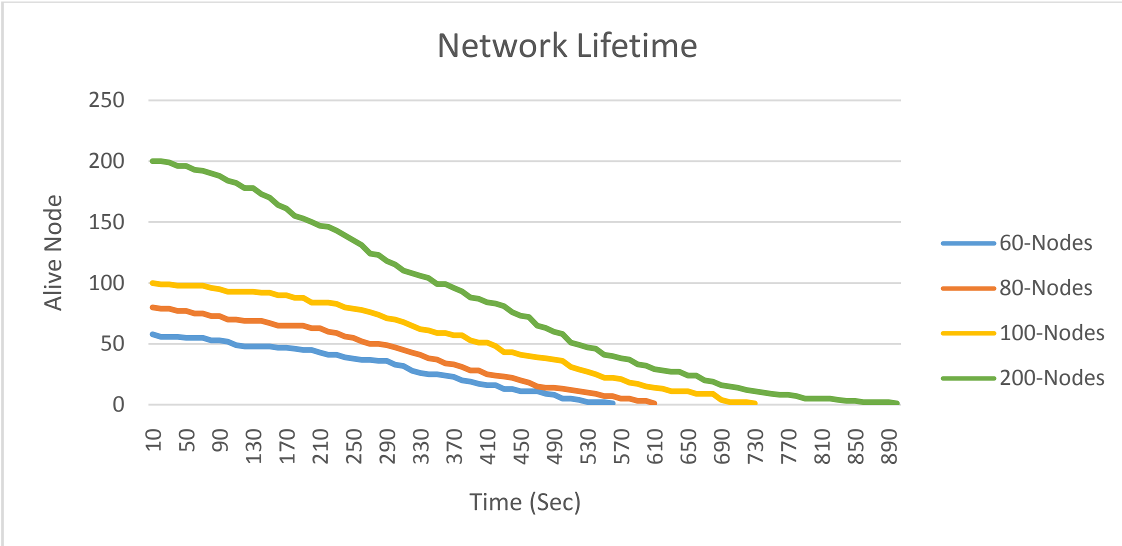


Figure 5.5: Network lifetime for different number of clusters.

Figure 5.5 shows that the number of nodes used in simulation doesn't affect the number of dead nodes, because the percentage of dead nodes seems to be the same for all results. In our simulation we will use 100 nodes.Table 5.4 shows a comparison between both LEACH and RCRP, where the values are the average value for different network topologies.

Table 5.4: Comparison between LEACH and RCRP protocol.

Time	LEACH		RCRP	
	Alive Nodes	Data (Byte)	Alive Nodes	Data (Byte)
10	100	754	100	1064
20	98	1599	97	2178
30	98	2403	97	3114
40	96	3376	95	4165
50	96	4400	95	5306
60	93	5491	94	6605
70	93	6493	94	7649
80	89	7574	93	8778
90	89	8592	93	9804
100	88	9688	92	10936
110	88	10656	92	11941
120	85	11723	90	13060
130	84	12615	90	14636
140	82	13547	89	15938
150	82	14545	89	16880
160	80	15608	88	17767
170	79	16576	87	18652

180	76	17614	85	19465
190	74	18673	83	20550
200	72	19669	81	21574
210	71	20606	81	23051
220	70	21652	78	24314
230	69	22590	78	25198
240	68	23614	76	26151
250	68	24466	76	27081
260	67	25404	72	28077
270	64	26159	71	29183
280	61	26860	70	30119
290	57	27811	70	30869
300	53	28762	68	31684
310	50	29643	66	32954
320	48	30515	61	34001
330	43	31258	56	35287
340	43	32012	56	36413
350	36	32803	55	37421
360	36	33570	52	38445
370	32	34365	49	39756
380	30	35129	48	41094
390	26	35775	43	42617
400	24	36368	42	43480
410	22	37084	37	43995
420	19	37718	35	44475
430	18	38331	26	44616
440	14	38917	25	44628
450	11	39360	23	45682
460	9	39728	22	46162
470	7	39997	21	47358
480	7	40229	20	48130
490	6	40412	20	48918
500	4	40502	18	49456
510	DEAD	DEAD	18	50592
520	DEAD	DEAD	15	51391
530	DEAD	DEAD	14	52359
540	DEAD	DEAD	13	52859
550	DEAD	DEAD	12	53427
560	DEAD	DEAD	12	53950
570	DEAD	DEAD	9	54448
580	DEAD	DEAD	8	54718
590	DEAD	DEAD	5	55219
600	DEAD	DEAD	4	55542
610	DEAD	DEAD	2	55787
614	DEAD	DEAD	1	55892

As shown in Table 5.4 , the simulation results shows that network lifetime extended after applying our new algorithm as the network last for 614 second in comparison with original leach which last only for 495 second.

Even though the network lifetime has increased we can also notice that the amount of data delivered to the BS reached 55.8 Kbytes while it was only 40.5 Kbytes for original LEACH. Figure 5.6 illustrate the network life time for both LEACH and RCRP, and Figure 5.7 illustrate the amount of data delivered to the base station for both LEACH and RCRP.

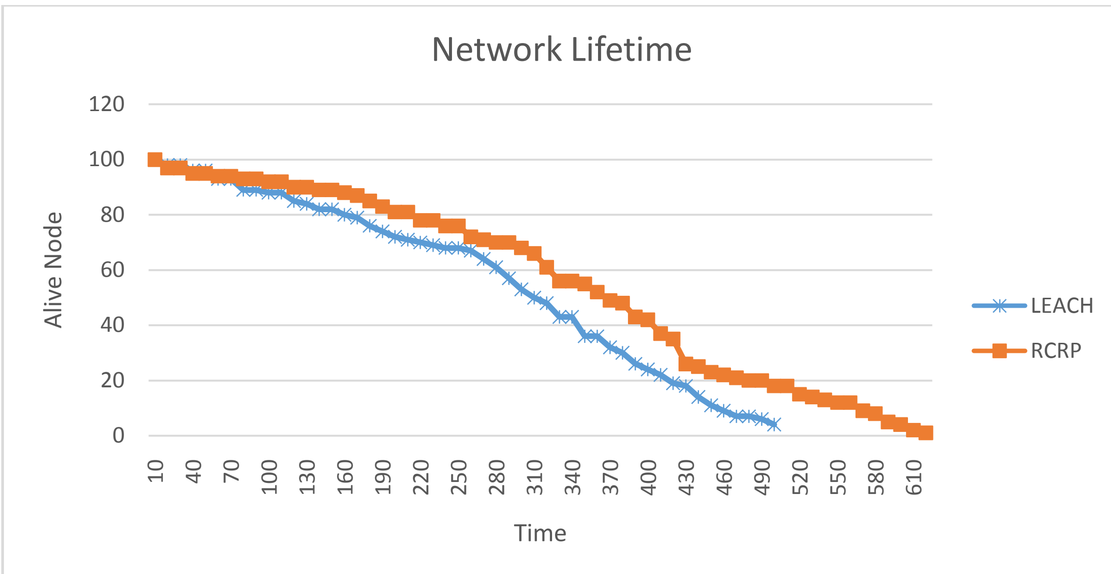


Figure5.6: Lifetime of both LEACH and RCRP protocol.

Figure 5.6 shows that our proposed protocol outperforms the typical LEACH in term of network lifetime as the death of node is faster rate in LEACH as curves shows. Due to the usage of MRHC algorithm the death rate is lower in our protocol.

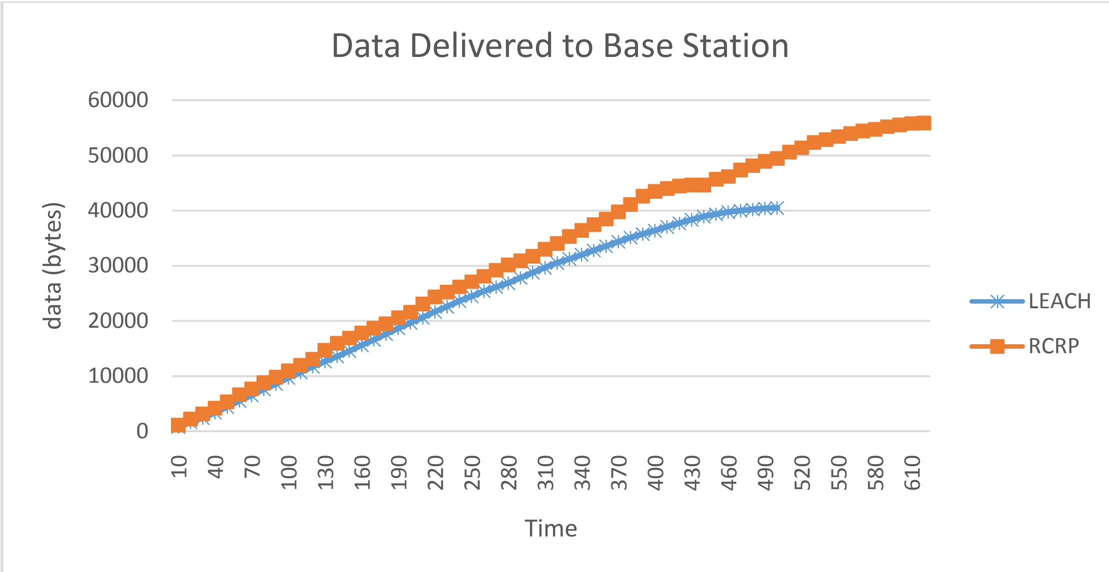


Figure 5.7: Data delivered to the BS for both LEACH and RCRP protocols.

5.6 Summary

We have showed that LEACH protocol outperform Static Clustering protocol, and we compare it later with one of modified protocol of LEACH called LEACH-C. And later we compared LEACH with the new proposed protocol.

In this section we will compare all previously mentioned protocol and show how our proposed protocol has extended network lifetime and also increased the amount of data delivered to BS from the sensing environment. Table 5.5 shows a comparison between each of LEACH, LEACH-C and our proposed protocol in terms of network lifetime and amount of data delivered for base station.

Table 5.5: Comparison between LEACH, LEACH-C and RCRP protocols.

Time	LEACH		LEACH-C		RCRP	
	Alive Nodes	Data (Byte)	Alive Nodes	Data (Byte)	Alive Nodes	Data (Byte)
10	100	754	100	1511	100	1064
20	98	1599	98	2982	97	2178
30	98	2403	98	4493	97	3114
40	96	3376	96	5999	95	4165
50	96	4400	96	7515	95	5306
60	93	5491	94	9024	94	6605

70	93	6493	93	10505	94	7649
80	89	7574	91	11871	93	8778
90	89	8592	90	13269	93	9804
100	88	9688	88	14581	92	10936
110	88	10656	86	16076	92	11941
120	85	11723	86	17495	90	13060
130	84	12615	86	18965	90	14636
140	82	13547	83	20385	89	15938
150	82	14545	83	21839	89	16880
160	80	15608	80	23269	88	17767
170	79	16576	79	24684	87	18652
180	76	17614	76	26021	85	19465
190	74	18673	74	27400	83	20550
200	72	19669	71	28735	81	21574
210	71	20606	70	30114	81	23051
220	70	21652	66	31407	78	24314
230	69	22590	64	32751	78	25198
240	68	23614	62	34030	76	26151
250	68	24466	61	35339	76	27081
260	67	25404	58	36546	72	28077
270	64	26159	55	37764	71	29183
280	61	26860	53	38863	70	30119
290	57	27811	49	40039	70	30869
300	53	28762	46	41094	68	31684
310	50	29643	44	42290	66	32954
320	48	30515	41	43370	61	34001
330	43	31258	38	44348	56	35287
340	43	32012	32	45149	56	36413
350	36	32803	27	46143	55	37421
360	36	33570	23	46910	52	38445
370	32	34365	16	47511	49	39756
380	30	35129	13	47932	48	41094
390	26	35775	9	48354	43	42617
400	24	36368	5	48624	42	43480
410	22	37084	DEAD	DEAD	37	43995
420	19	37718	DEAD	DEAD	35	44475
430	18	38331	DEAD	DEAD	26	44616
440	14	38917	DEAD	DEAD	25	44628
450	11	39360	DEAD	DEAD	23	45682
460	9	39728	DEAD	DEAD	22	46162
470	7	39997	DEAD	DEAD	21	47358
480	7	40229	DEAD	DEAD	20	48130
490	6	40412	DEAD	DEAD	20	48918
495	4	40502	DEAD	DEAD	18	49456
510	DEAD	DEAD	DEAD	DEAD	18	50592

520	DEAD	DEAD	DEAD	DEAD	15	51391
530	DEAD	DEAD	DEAD	DEAD	14	52359
540	DEAD	DEAD	DEAD	DEAD	13	52859
550	DEAD	DEAD	DEAD	DEAD	12	53427
560	DEAD	DEAD	DEAD	DEAD	12	53950
570	DEAD	DEAD	DEAD	DEAD	9	54448
580	DEAD	DEAD	DEAD	DEAD	8	54718
590	DEAD	DEAD	DEAD	DEAD	5	55219
600	DEAD	DEAD	DEAD	DEAD	4	55542
610	DEAD	DEAD	DEAD	DEAD	2	55787
614	DEAD	DEAD	DEAD	DEAD	1	55892

Figure 5.8 shows that the total amount of data delivered to the BS over the network life time is noticeably better in our proposed work in comparison with the LEACH and LEACH-C, where the total data delivered to the base station in our proposed protocol was 55.9 Kbytes where it was only 40.5 Kbytes in the original LEACH and 48.6 Kbytes for LEACH-C.

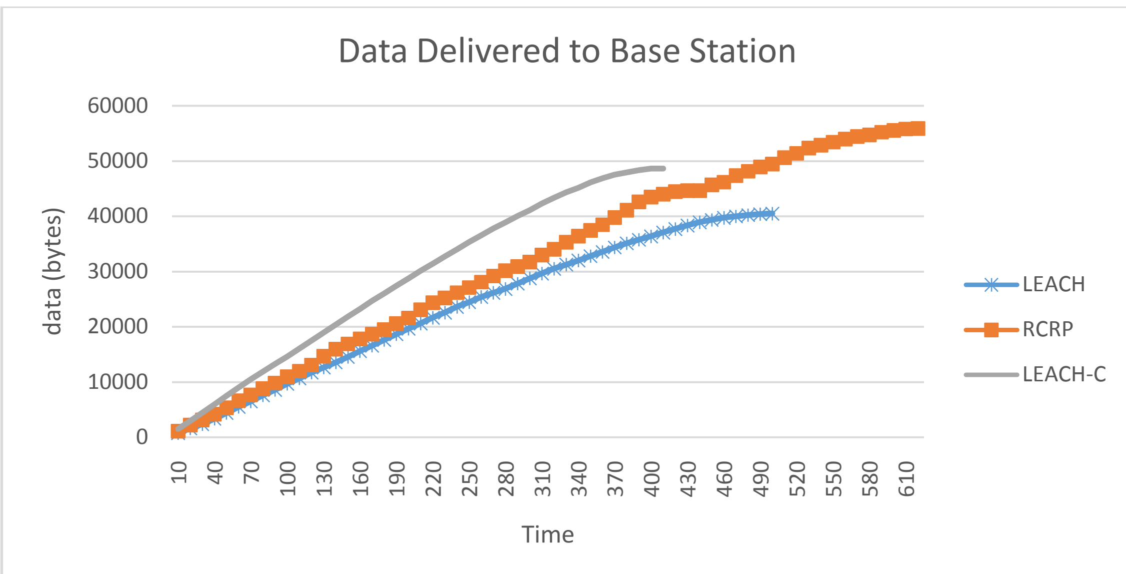


Figure 5.8: Data Delivered to Base Station Comparison between LEACH , LEACH-C and RCRP.

Figure 5.9 shows the comparison in term of energy dissipation over the whole network over the simulation time, the results show that the energy dissipation in the proposed work was increasing in a less rate than the original LEACH protocol or LEACH-C.

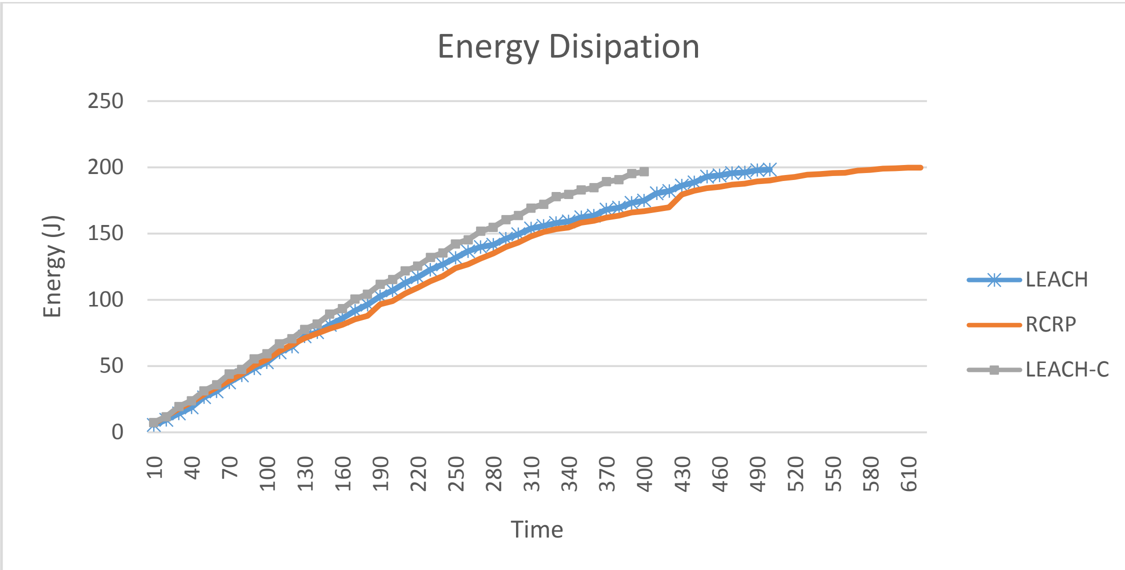


Figure 5.9: Energy Dissipation for LEACH , LEACH-C, RCRP.

Even that the total data delivered to BS is increased in the proposed model that does not affect the network life time as Figure 5.10, shows that the network lifetime is increased in terms of the number of alive nodes over the network lifetime, where the network lifetime in the proposed protocol was 614 second, where the lifetime of the original LEACH was 495 seconds and LEACH-C lifetime was only 400 seconds.

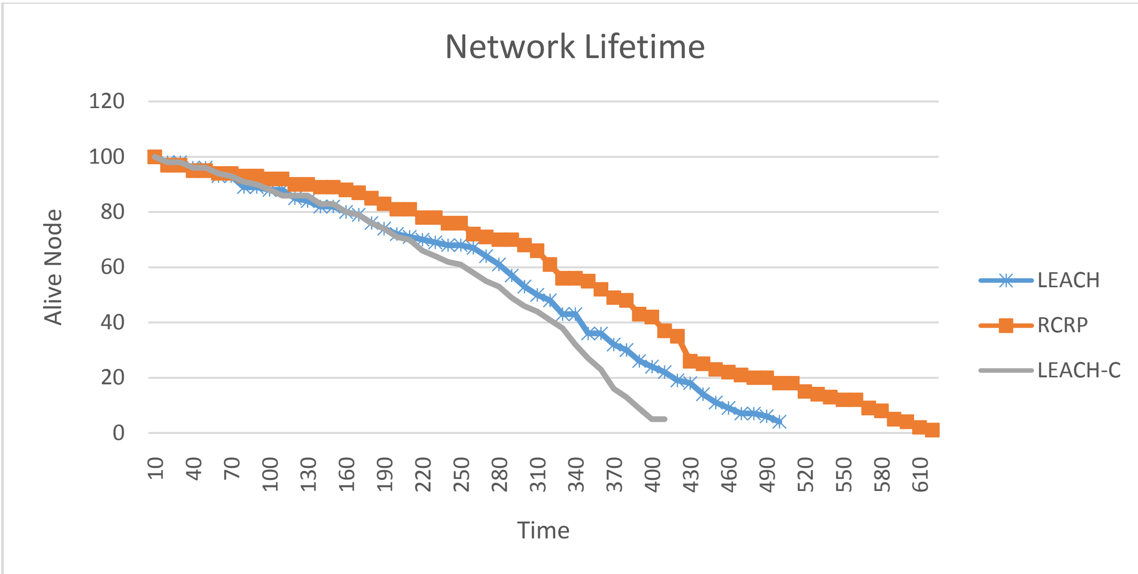


Figure 5.10: Lifetime Comparison between LEACH , LEACH-C and RCRP.

Even though, that new protocol RCRP outperforms both LEACH and LEACH-C in terms of network lifetime and amount of data delivered to the BS, our new protocol is the worst regarding End-to-End delay. Figure 5.11 shows the End-to-End delay for LEACH, LEACH-C and RCRP.

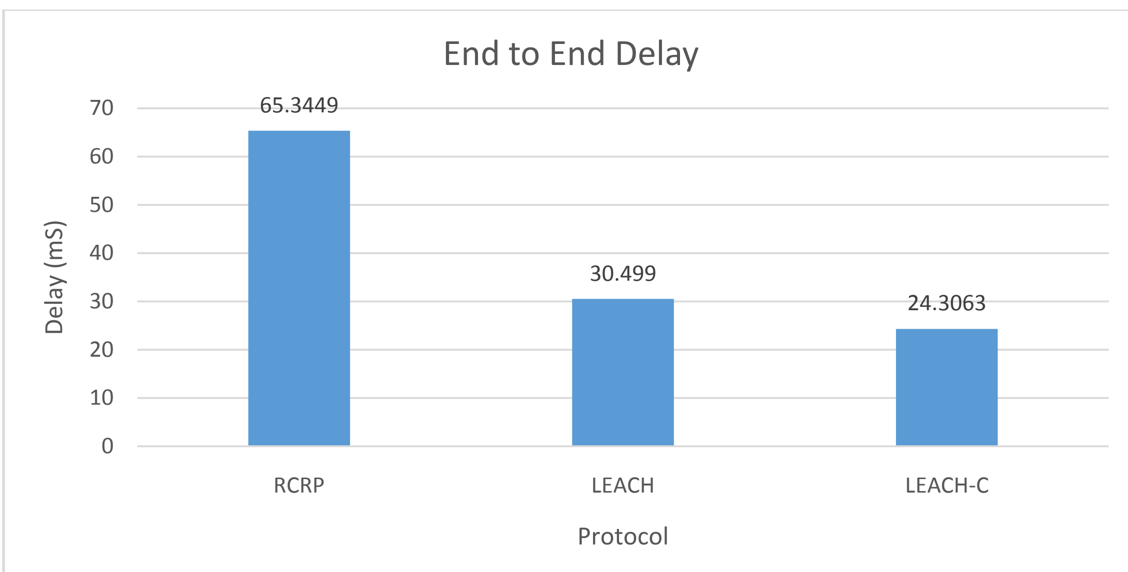


Figure 5.11: End to End delayfor LEACH , LEACH-C, RCRP.

Chapter Six

Conclusion

Chapter Six

Conclusion

6.1.Thesis Conclusion

WSN has been one of the leading technology for many area of applications in our world, and with the new upcoming leading technology of the Internet of Things, WSN has become one of the most reliable technology that helps to achieve the concept of IoT.

In this work we discussed many ways for integrating WSN toward IoT. However, such transition requires a better and more efficient WSN. As WSN is mainly depends on a low-cost sensors, and due to the fact that most of these sensor are battery powered protocols we have to utilize the battery as much as possible. In order to achieve that we have to design a new energy aware protocols to extend network lifetime, to make the network operates as long as possible.

In this thesis, we have surveyed a variety of routing protocols for WSN by taking into account several metrics. We have classified the routing protocol based on its network structure and we discussed and showed that hierarchical protocols are the most efficient protocols to be used for IoT technology.

We also discussed several of energy-aware protocols and proposed our new algorithm based on those protocols. Later we integrated the new algorithm with one of hierarchical protocols called LEACH.

We also proposed a new Energy-aware algorithm that we used to improve the communication between nodes and their CH where the communication was done in a single hop and the data sent directly to the CH, in our proposed algorithm we improve the communication to be multi hop where the data routed within cluster nodes till it reached the CH taking into account both the expected energy dissipation while sending data to the next hop, and the residual batterycapacity in the next hop node.

The simulationresults showed that our new proposed protocols RCRP has improved the amount of data delivered to the Sink, achieving a better results compared to LEACH-C which also outperforms LEACH. In addition to that, our new protocol extended network lifetime with an increment of 24% & 53.5% compared to both LEACH and LEACH-C respectively. And the amount of data delivered to the BS have increased by 38% and 15% compared to both LEACH and LEACH-C respectively.

Even that applying our algorithm in the communication within cluster has solved some of LEACH and LEACH-C problems. But applying such algorithm result to increase the end to end delay.

6.2.Future Work

In WSN, the lifetime is a vital metric for the whole network. As the most energy dissipated within routing process there are many algorithms that can be used to solve lifetime issue. However, we could later deploy our new algorithm in the communication between cluster head and BS rather than use it only in communication within cluster only.

We could also apply one of data compression technique in order to reduce data transmitted in the network .Hence reduce the energy used in communication process. And we could later add the mobility for the protocol to be able to use this protocol in MANET networks rather than only WSN.

On the other Hand, IoT have a higher priority for the privacy and security issue. However, dividing the network into cluster and having intermediate nodes (CHs) between source nodes and Base Station would help to propose a new encryption technique that will be applied only at CHs before sending data to BS instead of applying the encryption for all nodes.

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Appendix A

Published Paper

An Energy-Efficient Clustering Routing Protocol for WSN based on MRHC

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An Energy-Efficient Clustering Routing Protocol for WSN based on MRHC

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Abstract— **currently the world is adopting Internet of Things (IoT) as the future technology and the interest IoT development is increasing. As it's expected to be the leading technology by 2022 according to Gartner. WSN is the main technology component of the IoT since it rely on sensing and collecting data in a specific filed of interest. As the WSN main issue is the network life time due the limitation in sensors resource. Therefore, such lifetime-constrained devices require enchantment on the existing routing protocols to prolong network life time as long as possible. In our paper we propose enhancement in the well know WSN routing protocol LEACH by proposing a new Energy aware algorithm in communication within cluster, hence reduce power consumption in communication process .**

Index Terms—**WSN, Routing protocol, Power Aware, LEACH, SPIN.**

i. INTRODUCTION

Internet of Things (IoT) is a network of physical Objects, vehicles, buildings and other elements - Integrated with electronic devices, software, sensors, and network connection allows these objects to collect and share data. Internet technologies allow things to be sensed and controlled remotely across the existing network infrastructure.

In recent years, the Internet Objects (IoT) technology has been widely used to describe advanced solutions with different devices with computational ability and connected In the Internet. These solutions can be used in domains Such as Health, Agriculture, Smart Cities, and Industry including fields. Despite the fact that the term techniques processes relatively new, the idea of monitoring and controlling devices through computers and networks has been used for several decades, but it was limited within the network and it wasn't as wide as IoT proposed, as WSN have been used for sensing in the past it is the main component in the IoT, hence the IoT and WSN share the same challenges starting from security, privacy and ending in lifetime [1][2].

A Wireless Sensor Network (WSN) is a type of wireless ad hoc network that contain a large number of low-cost sensor devices spread over an area, where sensors report readings to a data collection destination (sink) or Base Station (BS), periodically or based on demand. The potential uses of this network range from military to medical applications. Their data can be as simple as measurements of physical parameters, such as temperature, pressure, relative humidity, etc. to as complex as multimedia content, as in recent years we have seen the researches of wireless video/visual sensor networks for a wide range of applications . Beside their memory capacity limitations, these low-cost sensors are limited in computation, communication capability and are usually battery-powered devices. Thus, such devices with limited resources require protocols that provide energy-aware routing [3][4].

As WSNs are deployed to collect and sense information for particular applications, energy-aware routing protocols are important parts since they help to increase the lifetime of any WSN network .A number of WSN Routing protocols have been proposed [5].

Routing Techniques Classified in WSN in Different terms, In Term of: Routing Processing, Network architecture, Network Operations in this paper the research team will focus on Network structure protocols, rely upon the architecture of network. Routing protocols in this category are distinguished on basis of nodes connections and technique they follow to transmit data packets from source to destination. This leads to following types of classifications as:

- Flat Protocol: The nodes are deployed evenly and have the same role i.e. each node is on the same level within the network. FLAT protocols can be categorized as: proactive, interactive, and hybrid protocols.

- Hierarchical Protocols: In these types of protocols, the nodes fall into clusters, and the node with the maximum power becomes cluster head. The cluster head coordinates the actions inside and outside the block. The cluster head is responsible for collecting data from cluster nodes and eliminating redundancy between collected data in order to reduce the power requirements for transmitting data packets from the cluster head to the base station e.g. LEACH, SEP, TEEN, APTEEN etc.

- Location based Protocols: Nodes are differed on basis of their location within the network. The distance between nodes is calculated based on the signal strength, the higher the signal, the closer the distance between them. Some protocols in this class allow the nodes to be in sleep mode, if no activity going on at the node e.g. GPSR and GEAR.

Among these categories of routing protocols of WSN, Hierarchical protocol is the best option for WSN lifetime constrains. The main aim of this paper is to improve hierarchical energy efficient routing protocols along with modifications over one of these protocols to get better lifetime for WSN. In wireless ad hoc network, there are huge numbers of routing protocols used for better energy consumption and operational life-time proposed in [6][7] [8] [9] [10].

ii. ROUTING CHALLENGES AND DESIGN ISSUES IN WSNs:

Even that, WSNs share many commons with wired and ad hoc networks, they also have a number of unique properties that distinguish them from the existing networks. These unique characteristics offer new routing design requirements that go beyond wired and wireless ad hoc networks. These challenges can be assigned to multiple factor including but not limited to:

i. energy capacity limitation: Since sensor nodes are powered by batteries, they have limited energy capacity. Energy is a big challenge for network designers in aggressive environments

ii. Limited hardware resources: beside, the limited energy capacity, sensor nodes have also limited capacity of processor and storage , therefore can only perform limited computational tasks. These constraints make many challenges in network protocol design for WSN.

iii. Data Aggregation: because the sensor nodes may generate significant repetitive data, similar packets from multiple nodes can be assembled and aggregated so that the number of transmissions is reduced. Data aggregation methods was used to achieve energy efficiency and improve data transfer in a number of routing protocols.

iv. Scalability: Routing protocols must be scalable in network size. In addition, sensors may not have the same capacity in terms of energy, processing, perception, and particularly communication. Thus, communication links between sensors may not be symmetric, in other words, a pair of sensors may not be able to have communication in both directions. This should be considered in the routing protocols.

There is more constrains and challenges that affect the design of Routing Protocol we mentioned the main and major constrains.[11] more details for routing challenges can be seen in [12].

iii. ROUTING PROTOCOLS IN WSNs

In designing of WSN routing protocols must take into account the challenges that mentioned in the previous section, to meet these challenges several routing protocol strategies have been proposed. One category of routing protocols uses a flat network structure where all nodes are at the same level (peers). The second category of routing protocols imposes Hierarchal network to achieve energy efficiency, stability and scalability. The third category of routing protocols uses the location in which the sensor node is processed [13]. Figure 1 summarize the taxonomy of WSN protocols in term of network structure.

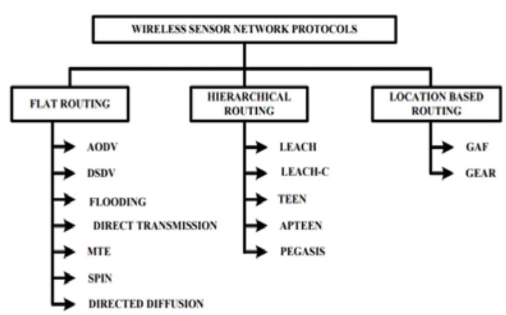

Figure 1: Taxonomy of WSN protocols in term of Network structure

A. FLAT ROUTING PROTOCOL:

In Flat Routing all nodes are considered peers. A flat network architecture has many advantages, including minimal overhead to maintain the infrastructure and the discovery of multiple routes between communicating nodes for fault tolerance. In this paper the research team will describe main flat routing Protocol:

a. SENSOR PROTOCOLS FOR INFORMATION VIA NEGOTIATION (SPIN)[14]:

The protocol was developed to improve classical flooding protocols and eliminate problems that could be caused, for example, explosions and interference. SPIN protocols are resources aware and resource adaptive. Sensors that operate on SPIN protocols can calculate the power consumption needed to calculate, send and receive data over the network. Thus, they can make informed decisions to use their resources effectively. SPIN protocols are based on two main mechanisms: negotiations and resource adaptation. SPIN allows sensors to negotiate with each other before distributing data to avoid injecting unreliable and redundant information into the network. SPIN uses metadata such as data descriptors that the sensors want to distribute. There is some improvement in SPIN protocol such as SPIN-2, SPIN-BC [14]. SPIN Protocol is the main protocol in flat category there is other protocol can be seen in [15] [16] [17].

B. LOCATION-BASED ROUTING PROTOCOL

In Location-Based Routing protocols the site is used to address the sensor node. A location-based directive is useful in applications where the node's location is related to the geographic coverage of the network by the query from the source node. Such a request may indicate a particular area in which the phenomenon of interest may occur or proximity to a particular point in the network environment

.

a. GEOGRAPHIC ADAPTIVE FIDELITY (GAF):

It is an energy-aware routing protocol, which is proposed primarily for MANET, but it can also be used in WSN, as it contributes to energy saving. GAF is stimulated by a power model that takes into account power consumption due to receiving and sending packets, as well as idle (or listening) time when the transmitter radio is turned on to detect incoming packets. GAF depends on the mechanism for turning off unnecessary sensors, while maintaining a constant level of routing accuracy (or uninterrupted communication between sent sensors). In GAF, the sensor field is divided into grid boxes, and each information sensor uses its location using GPS or other location systems can provide to connect to the specific network in which they are located. These links are used by GAF to determine equivalent sensors in terms of packet routing. Other Location-Based Routing protocols were proposed in [15] [16] [17].

C. HIERARCHAL ROUTING PROTOCOL

In Hierarchal Routing protocols, network nodes are organized in clusters in which a node with higher residual energy, will be a cluster head where, the cluster head is responsible for coordinating activities within the cluster and forwarding information to the information sink (base station). Clustering has reduced energy consumption and extended the lifetime of the network in comparison with the flat and location-based routing protocols. In this paper the main Hierarchal routing Protocol will be discussed:

a. LOW-ENERGY ADAPTIVE CLUSTERING HIERARCHY (LEACH)[18] [19]:

Is the first and most popular energy-efficient hierarchical clustering algorithm for WSNs that was proposed for reducing power consumption .In LEACH, The nodes are divided into clusters where each cluster have a CH to aggregate data and report it back to the Base station instead of sending it directly to base station, these will reduce the possibility of collisions and the amount of data transmitted to the base station and make the network more scalable and robust. Leach have two phases (i) setup phase, where cluster heads (CHs) will be selected as each node will select a random number between 0 and 1 and if the number is greater than Trsh (n) it will be cluster head otherwise will be an ordinary node and the nodes that have been a cluster head before will not be elected once more.

$$Trsh(n) = \begin{cases} \frac{\rho}{1-\rho*(r \bmod \frac{1}{\rho})} & if\ n \in N \\ 0 & othwerwise \end{cases} \quad (1)$$

Where ρ is the desired percentage of cluster head, r is the round number, N is the set of all nodes. After the CHs are elected they will send Advertisement requests and the network nodes will send join requests to desired CH and the clusters will be formed and CH will create a TDMA schedule for the current round. This phase were presented in [19] as flow chart in Figure 2.

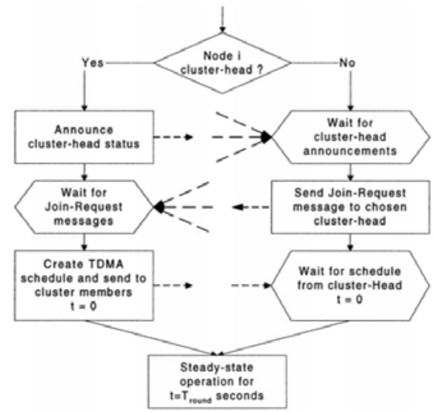

Figure 2: Flowchart of cluster formation algorithm for LEACH

(ii) Steady state phase, where the CH will send a TDMA schedule to cluster node where each node will send data on its TDMA slot and the CH will aggregates data and send it to the Base Station. There is many type of leach introduced in [10].

b. Power Efficient Gathering in Sensor Information Systems (PEGASIS):

The authors proposed a new Hierarchal routing protocol, where they aim. Firstly, to extend the network lifetime but distributing the energy consumption evenly over all nodes in the network. Secondly, to reduce the delay occurs in the other hierarchal WSN protocols where the data aggregate at specific node (usually cluster head) before being sent to the base station in this protocol the data sent directly to the base station. The authors assumed that nodes are deployed among an area of interest [20]. Where, all nodes have a global knowledge about all other nodes locations, in the first round the nodes will form a chain starting from BS to the closest neighbor till all nodes in the network are included in the formed chain as illustrated in Figure 3.

$$\begin{array}{c} n0 \rightarrow n1 \rightarrow n2 \leftarrow n3 \leftarrow n4 \\ \downarrow \\ BS \end{array}$$

Figure 3: PEGASIS Chain

Even that experimental results the authors provided shows that PEGASIS outperform LEACH in a certain scenario's where, for example, if the data comes from the furthest node from BS that will cause a high energy consumption over the whole chain which will result that many nodes will die ,hence , decreasing lifetime.

c. Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN) [21]:

Is a hierarchical routing protocol that combines sensors into clusters, each controlled by CH. The sensors in the cluster report their sensitive data to their CH. CH sends the collected data to CH at a higher level until the data reaches the receiver. Thus, reducing the transmitting time and increasing lifetime. However this protocol is not suitable for networks that require periodically update and information, since the user may not get any data at all if the thresholds were not reached. However, the authors in [14] presented a new routing protocol to overcome this issue called APTEEN. Other hierarchal protocol can be seen in [15][16] [17] [22].

vi. Energy Aware Protocols :

Several algorithm were proposed for wireless sensor network to extended network life time using energy based algorithm, in this section many algorithms will be discussed. To illustrate and understand how these algorithms works the research team will present example model from [19] in Figure 4 , where the source node will be A and the destination will be H , the numbers on arrows will be the cost and the numbers over battery symbol indicate the current battery level.

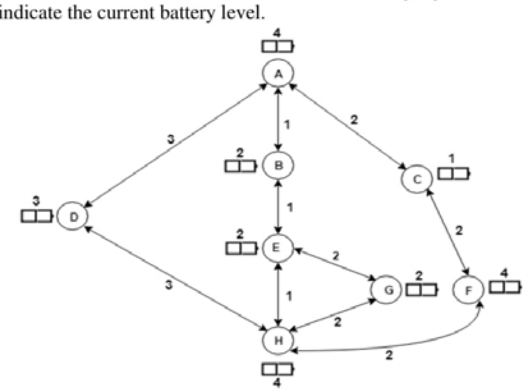

Figure 4: Example Model

a. MAXIMUM TOTAL AVAILABLE BATTERY CAPACITY (MTAB) [8]

In MTAB, the route with the maximum total available battery capacity in nodes within that route, without taking needless Nodes, is chosen. Mathematically: let assume that the battery capacity at node i is denoted as B_i , and the routes to destination d is

$$r_d = r_0 , r_1 , \dots , r_{N-1} \qquad (2)$$

Where r_d is set of all possible routes to the destination, and N is the number of all possible routes. Then the function of total available battery capacity P in path L is:

$$P_l = \sum B_i \qquad (3)$$

The optimal path will be the Max P_l in r_d. Table 1 illustrate how the optimal route is chosen in the example of Figure 4.

Table 1: MTAB Algorithm

Path Number	Path Hops	MTAB Value
1	A => D => H	3
2	A => B => E => H	2+2
3	A => B => E => G => H	2+2+2
4	A => C => F => H	1+4

The route 3 have a MTAB value of 6 which make it the max value within all other routes, however it will not be selected as there is extra needless hop (G) so eventually, the route 4 will be selected.

b. MINIMUM TOTAL TRANSMISSION POWER ROUTING (MTPR)

This algorithm make a simple metric of the route where it calculate the total energy consumed within route to reach the destination. Mathematically: let consider a generic route as follow: [9] [8].

$$r_d = n_0 , n_1 , \dots , n_d \qquad (4)$$

Where n_0 is the source node and n_d is the destination node, and the function:

$$\mathrm{P}(n_i , n_{i+1}) \qquad (5)$$

Is the energy consumed in transmitting in one hop. Then the total transmitting power over a route L is calculated using:

$$P_l = \sum \mathrm{P}(n_i , n_{i+1}) \qquad (6)$$

The optimal route will be the route with **minimum P Value**. Table 2 illustrate how the optimal route is chosen in the example of Figure 4.

Table 2: MTPR Algorithm

Path Number	Path Hops	TPR Value
1	A => D => H	3+3
2	A => B => E => H	1+1+1
3	A => B => E => G => H	1+1+2+2
4	A => C => F => H	2+2+2

As we see in the table the path with **Minimum TPR** value is the route 2 so it will be selected.

c. MINIMUM BATTERY COST ROUTING (MBCR)

This algorithm were proposed to overcome one of MTRP disadvantages where only the transmission power is considered and the batter capacity at the node is neglected in the route selections , which will result to always select the route with minimum power transmission and the nodes at that route will die quickly. To overcome this, the remaining battery capacity of each node more accurate to define the lifetime of each node. Mathematically: let the battery capacity at node I at time t denoted as $B_i(t)$ then the battery cost function is [9] [8].

$$f_i(B_i) = \frac{1}{B_i(t)} \qquad (7)$$

Then the cost of Route L is:

$$P_l = \sum f_i(B_i) \qquad (8)$$

Then the optimal route will be the route with the **minimum P value**. Table 3 illustrate how the optimal route is chosen in the example of Figure 4.

Table 3: MBCR Algorithm

Path Number	Path Hops	BCR Value
1	A => D => H	1/3
2	A => B => E => H	1/2 + 1/2
3	A => B => E => G => H	1/2 + 1/2 + 1/2
4	A => C => F => H	1/1 + 1/4

As the path 1 have the minimum value of BCR it will be selected. A new algorithm were proposed to overcome the drawbacks of this algorithm , where the nodes with Minimum BCR still may select a route containing nodes with small battery capacity , hence these nodes will die. The new algorithm called Min–Max Battery Cost Routing (MMBCR).The author of [9] proposed new algorithm called Conditional Max–Min Battery Capacity Routing (CMMBCR), where if there are routes which all nodes have a battery level higher than a given Threshold then the route will be selected that required the lowest energy per bit, otherwise, the MMBCR algorithm will be used.

d. Maximum Residual Packet Capacity (MRPC)

As its difficult to know the optimal path unless the total packet stream is already known, and as the battery metric is not always the optimal metric to be considered the author introduced a new algorithm that select the optimal path based on both the residual capacity and expected energy dissipated during the transmission of forwarded packets over a specific wireless link. In other words, this algorithm take into account all metric proposed previously mentioned algorithms. Mathematically: let consider the Function of node-link metric be as [10]:

$$f_{i,j} = \frac{B_i}{P_{i,j}} \quad (9)$$

Where B_i is the battery and node i and $P_{i,j}$ is the transmission energy required by node i to transmit a packet over link(i,j). Then the Maximal lifetime over a route L can be presented as:

$$M_l = Min\,(f_{i,j}) \quad (10)$$

Then the desired Route will be the route with the **Max** M_l value. Table 4 illustrate how the optimal route is chosen in the example of Figure 4.

Table 3: MRPC Algorithm

Path Number	Path Hops	RPC Value
1	A => D => H	3/3
2	A => B => E => H	2/1
3	A => B => E => G => H	2/2
4	A => C => F => H	1/2

Then the route 2 will be selected. As it have the Max RPC value. The authors in [10] showed the MRPC last longer than the previously mentioned algorithm.

vii. Propose Work:

As discussed earlier the hieratical protocols are better than flat or location based routing protocols, and the LEACH protocol is the favorite among all hierarchal protocols where it is suitable, reliable and scalable unlike PEGASIS which outperform leach in term on lifetime under certain conditions but it has some drawbacks if the data being sent come mostly from furthest node in the chain from the base station. Or TEEN routing protocol which is not suitable for IoT where most of IoT application require frequently and periodically information updated. In our work we introduce a new version of LEACH protocol to overcome its drawback and to increase network life time as long as possible to be suitable and reliable over any circumstances occurs in the network.

As it's known that leach protocol is a one hop communication protocol either intra cluster or inter cluster. In our proposed model we modified the way the nodes communicate within cluster, instead of sending data directly to the CH the data will be sent through nodes in cluster until it reaches the CH. In order to make the multi-hop communications more energy efficient we used the best energy aware algorithm presented in (vi) and modify it to be suitable for use in leach protocol where there is no predefined links between nodes and CH, and the decision will be more accurate and better as it will be taken for each hop instead of all link. The modification where only in the communication intra cluster. The cluster head selection or communication with base station remain the same.

a. Energy model

The Energy model that was used is the same as presented in [18] [19], the Figure 5 shows the Radio energy dissipation model as the author in [18] [19] illustrated.

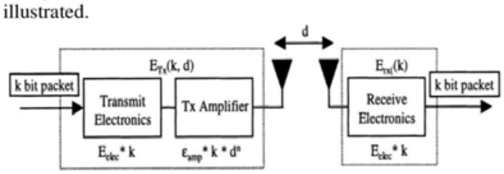

Figure 5: Radio energy dissipation model

The dissipated energy while transmitting will be as

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d)$$
$$E_{Tx}(k,d) = E_{elec} * k + \epsilon_{amp} * k * d^2 \quad (11)$$

Where k is the number of bits, and d is the distance between sender and receiver, and energy dissipated at the receiver side will be

$$E_{Rx}(k) = E_{Rx-elec}(k)$$
$$E_{Rx}(k) = E_{elec} * k \quad (12)$$

b. MAXIMUM RESIDUAL HOP CAPACITY (MRHC)

As in MBCR the $f_{i,j} = \frac{B_i}{P_{i,j}}$ where $P_{i,j}$ is the transmission energy required by node i to transmit a packet over link(i,j). In our proposed algorithm the decision will be made hop by hop so the $P_{i,j}$ represent the energy required to transmitting packet from one node to another via one hope communication and as illustrated in Equation(11) the energy dissipation in t relies on two parameter d which is the distance between the sender and receiver and k which is the number of data bits and as the bits are already the same but the distance varies the $P_{i,j}$ will be replace in our algorithm by the distance between the source node and the next hope. So the function $RHC = \frac{B_j}{dist_{i,j}}$ where B is the energy at the destination node and $dist_{i,j}$ is the distance between source and distention, the next hop will be the node in the same cluster that have the maximum RHC that satisfies the following condition:

First, the distance between source node and next hop is less than the distance between the source node and CH.

Second, the distance between source node and next hop is less than the distance between next hop and CH

If all nodes failed to satisfy these condition then the next hop will be CH, if no cluster head selected the next hop will be the base station. Mathematically:
Let assume that The MRHC will be applied to all $n_j \in N$
Where,
N: is the set of all nodes within cluster,
m: is the number of all nodes within cluster,
CH is the Cluster Head,
n_i is the source node,
CHD is Distance between the n_i and CH,
D is Distance between n_i and n_j,
NCHD is the distance between n_j and CH,
Next hop is the destination node.

The MRHC algorithm for a single next hop decision is illustrated Figure 6.

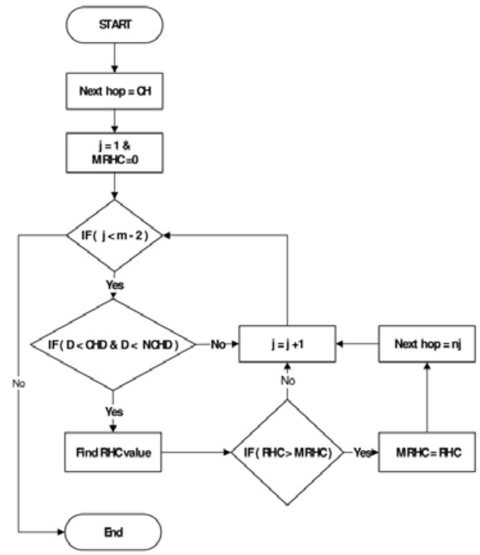

Figure 6: flowchart of MRHC algorithm

c. PSEUDO CODE

The pseudo code for the modified protocol will be as follow:

Step 1: Setup Phase

1. O_i choose r(0,1)
2. O_i compute Thre
3. if (r < Thre) The O_i become CH
4. else node will remain O
5. CH $\rightarrow$ N : id_H , Adv
6. O_i $\rightarrow$ CH : id_{O_i} , id_H , $Join\_Req$
7. CH $\rightarrow$ N : id_H , $(\cdots, < id_{O_i}, t_{O_i} >, \cdots)$, $Join\_Req$

Step 2: Steady State Phase

4. O_i $\rightarrow$ CH : $MRHC(d_{O_i}, id_H)$
5. CH $\rightarrow$ Bs : (id_H, id_{Bs})

Where CH is cluster head, O: ordinary node, Bs: base station
N: set of all nodes, MRHC: maximum residual hop capacity algorithm, and $(\cdots, < id_{O_i}, t_{O_i} >, \cdots)$ is the TDMA schedule

viii. RESULTS

Our proposed algorithm was made based on MIT µAMPS NS2 extension for LEACH project [23] using ns2.34 on ubuntu 10.04 LTS 32 bit operating system in VMware Workstation, all simulation parameters are summarized in Table 5.

Parameter	Description
Area Diminssions	1000 m X 1000 m
Number of Nodes	100
Mac protocol	Mac/802.11
Initial Energy	2 Joule
Channel Type	Wireless Channel
Radio Propagation model	Two ray ground
Antennae model	Omni antenna
Energy model	Battery
Simulation time	To Die
Topolgy	Heriarical , Random
Cluster Head Proportion	5%
Number of cluster heads	5
Routing protocol	LEACH , MRHC-LEACH

Table 5: Simulation parameter

To compare the new proposed protocol MRHC-LEACH, we modified MIT LEACH code, where the MRHC algorithm was added and modified in the receiving function as well. The results of the proposed protocol was compared with original leach protocol results under the same simulation parameter where the base station for both protocols was located at (50 ,175) , we have assumed that all nodes will start with equal energy all other parameters are summarized in Table 5 above.

In Figure 7, shows the comparison in term of energy dissipation for the whole network over the simulation time.

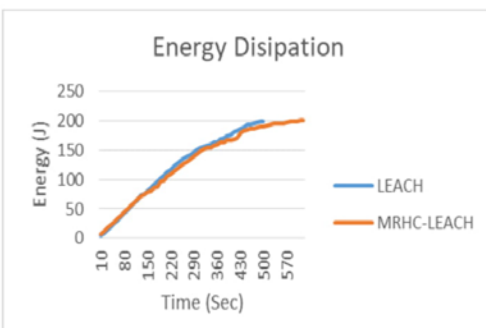

Figure 7: Energy Dissipation over Network lifetime

As shown in Figure 7 the results shows that the energy dissipation in the proposed work was increasing in a less rate than the original leach protocol as the communication within cluster in the proposed protocol increased the utilization of energy in the steady state phase increased. Hence, the energy dissipation decreased.

Figure 8, shows the network lifetime the new proposed protocol and original leach.

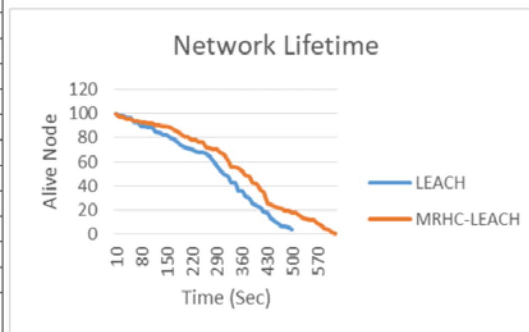

Figure 8: Number of Alive Nodes over the network lifetime

However, as the energy dissipation decreased in comparison to original leach. The number of alive nodes has increased in the proposed protocol .Figure 8 shows that the network lifetime has increased in term of lifetime, where the network lifetime in the proposed protocol was 614 second, in comparison to 495 second for the original LEACH protocol.

Figure 9, shows that total data delivered to the base station over the network life time.

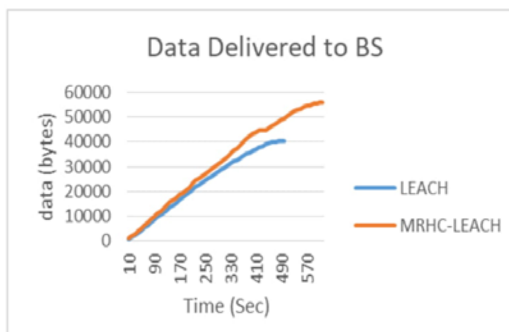

Figure 9: Data Delivered to Base Station over network lifetime

As shown in Figure 8 it's noticeable that the data sent to the base station is better in our proposed work in comparison to the original leach protocol, where the total data delivered to the base station in our proposed protocol was 55.9 Kbyte where it was only 40.5 Kbyte in the original leach.

ix. CONCLUSION:

In our paper, we proposed a new Energy-aware algorithm that we used to improve the communication between nodes and their cluster head where the communications were done in a single hop and the data sent directly to the CH, in our proposed algorithm we improve the communication to be multi hop where the data routed within cluster nodes till it reach the CH taking in account both the expected energy dissipation while sending data to the next hop, and the residual batter capacity in the next hop node.

The results showed that the new proposed protocol is suitable for the IoT application as the network lifetime increased by 24% compared to the original LEACH protocol without affecting the amount of data delivered to the Base Station, Even though , the data size increased by 38% compared to the original LEACH protocol. As a future work we can expand our algorithm to be applied to the communication between CH's and BS. Furthermore, as our work have solved the lifetime issue for IoT applications. Dividing the network into cluster and having intermediate nodes (CH's) between source nodes and Base Station would help to propose a new encryption technique that will be applied only at CH's before sending data to BS instead of applying the encryption all nodes.

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