Hierarchical Clustering Techniques for Energy-efficient Algorithms in WSNs

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رَبِّ إِنِّي لِمَا أَنزَلْتَ إِلَيَّ مِنْ خَيْرٍ فَقِيرٌ

My Lord! Surely, I am in need of whatever good that you bestow on me.

Quran [28:24] (AL-QASAS)

I want to dedicate this thesis to my father Mohamed, my mother, and my wife, who have been a source of inspiration, selfless love and devotion throughout my life.

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Liverpool, UK, 2019 **Walid Abushiba**

Abstract

In Wireless Sensor Networks (WSNs) with large number of micro-sensor nodes, successfully receiving all the useful data with unnecessary loss of energy is a major challenge. WSNs are extremely important for many applications in civil and military domains. Despite their use in many successful applications, the sensor nodes are randomly deployed. This creates many operational and design challenges for WSNs that result in reduced network lifetime. This is because of limited energy available in the nodes and increased energy consumption with large sized networks. Therefore, giving attention to large-scale integration and energy consumption helps to improve the energy-efficiency of the sensor node. This plays a fundamental part in increasing the lifetime of WSNs. Despite the development of many WSNs protocols, such as the hierarchal routing protocols to address this issue, the energy-efficiency is still a limiting factor.

This thesis, addresses the above-mentioned challenges by proposing a novel set of Energy-Adaptive Clustering Protocols (ECP) for energy-efficiency in WSNs. The proposed routing strategy takes on several approaches to improve energy efficiency in WSNs. This functional set of protocols are integrated with each other. The proposed novel solutions have been implemented using simulation and evaluated for a range of given metrics. The evaluations were based on the most critical metrics in WSNs, such as node density, throughput and network lifetime etc.

For validation and evaluation purposes, the proposed techniques have been compared with existing solutions. It is found that our proposed protocols exhibit reduction in energy consumption over well-known protocols such as LEACH, DEEC, EE-LEACH and HT2HL. While the proposed technique network lifetime improved by average of 67 %, 17 %, 21 % and 8 % more than LEACH, DEEC, EE-LEACH and HT2HL protocols respectively.

The ECPs were also evaluated to include mobile node detection. It is named Energy-Adaptive Clustering Protocols (*d*-ECP) for mobile node detection in WSNs. The proposed *d*-ECP has potential applications in scenarios where RFID type mobile nodes are used. For example wildlife monitoring, condition monitoring, industrial applications and IoT.

Keywords: Wireless Sensor Network, Routing Protocols, Network Lifetime, Energy Consumption, Cluster-Head, Radio-frequency identification (RFID).

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List of Used Abbreviations

BS Base-Station

CBR Constant Bit Rate

CH Cluster-Head

ECP Energy-Adaptive Clustering Protocols

IoT Internet of Things

LEACH Low Energy Adaptive Clustering Hierarchy

MANET Mobile Ad hoc Networks

PDAs personal digital assistants

PDF Packet delivery fraction

QoS Quality of Service

RREP request reply

Rx Receive module

SN Number of sequences

SNs Sensor-Nodes

Tx Transmit module

WLAN Wireless Local Area Networks

WMAN Wireless Metropolitan Area Networks

WPAN Wireless Personal Area Networks

WSNs Wireless Sensor Networks

WWAN Wireless Wide Area Network

Chapter 1

Introduction

Currently, people carry a large number of mobile devices, such as, mobile phones, various personal digital assistants (PDAs) and laptops. All these devices could communicate with each other on an Ad hoc basis, which means that the devices do not have to be tied up to the network permanently. Wireless Sensor Networks (WSNs), are a set of nodes; the nodes that communicate among themselves wirelessly and have self-organising capabilities using a set of protocols and algorithms. In these WSNs, each node has its processor, which allows it to transmit only the necessary part of the processed data instead of sending the whole data set to the next node. Furthermore, the size of a message in WSNs depends on the applications that run on the network. The message size could be identified as large size, medium size or small size (Akyildiz et al., 2002a, Peiyan and Layuan, 2006, Abushiba and Johnson, 2015).

One of the fundamental factors in WSNs that affects the protocol design is the energy efficiency of the network. The energy efficiency in turn affects the network lifetime, which is important in WSNs, as the sensor nodes are powered with batteries and have limited resources. One type of protocol design is clustering algorithms, in which the sensor nodes around the base-station (BS) could act as communicators for the sensors, which are far from BS. Therefore, using the clustering algorithms can help the sensor nodes to extend and maintain their lifetime, which in turn extends the lifetime of the overall network (Heinzelman et al., 2000, Handy et al., 2002, Abushiba et al., 2017).

One example of cluster-based architectures is Low-energy adaptive clustering hierarchy (LEACH) (Heinzelman et al., 2000). In non-clustering algorithms, all neighbouring sensor nodes normally have the same data of an event and each node transmits to the BS individually, this will cause increased energy consumption and the nodes will last only for a short time. Whereas, cluster-based architectures reduce the energy consumption by allowing only the cluster-heads (CHs) to transmit the data directly to BS, and the other nodes will only transmit the collected data to CHs. Hence, the CH selection process will effectively define the lifetime of the network (Handy et al., 2002, Abushiba et al., 2017).

1.1 Application areas of wireless sensor networks

WSNs consist of small sensor devices equipped with a wireless communication module. Scattered in the environment, these sensors are responsible for performing physical measurements, converting them to digital signal format, and transmitting them for further processing to BS, which acts as an interface between the network and the user. This collection of information is subject to the resource constraints of the sensors, in terms of their capabilities in processing, storage memory and energy reserves in the form of batteries. Therefore, the deployed protocols have been adapted to these constraints. WSNs are being deployed in a multitude of applications in fields as diverse as environmental monitoring, healthcare, urbanism, transport, home automation, the military domain etc. However, these networks introduce their own problems due to resource constraints, besides the security of the data itself. While the authentication and encryption mechanisms are employed in most computer systems, more expensive cryptographic protocol mechanisms need to be adapted to the world of sensors (Negra et al., 2016, Modieginyane et al., 2018).

At present, more and more sensors are being integrated in the environment for the control or surveillance of premises or systems. One such example is the monitoring of people who are losing their independence and are living alone in their homes. WSNs can significantly improve the quality of life and automate the monitoring process by providing remote information on the status of health of these people and their living environment. There is a lot of the literature focusing on the application of WSNs (Chi et al., 2014, Hodge et al., 2014, Suryadevara et al., 2014, Mejjaouli and Babiceanu, 2015, Ez-Zaidi and Rakrak, 2016).

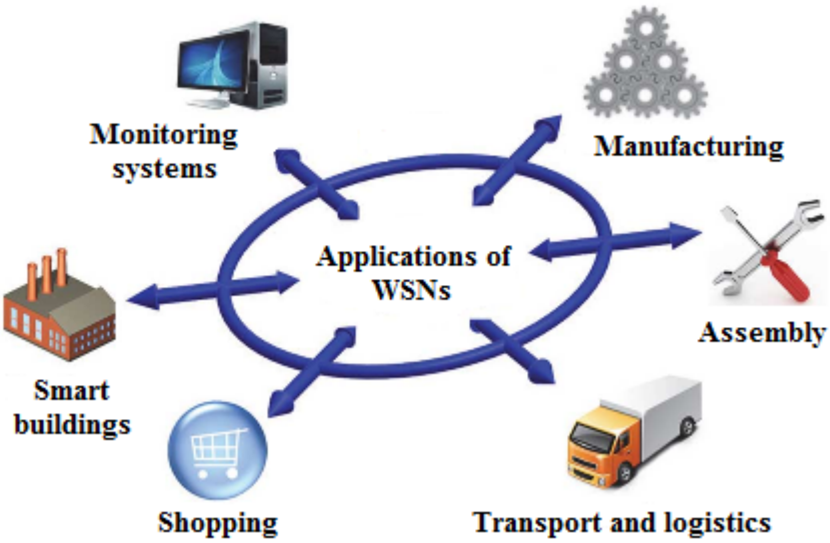

Figure 1.1– Applications of Wireless Sensor Networks

Below are some of the major application areas for WSNs, which require exceptionally high levels of conserving battery life.

1. Smart Home Applications.
2. Manufacturing Applications.
3. Monitoring Applications.
4. Smart Buildings Monitoring, Transport, and logistics.

1.2 Impact of wireless technologies

The choice of wireless technologies has an impact on the design of WSNs. There are three types of known wireless media: radio, infrared, and optical. There are commonly encounter four types of wireless networks based on communication coverage range and area: Wireless Personal Area Networks (WPAN), Wireless Local Area Networks (WLAN), Wireless

Metropolitan Area Networks (WMAN) and Wireless Wide Area Network (WWAN), each category of wireless network has the rate of power consumed. In our proposed application, the small-scale WPAN personal networks can cover all the sensors deployed in the living environment of the person. However, WMAN or extended metro type networks can cover inter-habitat communications, and communication with the outside world (Fowler et al., 1991, Howitt and Gutierrez, 2003, Yao et al., 2001, Sinha et al., 2002)

1.3 Research challenges and thesis motivation

Several dynamic selection processes for the algorithms particularly in remote monitoring of people have been proposed. For example, the random protocols, which statistically obtain a good network coverage, this kind of protocols depends on selection based on the residual energy of the sensors, the advantage of which is to offer a better load distribution, hence the major design aim of WSNs is to save energy and extend the network lifetime. Furthermore, process of democratic election, based on reputation scores, which further improves the residual energy of the sensors. In addition to concrete algorithms, it is sometimes useful to be able to represent a process in a more formal aspect. Validated by simulations, some of the proposed methods are also modeled using Markov chains or particular Petri nets.

In recent years, despite the progress that has been made, several scientific aspects remain unresolved (Akyildiz et al., 2002a). Today, the sensors are used in a multitude of applications in fields as diverse as the environment, health, urbanism, transport, home automation, and of course the military domain. Linked to both technological advances and the emergence of new uses in the exploitation of data, the concepts of intelligent transport, smart cities or Internet of Things (IoT), are slowly developing and seem to promise more and more intensive use of WSNs.

In summary, the main problem addressed by this research is conserving energy of the individual nodes in the presence of mobility, thus enhancing the network lifetime to levels that improve the lifetime of the network. Novel clustering protocols designed in this research extend the lifetime of the network comprising static and mobile nodes, by conserving energy consumption for data transfer. Moreover, the design and architecture of the protocols enable effective detection of mobile nodes in the network with minimal update time, and work seamlessly with increased scalability of mobile nodes. As indicated in the technical chapters, the proposed protocols could be applied to several real-life applications such as IoT, wildlife detection, etc.

1.4 Aim, research objectives and contribution

Aim: To design a set of novel clustering protocols for enhancing the network lifetime in WSNs.

The principal objectives of the research are summarised below:

- To evaluate the existing routing protocols applicable for both Ad hoc and WSNs, namely, AODV, DSR and LEACH. These protocols were selected for their ability to support on-demand routing, node mobility and energy conservation.
- To design a novel set of Energy-Adaptive Clustering Protocols (ECP) for energy-efficiency in WSNs, based on LEACH to improve network lifetime. The performance of ECP has been evaluated against LEACH for energy-efficiency of the network (network lifetime) and throughput. A novel feature in the proposed protocol is the ability to pre-select the number of clusters depending on the network size allowing for further improvements in network lifetime. This feature contributes to the better performance of ECP over LEACH.
- To enhance ECP to support mobile nodes in the WSNs. The ECP has been demonstrated to effectively detect the mobile nodes in the network.
- The ECPs were also evaluated to include mobile node detection. It is named Energy-Adaptive Clustering Protocols for mobile node detection in WSNs (*d*-ECP).
- The network was demonstrated through extensive simulations, to preserve the improved network lifetime in the face of increased mobility.

In this thesis, we present a set of Energy-Adaptive Clustering Protocols for energy-efficient WSNs. Furthermore, the architecture contains its own set of novel schemes and mechanism in order to address the emphasized challenges and achieve our research objectives. Precisely, our novel contributions can be summarized as follows:

In Chapter 5, novel strategies for both network topology are proposed to maximize network lifetime. Energy-Adaptive Clustering Protocols (ECP) for energy-efficiency in WSNs are presented. The proposed ECP architecture includes variants based on the way the sensor nodes communicate to the BS via CH. In this proposed architecture, there may be one or two variant scenarios, which do not fit with the overall expected ‘normal situation’. Two such outlier scenarios have been considered to modify the proposed protocol to address issues arising in such situations. ECP could be easily adapted to these situations. The results showed significant improvement in network lifetime, in comparison with similar, well-known algorithms in the field of WSNs.

In Chapter 6, the next research objective was to demonstrate mobile node detection in Energy-Adaptive Clustering Protocols (*d*-ECP), where the ECP strategy was shown to successfully detect mobile nodes without sacrificing the network lifetime when introduced into the sensing environment. This was dealt with in Chapter 6, where the performance of the *d*-ECP has been evaluated under conditions of mobility. The mobile nodes introduced in the WSNs had similar characteristics to that of the static nodes, with a communication range the same as an RFID tag. This approach is based on detecting the position of an M-node, which in this proposed work was RFID. The *d*-ECP was evaluated for a range of metrics: Network throughput, network lifetime and mobile node capture.

The Simulation results demonstrated the performance of the *d*-ECP protocols for their effectiveness in terms of both the accuracy of the M-nodes’ detection and the distance, with one and 10 mobile nodes.

Original research results generated by the thesis have been published in Chapter 4 (Abushiba and Johnson, 2015) and Chapter 5. (Abushiba et al., 2017). A further contribution is submitted, given in Appendix A.

1.5 Thesis organization

The layout of the thesis is as follows: Chapter 1 sets the general context for the research through presenting the applications of WSNs, research challenges and motivations, research objectives and contributions. Chapter 2 presents a critical review of the related studies that has had an impact on the design of WSNs protocols, their architecture and the constraints related to this type of network, especially focusing on their constraints based on energy consumption. In Chapter 3 the most well-known routing protocols in the Ad hoc Networks and WSNs are presented, especially those algorithms designed for conserving the energy of the sensor nodes. Chapter 4 presents the simulation of the existing algorithms, selected for their capability for on-demand routing, ability to handle mobile nodes and energy-conservation. The simulation results are analysed and compared with established algorithms in this research topic. In Chapter 5, the overview of the proposed hierarchical techniques protocols are presented along with the simulation results. The experimental results of the proposed hierarchical techniques for the WSNs with mobile nodes is presented in Chapter 6. In conclusion, a summary of the research work carried out during my PhD study, the different selection mechanisms of novel algorithms, their main characteristics, and their use cases are reviewed in Chapter 7. In addition, a comprehensive discussion on suggestions for extension of this research in the future is presented in this chapter.

Chapter 2 Wireless Sensor Networks: Literature Review and Background

This chapter defines the main elements that constitute Wireless Sensor Networks (WSNs); since the work presented in this thesis deals with WSNs, firstly, it seems essential to introduce the architecture of WSNs. Therefore, the present chapter describes the basic operation of WSNs. In the second phase, some of the main components of a sensor node are briefly introduced, including capabilities of the sensors, the requirements, factors and limitations influencing WSNs protocol design. Connectivity in the WSNs is also presented.

2.1 Architecture of wireless sensor networks

WSNs are networks consisting of sensors and BS. The sensors exchange data by wireless communications, using protocols, such as those defined in the IEEE 802.11 stack. Packet routing in the network can use one of many protocols developed for this purpose, such as. LEACH (Heinzelman et al., 2000), Distributed Energy Efficient Clustering (DEEC) scheme for heterogeneous (Qing et al., 2006), which are based on centralized control and data transfer. The sensors collect information about their environment and send them back to the BS, which sometimes is called the sink; the BS is responsible for collecting and processing data from the sensors. Once the sensors are deployed, the administrator only interacts with the network through the BS. A basic architecture used by the WSNs is shown in Figure 2.1. The topology of a given network is very often associated with graph network connectivity. Therefore, for this reason, reference is often made to sensors under the term of nodes (Sohrabi et al., 2000, Van Dam and Langendoen, 2003, Al-Karaki and Kamal, 2004, Wang and Jiang, 2016, Khan et al., 2015b).

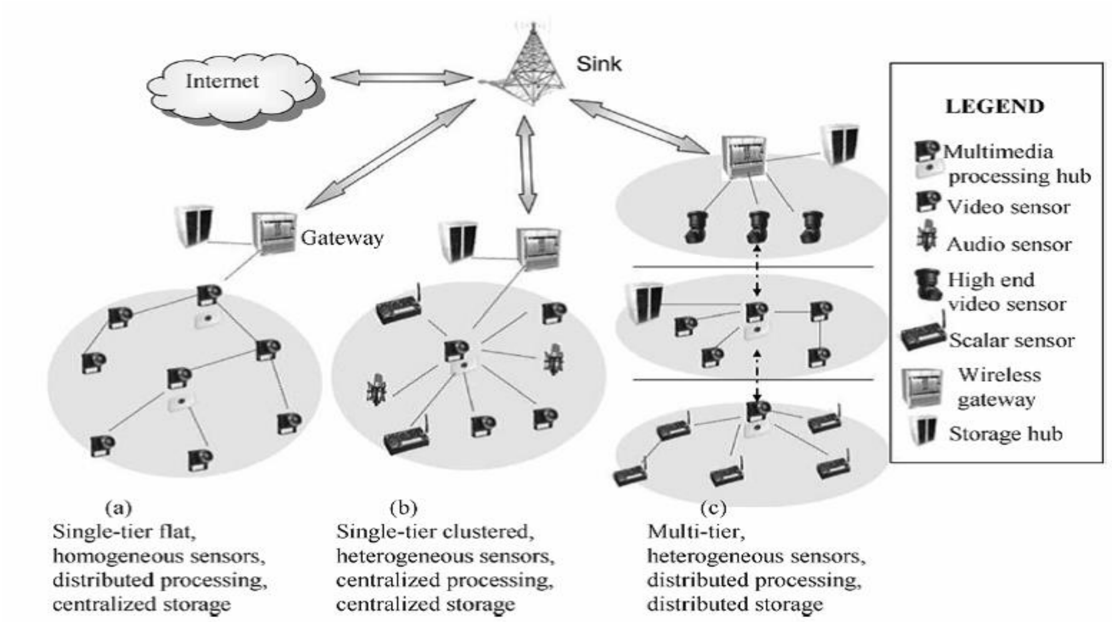

Figure 2.1– Architecture of Wireless Sensor Network (Akyildiz et al., 2007)

Furthermore, a typical WSN can be considered as an uncommon breed of wireless Ad hoc networks with decreased or no mobility. These networks combine wireless communication and negligible on-board computation facilities with detecting and monitoring of physical and environmental phenomena. Sensing is a technique used to gather information about a physical object, process, environmental phenomenon or the occurrence of events, such as changes in the state and rise or drop in temperature. These small sized, low-cost sensor modules comprise on-board radio transceiver, micro-controller, memory, power supply and the actual sensors. All these components together in a single gadget shapes so-called remote Sensor-Node or a Sensor. The diversity of WSNs' applications and the development of new sensor components have led to the emergence of new network architectures, presented in two works, (Akyildiz et al., 2007, Abushiba et al., 2017).

There are three types of architectures: Architectures with a single level of "Single-tier Flat", architectures with a single level of clustering "Single-tier Clustered", and architectures with several levels of collection "Multi-tier flat". Each of these architectures has special properties, depending on their deployment and the application requirements.

2.1.1 Single-level architecture

The architecture with a single level of capture consists of homogeneous sensors with distributed processing of tasks and centralised storage. Each node in the network performs all tasks required by the application, such as capturing temperature, acceleration, movements, etc. In architecture with a single level of clustered capture, there are heterogeneous sensors with processing and storage that are centralised at a dedicated central node.

In flat architectures, any sensor node can communicate directly with the BS, by using high transmission power or through a multi-hop communication using much lower transmission power. In the first case, the energy consumption of the node for sending data to the BS is more important, because of the high power used; thus, these nodes can quickly exhaust their energy with this mode of transmission. In the case of multi-hop communication, which is the most frequently used technique, a sensor node that wants to transmit its data to another destination node out of transmission range, e.g. BS, can use other nodes as intermediary relays or routers. The multi-hop mode offers many advantages such as, the possibility of scalability, redundancy management and fault tolerances. However, as the disadvantage to be noted is the higher consumption of energy in the entire network, because all the sensor nodes will participate in the routing and exhaust their energy by relaying packets from other nodes. However, a higher latency caused by the passage of messages by several relays of the multi-hop before arriving at the destination is a notable disadvantage of the multi-hop communication. Finally, it should be emphasized that higher consumption of energy occurs across the entire network and security concerns due to the fact that data not intended for intermediary third parties or relays may be received, processed and transmitted by them (Abbasi and Younis, 2007, Handziski et al., 2005, Farooq and Kunz, 2011).

2.1.2 Multi-level architecture

The architecture with several levels of data capture is constituted by heterogeneous nodes with the processing and storage of data distributed at each level. In this architecture, the task is distributed between the different participating nodes. Therefore, it is not useful that a node embeds all types of sensors. Furthermore, all the nodes are classified, according to their capacities; for instance, treatment, capture, storage, resource and energy constraints, etc. Nodes with limited resources, in terms of energy, may perform simple tasks, such as capturing the temperature, detecting the movements, capturing a low-resolution image, etc. Moreover, sensors with more resources such as energy and computing, which support the handling of more complex tasks, such as high-resolution cameras that can be woken up at the supervisor's request for recognition and localization. To achieve the common goal of surveillance, the nodes of each level interact according to an appropriate communication protocol to reach the remote supervisor (Leguay et al., 2008, Lin and Gerla, 1997, Liu, 2015, Phanish and Coyle, 2017).

2.1.3 The components of a sensor node

A sensor node normally consists of four basic components:

Capture unit, this unit plays the role of sampling and signal conversion from physical to electrical signals as well as analog-to-digital conversion. The processing unit will then process the data collected by this unit. There are different types of generic sensors such as temperature, humidity, occurrence of the location sensors, and so on.

Processing unit, also known as processor, works with an operating system specially designed for micro-sensors e.g. Tiny-OS. Therefore, this unit is responsible for the execution of the various communication protocols allowing collaboration between the sensor nodes of the WSN. It can also analyse and aggregate data captured by several different source nodes in order to lighten certain tasks at the BS.

Communication unit, "transceiver” is composed of a transmitter and a receiver, allowing the sensor nodes of the network to communicate with each other via radio links. Thus, it performs all transmissions and receptions of data on the medium without thread. It can be the optical type or the radio frequency type. Note that media type optics are robust against electrical interference.

Battery unit feeding the various enumerated units of the sensor node described above. The energy provided by the sensor batteries is one of the most valuable resources in a WSN, because it has a direct influence on the lifespan, known as network lifetime, of the sensor nodes and therefore the network as a whole. The energy consumption of the sensors is therefore one of the fundamental criteria that must be considered in the design and deployment of a given WSN. There are several types of sensors, for instance, sound, temperature, pressure sensors, cameras wireless sensors, etc. Thus, several manufacturers in the global market who have embarked on the manufacture of this equipment have seen their use grow in several areas. Among these manufacturers, one can mention Crossbow, Dalsa, EuroTherm, Sens2B, and Arago Systems(Mainwaring et al., 2002). In Table C.1 – Consumption Parameters of Widely used Sensor Node Platforms, provided the capacity of batteries for a number of sensors, and are given in Appendix C.

2.2 Literature on energy consumption in the WSNs

In WSNs, energy conservation techniques and classifications have always attracted the attention of several researchers. These preservation techniques generally implement approaches that can optimize the energy consumption of sensors according to their activity modes, *i.e.*, receive module (Rx), the transmit module (Tx) and sleep mode (Sleep). The energy consumed by a sensor node is essentially due to the following operations of capture, processing and communication (Heinzelman et al., 2000, Ye et al., 2002, Lin et al., 2016).

The data capture is one of nodes energy consumption sources for detection operations, which including sampling, analog-to-digital conversion, processing of signal and capture analysis activate (Heinzelman et al., 2000). In other words, the capture energy is the part of energy, which is consumed by a sensor node when it performs sampling, analog-to-digital conversion and its capture module. The cost of this energy depends on the specific type of sensing for instance, image, sound, temperature, etc. This energy is generally very low compared to the total energy consumed by a given sensor node (Leu et al., 2015, Azharuddin et al., 2015).

Another main source of nodes energy consumption is the processing energy that represents the energy amount spent by the sensor during read and write operations in memory. This energy is split into two categories, switching and leakage energy. The supply voltage and the total capacity switched are determining the switching energy. The leak energy represents the energy dissipated when the processor does not perform any processing. The energy of processing is relatively small compared to the energy spent during communication (Sohn et al., 2016, Wang et al., 2016).

The communication energy of a sensor node is divided into two parts, the energy expended during Tx and that spent during Rx. This energy depends not only on the amount of data to be transmitted or the packet size, but also the distance between the transmitter and the receiver and the type of the communication used. Undeniably, the range of a signal depends not only on its Tx power, power transmission, but also the physical properties of the propagation medium (Shaikh and Zeadally, 2016, Kamalinejad et al., 2015).

However, the transmitting power greatly affects the range of the signal. So when the transmission power is high, the signal will have a large range, and therefore the energy consumed will be more important. The energy consumed by a sensor node, by far the largest part is communication energy.

In Appendix C, Table C.1 gives the illustrations of the energy requirements for sensor nodes, as well as a number of example for widely used sensors, which are commercially available.

2.3 Techniques for minimizing energy consumption, energy recovery and backup techniques

In Ad hoc networks, energy consumption has been considered as a determining factor but not an essential one because the user can replace the energy resources. In most cases, these networks focus more on Quality of Service (QoS), than on energy consumption. On the other hand, in WSNs, the consumption of energy is very important since usually the sensors are deployed in areas, which are inaccessible. Thus, it is difficult or impossible to replace the batteries after their exhaustion. As a result, energy consumption at the sensor level influences on the service life of the network (Wood et al., 2007, Rodoplu and Meng, 1999).

After describing, the main causes of energy consumption in the WSNs. The different techniques used to minimize consumption, energy recovery and backup techniques for minimizing energy are present below.

Firstly, the techniques for minimizing energy are presented; and these techniques are applied either at the link layer or at the level of the network layer. The following gives an overview of these mechanisms. The energy of the sensor can be saved either at the capture level, at the level of processing or at the level of communication.

a) The only solution for minimizing energy consumption at the level of capture consists of reducing the frequencies and duration of captures.
b) The computing energy can be optimized using two techniques:

- The DVS (Dynamic Voltage Scaling) approach (Ziane and Mellouk, 2005), which consists of adjusting in an adaptive way the supply voltage and the frequency of the microprocessor to save computing power without degrading performance.
- The system partitioning approach involves transferring a calculation prohibitive in computing time to BS that has no energy constraints and has a great computing power (Santi, 2005). Minimizing energy consumption during communication is closely related to the protocols developed for the network layer and the underlying MAC. These protocols are based on several techniques: data aggregation, negotiation and the Collaborative Signal and Information Processing technique (CSIP).

This last technique for minimising the energy consumption is a discipline that combines several domains, the communication and low-power computing, signal processing, algorithms distributed, fault tolerance, adaptive systems and the theory of fusion of sensors and decisions. These techniques have the purpose of reducing the number of transmissions receiving messages (Kumar et al., 2002).

For Energy Recovery and Backup Techniques, in recent years, there are methods to produce and store energy from sources such as solar energy, thermal energy and mechanical energy. The recovery of this energy will depend on the location of the sensor nodes and the exposure of the supervised person to the ambient sources. A node can also embed other components such as energy generators of different types: solar panels, mechanical or thermal generators. The use of photovoltaic panels is a very common technique (Paradiso and Starner, 2005, Pantazis et al., 2013).

Other sources of recovery such as thermal energy harvesting can also be used. Variation thermal gradients like temperature and pressure, which are mainly obtained from heat such as the human body, can be used for medical sensors. Testified results achieved from micro-fabricated devices are 0.14 W/mm^2 for a 700 mm^2 device, 0.37 W/mm2 for a 68 mm^2 device and 0.60 W/mm^2 for a 1.12 mm^2. Other means of recovery are used as mechanical energy (due to the movement of a subject for instance, person or animal), energy electromagnetic, piezoelectric energy and RF radio energy. The quantities of energy that a WSN can recover depend on the time of day from different sources (Bhatti et al., 2016, Orrego et al., 2017)

In the next section, we present various solutions and techniques proposed to improve energy conservation. Despite the progress that has been made, several scientific aspects remain unsolved. Some futuristic perspectives and visions on the current major challenges are presented.

2.4 Energy conservation solutions and techniques

Currently, new energy conservation solutions are proposed, ranging from physics and modulation techniques, up to the application layer and software development specialized, where the energy is driven by control tools (Akyildiz et al., 2002b, Akyildiz et al., 2007, Magno et al., 2014, Martinez et al., 2014).

A detailed classification on different approaches to energy conservation is presented by (Anastasi et al., 2009) . The authors rank techniques in three categories: *duty cycling*, *data-*

driven approaches, and *mobility*. It has been shown by the authors that conservation of energy at the MAC layer can be very significant; the three most well-known categories of MAC protocols are:

- The fixed allocation based protocols which rely on the TDMA access method such as the TRAMA protocol (Rajendran et al., 2006).
- contention-based protocols such as: B-Mac, S-Mac (Polastre et al., 2004, Ye et al., 2004).
- Hybrid protocols such as Z-Mac (Rhee et al., 2008).

Various solutions and techniques proposed to improve energy conservation. The below present the basic techniques used by energy conservation protocols (Anastasi et al., 2009):

- Putting the nodes in sleep mode, represents the most effective technique to avoid the unnecessary consumption of sensors. It consists of turning off the sensor radio when the latter has no data to transmit or receive. There are three types of alarms, periodic alarms, alarm clocks active where due to triggers or changes in capture parameters by reaching a certain threshold and organized awakenings which use algorithms that synchronize and organize the sensors to wake up to assurance a minimum network coverage.
- Decrease of the coverage area of the network: By managing, the transmission power reducing collision, domains and interference zones (advantage of multi-hop architectures). Some approaches to increase spatial reuse by maintaining network connectivity are presented in the following works (Wattenhofer et al., 2001, Ramanathan and Rosales-Hain, 2000, Pantazis et al., 2013).
- Aggregation, data fusion and compression techniques: to send only the useful data. Only significant changes or variations in the data should cause sending the data. Sensors located in the same surveillance zone must allow aggregation of data received in a single message (Cui et al., 2018).

- Choice of a suitable topology and organization of exchanges: each architecture has its own advantages and disadvantages. Clustering-based protocols can improve duration of the network life. (Akyildiz et al., 2002b).
- Inter-sensor cooperation: because of their high density, cooperation and distribution of tasks between network nodes can lead to energy saving. Nodes can reduce their activities (if they operate with a low battery) by informing the other nodes that self-organize accordingly (Akyildiz et al., 2007).
- Limitation of acknowledgments: In the case of a dense network, the acknowledgment messages can overload the network (Stone and Colagrosso, 2007).
- Optimization of the type of transfer: according to the needs of the application: periodic, continuous, random, or on demand.
- Optimization of the switching frequency between the various modes of operation of the sensor: to meet the requirements of the application, this must be low frequency, for instance, the frequency of restarting the radio.
- Routing techniques, selecting the best routes containing nodes with the best autonomy to reach Sink (Akyildiz et al., 2007).

2.5 Sensors node placement methods in the WSNs

The placement of the sensor nodes in an area of interest is not necessarily determined by upstream in the design and deployment of a given WSN. Thus, the nodes can be placed randomly in the area of interest or placed deterministically. Investment methods nodes usually depend on the type of application and the type of environment in which they are located or deployed. The main two methods of nodes placement in the WSNs are the random placement and deterministic placement (Yetgin et al., 2017, Yang and Chin, 2016).

2.5.1 Random placement

The random placement method is typically used for the deployment of sensor nodes in unknown, difficult to access or inaccessible areas, for instance battle zone, mountain, atmosphere, etc. In this case, the nodes can be deployed using various means, for example via planes, boats, etc. However, these random placement methods usually require frequent topology control and reconfiguration techniques nodes in order to guarantee the stability of the network and to ensure efficient transmission of data and energy efficiency (Osais et al., 2010).

2.5.2 Deterministic investment

In the case, where the sensor deployment environment is accessible or known, and the nodes can be placed deterministically. In this case, the nodes can be placed at fixed and known positions using a 2 dimensional or 3 dimensional coordinate system. However, for many WSNs applications that require optimal deployment of the nodes in the area of monitoring, it is necessary to study and plan the appropriate deployment method during the design and deployment of the WSN. Indeed, the deployment method greatly influences the performance of a WSN (Fei et al., 2017).

The study of the placement of the nodes in a WSN makes it possible to determine the number of sensor nodes necessary for the deployment as well as the position of each in the surveillance zone, so as to ensure full functionality of a given application. This investment method allows between another to define the topology of the WSNs.

2.6 Connectivity in the WSNs

After the placement, deployment phases of the nodes in the area of interest, all the nodes should be process to connected network in order to ensure the transfer of information captured by source nodes to the BS. Depending on the type of architecture used, all the nodes of the network or part of it must connect permanently as soon as a source node transmits its data to the BS. To define the connectivity between two nodes in WSNs, as two nodes are connected, if and only if, these nodes can communicate directly or indirectly by multi-hop. In other words, the WSNs are connected, if there is at least one route between each node of the network and the BS.

Therefore, it can be assumed that the connectivity essentially depends on the existence of routes.

The connectivity is consequently affected by topology changes usually due to node failures, mobility, etc. These changes in topologies result in the loss of communication links, isolation nodes, partitioning the network, etc. Like coverage, connectivity in WSNs is considered a very important performance measure especially in the case of the Wireless Sensor Network applications. Thus, to fully guarantee all the features of such applications, it is necessary to study and take into account the connectivity properties, when designing and deploying such networks (Rault et al., 2014).

There are many types of connectivity in WSNs, which are full connectivity and intermittent connectivity. For instance static coverage, also known as simple coverage that includes efficient coverage area, path coverage and k-coverage. There is also dynamic coverage which includes virtual force based and graph-based. Complete connectivity can be either simple connectivity, or multiple k-connectivity (Mohamed et al., 2017).

Full connectivity of WSNs, should be simple, if there is only one path between each source node and the BS, and it is called multiple if there are several distinct paths between each source node and the BS. According to the strategies of placement of the nodes in the surveillance zone and according to the characteristics of the application, a connectivity can be provided during the placement phase of the nodes or be obtained during a phase of redeployment or self-configuration of the nodes. In the case of certain applications of the WSNs, it is not necessary to ensure and maintain continuous full connectivity of the network. Indeed, for such applications, it is sufficient to guarantee intermittent connectivity using, e.g. one or more mobile BSs moving to collect the measurements collected by the disconnected sensor nodes (Wang, 2011, Rault et al., 2014).

2.7 Requirements factors and limitations influencing WSNs

Given the specific characteristics of WSNs, there are several factors and limitations to be considered when designing and deploying WSNs. The main factors and limitations are discussed below:

- **Reliability,** the malfunction of a sensor node, due to low energy, or other failure may involve a change in the topology, which requires the network to self-organise. A low percentage of nodes that fail should not induce failure of the entire system. The good behaviour of a sensor is related mainly to three fundamental aspects: the reliability of measures collected from the person or environment; the reliability of inter and intra communication links WSN; and the reliability of the data analysis collected at the sink level (Prehofer and Bettstetter, 2005, Kim and Cho, 2017).
- **Scaling**, generally, a network of sensors consists of many nodes distributed in specific areas of the habitat. Having a large number of sensors close to the person being monitored ensures and improves the quality and reliability of measurements. Scaling up is one of the criteria used to test the scalability, also known as network overhead of communication, in particular MAC medium access protocols and routing protocols (Alemdar and Ersoy, 2010, Cavallari et al., 2014, Ahmad et al., 2015).
- **Packet size**, the size of the packets exchanged in the WSN can affect the energy consumption of nodes, and therefore the lifetime of the network. This size must be reasonable for the network and it must be compliant for the type of application. Therefore, it must be neither too high nor too low. Indeed, if the size of the packets is very small, then not only the number of packets for a given message increases but also the number of packets of signalling control are also increased. On the other hand, if this size is very large, then greater power will be necessary to transmit each packet of data, which will have, consequently, a higher energy consumption. Furthermore, note that most MAC protocols for the WSN network with exchange of control messages connectivity, linkage, etc., often require additional headers thus contributing to additional energy costs.

- **Energy consumption**, the nodes integrated in the habitat are often fed by small batteries or traditionally by AAA batteries of 1,5 V and 2200-2500 mAh. The economy of energy is one of the crucial design factors. To accomplish their missions, the sensor nodes for instance in medical sensors injected in the body of the person, must save their energies to operate for a few months, or even a few years. *Battery replacement* can be highly *costly* and sometimes impossible especially for intra-corporeal sensors. Following the architecture of the network, the lifetime of a node has a greater or lesser influence on the lifetime of the entire network. To reach its destination, the packet sent by a sensor can pass through other nodes that then act as relay or routers. However, the less the nodes consume, the longer the life of the network will meet the requirements of the application (Mainwaring et al., 2002, Healy et al., 2008).

2.8 Summary

In the first part of this chapter, a review of the literature relevant to this research was addressed. This chapter is also focused on Techniques for Minimizing Energy, Energy recovery and Backup Techniques, its main design constraints and energy consumption, which relate to the well-known techniques are considered here.

The second part of the chapter focused on Connectivity in the WSNs, due to the potential simplicity that they can provide for implementation of the proposed architecture. In the next chapter, main routing protocols are summarized for both Ad hoc networks and WSNs.

Chapter 3

Literature Review on Routing Protocols

In this chapter, the literature review is focused on the main routing protocols, proactive and reactive routing in Ad-hoc Networks, Flat and hierarchical routing protocols in WSNs including network topologies connected with the proposed work. The review especially evaluates the protocols based on energy-efficiency that could be achieved in the resource constrained network environment. To challenge the issue of the limited capabilities of the sensors and possible needs for partitioning of the network to obtain more energy efficiency, and at end of the chapter, the proposed protocol is briefly introduced.

3.1 Routing protocols in Ad-hoc networks

WSNs and Ad hoc Networks have several properties in common, such as lack of infrastructure. Nevertheless, one of the key differences between the two architectures is the scope. Ad hoc networks, in their mobile configuration are known as Mobile Ad hoc Networks (MANET) (Royer and Toh, 1999).

In this case, the nodes communicate with other nodes, which means, it is necessary for the nodes to pass the data from other nodes that have been forwarded to them. Depending on how infrastructures are created and maintained during the routing of data, routing protocols in Ad hoc Networks can be separated into two categories; reactive protocols and proactive protocols. Reactive protocols explore the routes on demand, while proactive protocols establish the routes in advance, which can be established on the periodic interchange of routing tables (Broch et al., 1998).

3.1.1 Proactive routing protocols

In Ad hoc mobile networks, proactive routing protocols share the same methodology, as in wired networks, conventional routing protocols mostly used wired networks. The two main methods used in this class of proactive protocols are the link state (LS) method and the distance vector method (Abolhasan et al., 2004). These methods are also used and developed in recent years by researchers in WSNs. Among the routing protocols, the best-known routing protocols are DSDV, GSR, FSR and DREAM (Qin and Kunz, 2004).

3.1.1.1 Destination Sequence Distance Vector (DSDV)

The DSDV protocol is a table-driven algorithm based on the Bellman-Ford routing mechanism. A routing table is established within the network for every portable node, for both the number of hops to each destination and the number of available destinations. The main goal is to allow a collection of mobile nodes to exchange data within the network. The routing tables of DSDV contain, each possible destination, the number of hops or nodes needed to reach the final destination and the number of sequences (SN), which corresponds to a node destination. A number of sequences is needed to be used in DSDV to differentiate between the old and new routes, this technique is used to avoid the formation of course loops, each and every node transmits updates periodically, including routing data to its direct neighbours (Royer and Toh, 1999, Abushiba and Johnson, 2015).

3.1.1.2 Global State Routing protocol (GSR)

The GSR protocol is similar to the DSDV protocol. This protocol uses LS based on routing ideas, and improves them by avoiding the inefficient mechanism of flooding routing messages. The GSR uses a global view of the network topology, as is the case in LS protocols (Chen and Gerla, 1998).

The protocol also uses a method called dissemination method, used in the distributed Bellman-Ford (DBF) method, which has the advantage of the absence of flooding. In this protocol, each node ‘i’ maintains a list of neighbours, a table of topology, a table of the following nodes ‘Next Hop’, and a table of distance. The table of the topology contains, for each destination, the information of the LS as it was sent, by the destination and a stamp of the information. For each destination node ‘j’, the table contains the node to which the packets destined for ‘j’ will be sent. The distance table contains the shortest distance for each destination node (Chen and Gerla, 1998, Iwata et al., 1999) .

3.1.1.3 Fisheye State Routing protocol (FSR)

FSR protocol is built on the use of the technique "fish eye" and is used to decrease the amount of data needed to describe graphical information. In practice, the fisheye catches precisely, the points close to the focal point. Precision decreases when the distance separating the point seen and the focal point increases. In the context of routing, the fisheye approach is applied for a node in the maintenance of data concerning the accuracy of the distance and the quality of the path of a direct neighbour, with a gradual decrease in detail and precision, when the distance increases. The decrease in accuracy is ensured by changing the update frequencies (Pei et al., 2000).

This technique uses different exchange periods for different entries of the routing table. All entries corresponding to the nearby nodes are sent to the neighbours with a high frequency and therefore with a relatively small exchange period, Rx and Tx (Pei et al., 2000, Abolhasan et al., 2004).

3.1.1.4 Distance Routing Effect Algorithm for Mobility protocol (DREAM)

DREAM protocol is a proactive protocol based on the location information of mobile nodes. It broadcasts data destined for a certain destination by performing a partial flooding. Each node of the Ad hoc mobile network periodically sends control messages to inform all other nodes of its location. The distance influences this exchange, because the control messages are sent frequently to the nearest nodes, which is the same technique used in FSR. In addition to this, the protocol adapts to the mobility of the network by the frequency update control which is based on the speed of the node movements (Basagni et al., 1998).

When sending the data, if the source has recent information on the location of the destination node, it chooses a set of neighbouring nodes that are located in the source or destination direction. If such a set does not exist, the data is flooded in the entire network. In the event that such nodes do exist, before transmission, a list containing their identifiers is inserted at the head of the data packet, and only the nodes that are specified in the header list could process the packet. Upon receiving the packet, the transit node determines its own list of nearby nodes, and sends the packet with the new header list. If no neighbour is located in the direction of the destination, the received packet is ignored, when the destination node receives the data, it sends acknowledgments to the source in a similar manner.

However, in the case of flood reception, the acknowledgments are not sent, but in the case where the source sends the data specifying the destination nodes based on the locations, a timer associated with the reception of the acknowledgments is activated. If no acknowledgment is received before the timeout expires, the data will be retransmitted using regular broadcast (Basagni et al., 1998, Abolhasan et al., 2004).

3.1.2 Reactive routing protocols

Routing protocols in this category create and maintain routes as required, when a source needs a route, a discovery procedure for the global route is launched.

3.1.2.1 Dynamic Source Routing (DSR)

DSR (Johnson et al., 2001) protocol is based on the use of the source routing technique. In this technique, the data source determines the complete sequence of nodes through which the data packets will be forwarded.

To send a packet of data to another node, the transmitter builds a source route and includes it at the top of the packet. The construction is done by specifying the address of each node through which the packet will pass to reach the destination. Subsequently, the transmitter transmits the packet, using its interface, to the first node specified in the source route. A node that receives the packet and is different from the destination deletes its address from the header of the received packet and forwards it to the next node identified in the source route. This process is repeated until the packet reaches its final destination. Finally, the packet is delivered to the network layer of the last host.

The two basic operations of DSR protocol are route discovery and route maintenance. The route discovery operation allows any node in the Ad hoc network dynamically discover a path to any node in the network. An initiator host of the discovery operation broadcasts a route request packet that identifies the target host. If the discovery operation is successful, the initiating host receives a route response packet that lists the sequence of nodes from which the destination can be reached.

3.1.2.2 Ad hoc On-demand Distance Vector protocol (AODV)

The AODV protocol (Perkins et al., 2003), is essentially an improvement on the DSDV algorithm discussed in section 3.1.1.1. It reduces the number of message broadcasts by creating routes as needed. Unlike the DSDV, which maintains all routes, AODV builds routes using a route request and route reply query cycle between the destination and source nodes with no prior information. It broadcasts a route request (RREQ) packet. Nodes receiving a RREQ update their information and set up backward pointers to the source node. When the source node receives the request reply request reply (RREP), it begins to forward data packets to the destination. This mechanism is also used by the DSR (Abolhasan et al., 2004, Zhao and Zhu, 2008, Macedo et al., 2009, Abushiba and Johnson, 2015).

This protocol uses the principle of sequence numbers to maintain the consistency of the routing information. Because of the mobility of the nodes in Ad hoc networks, the routes change frequently so that the roads maintained by certain nodes become invalid. The sequence numbers make it possible to use the newer or, in other words, the recent routes. As DSR does, AODV uses a route request to create a path to a certain destination. However, the AODV maintains the paths in a distributed manner by keeping a routing table at each transit node belonging to the searched path. The routing table essentially contains:

- Destination address.
- Number of nodes and next hop node.
- Number of destination sequence.
- Expiry time of the entrance in table.

3.1.2.3 Temporary Ordering Routing Algorithm (TORA)

The TORA (Park and Corson, 1997, Royer and Toh, 1999) has been designed primarily to minimize the effect of changes in network topology. The algorithm adapts to the mobility of the node location by storing multiple paths to the same destination, so that topology changes will not affect the routing of the data unless all paths that lead to the destination are lost. The main feature of TORA is that control messages are limited to a small set of nodes. This set represents the nodes close to the place of the occurrence of the change of the topology.

Furthermore, in this protocol, the backup of the paths between a given pair source and destination does not take place permanently. The paths are created and stored when needed, as is the case in all the protocols of this category. Route optimization, i.e. the use of the best paths, is of secondary importance, long paths can be used to avoid the control induced by the process of discovering new paths. This ability to initiate and react infrequently serves to minimize the control communication time used which continually discovers the best path to the destination.

3.1.3 Energy efficient routing protocols in Ad-hoc networks for WSNs

3.1.3.1 Extended Ad hoc On-Demand Distance Vector (EAODV)

EAODV (Zhang et al., 2015) is an algorithm for multi-hop WSNs in a two-dimensional plane area. In this protocol, the authors have assumed that all the nodes are static or moving slowly. In addition, each sensor node has the same transmission range and fixed transmission power.

The routing technique focussed on distributed minimum transmission (DMT). The sensor nodes will connect the multicast cluster to establish the optimised route between the sensor nodes and BS. The sensor nodes also have an option to join different multicast cluster based on the characteristic of a particular nodes.

Furthermore, in the context of routing, the EAODV approach is applied for the forwarding routes, which can connect more multicast receivers to solve routing optimization problem. In the maintenance of data that concerning the accuracy of the distance and the quality of the path of a direct neighbour. The method proposes dynamic strategy to change the multi-cast tree structure based on the characteristic of node mobility of WSNs.

Although the method improves the efficiency of multicast routing. Still, the main insufficiency of the protocol is delay caused due to the route discovery by nodes in process of transferring the data without taking to the account the energy consumption.

3.1.3.2 Energy-aware span routing protocol (EASRP)

EASRP (Ravi and Kashwan, 2015) is an algorithm uses energy saving approaches such as Span (Chen et al., 2002) and the Adaptive Fidelity Energy Conservation Algorithm (AFECA) (Xu et al., 2000). This protocol uses hardware circuit called the Remote Activated Switch (RAS) to wake up sleeping sensor nodes for further improving of energy consumption.

In this protocol, the authors have assumed that the network is consists of coordinator and non-coordinator nodes. The coordinator nodes helps to construct the network backbone that supports the exchange of information with minimum energy level. The non-coordinator nodes can save their energy for future purpose. Both coordinator and non-coordinator nodes depend on the algorithms mention above Span and AFECA on this process of placing the nodes in sleep mode for a certain period.

The above-mentioned approach has some limitations that does not deal related to the network information. Furthermore, this approach consider only energy parameter of the nodes; the approach does not consider other parameters that effect the network lifetime.

3.2 Routing protocols in the WSNs

Routing protocols are one of the most important functions in a communication network in general and in WSNs in particular. This function allows the nodes to propagate data captured from sources to destinations. Routing in WSNs is generally a multi-hop routing because the sensor nodes have weak communications, processing and calculations, low power of emission, low capacity for calculations, etc. The transmission of information from a source to the final destination, which is usually the BS, is through several intermediate nodes. Therefore, a node consumes energy either to transmit its data or to relay data to other nodes.

In this context, a routing policy that does not take into account problems of energy management of the sensor nodes can result in high energy consumption in the nodes along the route, and therefore reduce the life of the network. Thus, a good routing policy adapted to the WSN must take into consideration all the characteristics of the sensor's energy consumption, reliability, etc., in order to ensure better performance of the system depending on the type of application. The coverage properties of the monitoring area, as well as network connectivity, should also be taken into account. Consideration in the design and implementation of a good routing policy for several applications of WSNs several algorithms have been developed for routing in MANETs. However, routing in the WSNs differs from that used in MANETs by the following characteristics (Rault et al., 2014, Sangwan and Singh, 2015, Khan et al., 2015a):

- It is not possible to establish a global addressing system for a large number of nodes in the case of the WSNs.
- Many WSNs applications typically require the sending of captured data from multiple sources to a particular node that is the processing center.
- Multiple sensors can produce the same measurements near a phenomenon monitored (redundant measures).
- The sensor nodes have material resource constraints such as energy and thus require a very rigorous management of these resources.

Because of these differences, several algorithms have been proposed for routing in WSNs. In most of these proposals, the strategies used can be classified according to the network topology as flat or hierarchical, and according to the type of application. Therefore, to ensure a good routing policy in the WSNs, all layers must take into account the limited energy of the sensors in order to be able to optimize the lifetime of the network. In addition, the following considerations need to be taken into account in addition to the energy constraints in nodes:

- Limited bandwidth
- Absence of global addressing
- Redundancy of data
- Multi-source network and single destination
- Resource management
- Limited storage capacity
- Limited computing capabilities

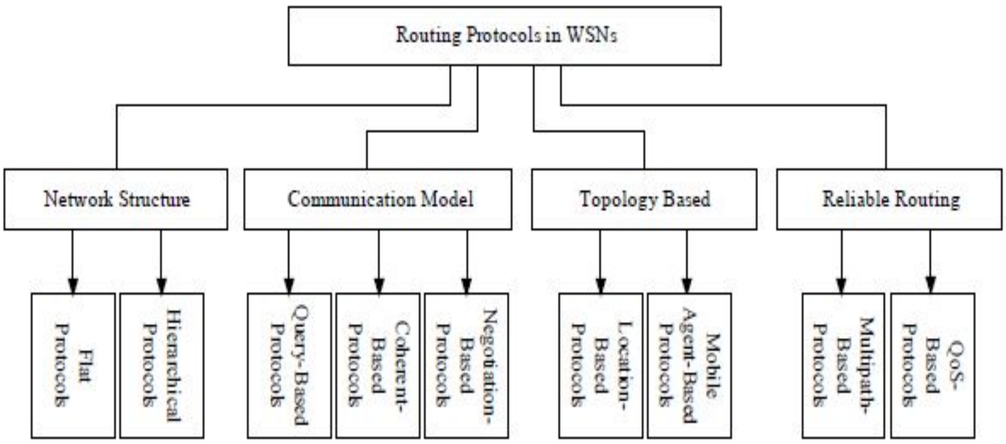

Figure 3.1– Classification of routing protocols in WSNs (Singh and Sharma, 2015, Yan et al., 2016)

In sections 3.2.1 and 3.2.2 a number of routing protocols that are among the most used in the WSNs are presented.

3.2.1 Flat routing protocols

3.2.1.1 Sensor Protocol for Information via Negotiation (SPIN)

SPIN is one of the first negotiation-based routing protocols that was proposed by Heinzelman et al. (1999). The main purpose of this protocol is to solve the flood problem generally caused by the unnecessary duplication of the same data and the redundancy coverage related to the dense deployment of sensors. Indeed, by using the flooding technique, the sensors that have overlapping coverage areas will produce similar measurements or almost identical. This phenomenon usually causes unnecessary energy expenditure during Tx and Rx phases and greatly affects network performance especially the lifetime. In order to solve such problems, SPIN adopts the principles: negotiation and adaptation to resources.

The negotiation allows sensor nodes to avoid the problem of implosion. To do this, each issue of a given information is preceded by the description of that information using the concept of meta-data. Thus, the receiver can either accept or ignore the data based on its description. Resource adaptation allows sensor nodes to control their energy levels continually. Thus, the protocol can adapt the state of each sensor node to Tx, Rx, or sleep according to its residual energy. However, SPIN has the major disadvantage of being a non-evaluative protocol.

3.2.1.2 Directed Diffusion (DD)

DD (Intanagonwiwat et al., 2000, Intanagonwiwat et al., 2003) is a data propagation routing protocol, allowing the use of multiple paths. DD is based on the following operating principle: The BS broadcasts a message of interest to all the sensor nodes in order to interrogate the network. A response packet called gradient, which is a link of response from the node, acknowledges this request. Thus, using this mechanism, a multitude of paths can be established between a given source and the receiver. Then one of the paths is selected by reinforcement and if it fails, then another path must be established. In the event of a breakdown from a path packet loss, reduced throughput, etc., then the receiver can send a negative reinforcement on the failed path by specifying the base rate and taking as alternative the positive reinforcement of another path.

3.2.1.3 Rumour Routing (RR)

RR (Braginsky and Estrin, 2002) is a variant of the DD protocol that tries to find a compromise between flooding interests and the propagation of data. Indeed, in DD, the nodes usually flood the network through the dissemination of interests, whereas in the case of certain applications, only a small amount of data is requested by the BS. The RR protocol helps to avoid this flood problem by routing the data only to the nodes that captured a particular event. To do this, it uses the concept of "agent" which is a package with a large TTL (Time To Live) traversing the network to inform all nodes of events that it encountered throughout its travels on the network. Thus, each node maintains a table of local relays containing the next hop to the BS and a metric that represents the number of jump to each relay node. When a node detects a new event, it adds it to its local table and then creates a new agent based on a certain probability.

3.2.1.4 Cougar

In the Cougar protocol (Yao and Gehrke, 2002) the network is seen as a distributed database and the data captured by the nodes are modelled as a relational table. In this table, each of the attributes represents either information on the sensor node or data produced by this node. In order to manipulate the tables of the distributed database at dual level BS, Cougar provides a management and data manipulation interface similar to the SQL interface. This interface allows the BS to interrogate the network about particular information. Note that Cougar also provides sensor nodes with a mechanism for partial aggregation of data.

3.2.2 Hierarchical routing protocols

The architectures in the WSNs depend on the type of applications and techniques used for transmitting data captured by different sensor nodes to the BS . There are mainly two types of architectures for the WSNs, which are flat architectures and hierarchical architectures.

In hierarchical architectures, the network is partitioned into clusters. In each cluster, a node called CH is elected, which represents all the node members of its cluster. Thus, any sensor node must be either CH or a member of a cluster. A node that is not CH cannot send its captured data directly to the BS. A node sends them to its CH, which in turn can send this data to the BS. CHs can also aggregate data received from several different sources before sending them to the BS, thus lightening the load of certain processing tasks, and also decreasing the traffic in the network (Al-Karaki and Kamal, 2004, Akkaya and Younis, 2005).

3.2.2.1 Low Energy Adaptive Clustering Hierarchical protocol (LEACH)

LEACH (Heinzelman et al., 2000, Al-Karaki and Kamal, 2004, Yan et al., 2016) is a hierarchical routing protocol based on the principle of clustering in network nodes structured in two levels, Cluster-Head CH and node members.

LEACH is a distributed, proactive and dynamic routing protocol. CHs are randomly chosen according to a round-robin management policy in order to guarantee a balanced energy consumption between different nodes of the network.

Note also that in LEACH, CHs can aggregate data received from multiple member nodes to reduce the amount of data transmitted to the BS. In LEACH, each round consists of a set-up and a steady state phase, sometime called communication phase. In the set-up phase, the CHs are elected representatives and a policy of access to the medium is established within each group. This phase starts by local decision-making at each node to become CH or member.

After this set-up phase, each node that is elected CH will send a message of notification to allow non-CH nodes to decide whether or not to belong to their cluster. This decision of belonging to a cluster is based on the amplitude of the received signal. By doing so, the CH with the strongest signal is chosen, that is, the closest for a given node. In the case of equality, a random leader is chosen.

During the steady state phase, the member nodes can transmit their captured data by using scheduling with TDMA slots. This transmission technique thus enables the member nodes to turn off their radio outside their reserved slots for the purpose of saving their energy. Communications between the CH nodes and the BS is done in a direct manner. Thus, the CHs who must transmit must adapt their radio transmitters in order to directly reach the BS. However, note that the main disadvantage of LEACH is that the CHs send the data directly to the BS, which can cause a large energy consumption for these CHs.

3.2.2.2 Distributed Energy-efficient Clustering (DEEC)

DEEC (Qing et al., 2006) is an algorithm where the network is divided into clusters and each CHs are selected by probability calculation between the mean value of the network total energy and remaining energy of the sensor nodes.

In this protocol, the authors have assumed that all the nodes are equipped with different energy levels when the network operation starts. In this case, the nodes with greater residual energy have more possibilities to become CHs for a specific round.

The CH formation in DEEC and LEACH is similar, however, the probability for nodes to become CH is different and rotating probability given by:

$$p(i) = \frac{PoptN(1+\alpha)Ei(r)}{(N+\sum_{i=1}^{imax} \mathrm{ai})E(r)} \tag{3.1}$$

Where popt is the desired probability of CHs, N is the total number of nodes, Ei(r) is residual energy of node, and E(r) is network's average energy.

DEEC estimates the ideal value of network lifetime, which is used to compute the reference energy that each node should expend during a round. However, the clusters formation in DEEC lead to uneven clusters.

3.2.2.3 Energy-efficient LEACH Protocol for data gathering (EE-LEACH)

EE-LEACH (Arumugam and Ponnuchamy, 2015) is a protocol uses also an energy-efficient routing algorithm based on LEACH. It provides an optimal cluster formation and efficient data aggregation, which saves a significant amount of network energy comparing to LEACH. In this protocol, the CH with the maximum residual energy can provide routings for multiple clusters. These optimal clusters are formed based on neighbours' information. The information of neighbour nodes is taken into account when establishing the clusters. All neighbour nodes list is sorted in descending order based on the hop distance. Then the nodes, which have two-hop neighbour, become a candidate for the CH.

For data aggregation, it uses conditional probability formula. This helps increases reliability of data and decreases the latency for data transmission in heterogeneous networks. However, the data forward by CHs to the BS lacks data confidentiality.

Although, EE-LEACH performs better than LEACH in terms of better data throughput and reduced energy consumption. In addition, this protocol has several advantages. For instance, it selects nodes with the maximum remaining energy to send data to the BS, thus increasing the network lifetime.

Moreover, this protocol has lesser consumption of energy. However, it consists of several techniques and due to that, its complexity increases. It lacks inapplicable to large-scale WSNs because the protocols only considered that the CHs can communicate with the BS directly and nodes mobility was not taken in to account of the proposed evaluation.

3.2.2.4 Hybrid threshold sensitive and two-level heterogeneous LEACH protocol (HT2HL)

HT2HL (Alharthi and Johnson, 2016) is a protocol uses the operation of heterogeneous network that used in LEACH and TEEN protocols. In this protocol, the two-level heterogeneous network that contents of N the total nodes, which have m fraction of advanced nodes, equipped with a factor α additional energy than normal nodes. The total initial energy of the network *Et* is given by:

$$Et = N * (1 - m) * Eo + N * m(1 + \alpha), \tag{3.2}$$

$$Eo = N * (1 + \alpha)\, Eo \tag{3.3}$$

Where $N*(1\text{-}m)$ normal nodes each with an initial energy $Enrm = Eo$. $N*m$ advanced nodes each with an initial energy $Eadv = (1+\alpha)\, Eo$.

In HT2HL. The formation of the CHs election divided into periods, one for normally nodes and the other for advance nodes. In each period, CHs are elected based on the weighted probabilities. The nodes that far away from the BS have less probability to be elected as CHs.

Threshold is used for reducing the number of transmission, which in turn saves energy consumption. However, the nodes not transmit their aggregated data continuously, which can effected the data throughput to BS.

Although, the nodes can communicate directly with the BS if all CHs are far from nodes and nodes adjust their transmission power based on the distance from CHs and the BS. It lacks inapplicable to large-scale WSNs due to the balancing of the cluster size, which was not taken in to account of the proposed.

3.2.2.5 Power-Efficient Gathering in Sensor Information Systems (PEGASIS)

PEGASIS is an improved version of LEACH that has been proposed by Lindsey and Raghavendra (2002). The main idea of the PEGASIS protocol is to form a chain between the different sensor nodes so that each sensor node can transmit and receive to a nearby neighbour.

The data collected are transmitted from one sensor node to another, which will in turn be responsible for aggregating them, then relay them until they arrive at the BS. A selection mechanism by rotation based on the round-robin algorithm is implemented for all the sensor nodes that transmit the data to the BS in order to reduce the average energy dissipated by a given node during a period 'round'. Unlike LEACH, PEGASIS avoids training clusters and provides a single node in the chain sending data to the BS. PEGASIS is not suitable for all architectures in for WSNs due to supporting only one-hop commination from CH to the BS. Therefore, its use in architectures with mobile sensor nodes could degrade its performance considerably.

Another centralized routing protocol called Hierarchical PEGASIS, has been designed to improve the PEGASIS protocol. In this protocol, the string is divided into groups so that each sensor node communicates with a single node at the lower level of the hierarchy. Simultaneous transmissions in different groups thus minimize delays of transmission.

3.2.2.6 Threshold-sensitive Energy Efficient Sensor Network Protocol (TEEN)

Manjeshwar and Agrawal (2001) proposed TEEN, which is also a routing protocol based on clustering and similar to the LEACH protocol. This is a routing protocol that is adapted to critical applications where the change of some parameters can be abrupt. In this protocol, the network is hierarchical in several levels in which the nearest nodes form clusters. Then the clustering process goes to the second level and so on until the BS is reached. After the cluster formation phase, each CH transmits at its nodes a threshold HT (Hard Threshold) representing the threshold of the parameter monitored by the sensors and another threshold ST (Soft Threshold) representing a small variation in the value of the monitored parameter. Thus, as soon as a node realizes that the value it has captured has exceeded the threshold HT, then the node must issue a report to its CH. A node will issue a new report only if the value of the monitored parameter changes drastically, in other words, as soon as the difference exceeds ST. This mechanism therefore makes it possible to implement a reactive behaviour, while limiting the number of messages used.

3.2.2.7 Adaptive Threshold-sensitive Energy Efficient Sensor (APTEEN)

APTEEN is a hybrid protocol that extends the TEEN protocol by correcting limitations of the latter (Manjeshwar and Agrawal, 2002). APTEEN allows the periodicity and threshold values used in TEEN to be changed according to the needs of the user and the typed application. In this protocol, CHs transmit to their members the set of parameters that the user needs in order to obtain information on the WSN. The thresholds HT, ST, the TDMA "schedule", as well as a time counter (which measures the period between two successive transmissions of a given sensor node) are also transmitted by each CH to all of its member nodes. APTEEN offers great flexibility that allows the user to choose the threshold values HT, ST and the interval for the time counters so that the energy consumption of the nodes is controlled by the variation of these parameters. However, APTEEN requires additional complexity for the implementation of functions thresholds and time counters.

3.2.2.8 Hybrid Energy-Efficient Distributed Clustering (HEED)

HEED is a distributed clustering protocol for WSN proposed by (Younis and Fahmy, 2004). In contrast to previous routing techniques, HEED has no restrictions on distribution and density of the nodes and does not depend on the network topology nor its size but it assumes that the sensors have the ability to adjust their transmission powers. In HEED, CHs are elected according to criteria such as residual energy and degree of knots. It aims to achieve an uniform distribution of CH in the network. This protocol also aims to generate clusters of balanced size in order to guarantee the connectivity of the graph formed by all CHs.

$$CH_{prob} = C_{prob} \times \frac{E_{\text{residual}}}{E_{max}} \tag{3.4}$$

Where $E_{residual}$ energy and E_{max} respectively represents the estimated current energy of the node, E_{max} is a reference maximum energy, which corresponds to a fully charged battery. However, it is difficult to evaluate Total E_{max} because of the distributed approach (absence of any central control). Another difficulty in HEED also lies in the determination of the optimal number of clusters. In addition, HEED does not specify the use of a particular protocol to ensure communication between the CHs and the BS.

3.3 Challenges and limitations of existing routing algorithms

In the routing which used clustering methods to improve performance of the network lifetime such as, LEACH, PEGASIS and SEP, these protocols depend on the probabilities of each node to become a cluster-head, after considering the residual energy in each node. These traditional routing techniques are inefficient in some cases, especially when the number of nodes increases rapidly in networks. In addition, PEGASIS uses a hierarchical chain-based binary aggregation scheme to achieve a high degree of parallelism that reduces energy consumption but this comes at the expense of delay.

Global routing algorithms use localised and globalised strategies. Therefore, the protocol makes routing decisions based on the global state of the system in globalised strategies. In order to improve the network lifetime, these routing techniques exploit the state information available to them, but in localised routing algorithms, the sensor nodes make routing decisions based on the location of their neighbours (sensor nodes around them) and the destination. In both cases, it is necessary to transmit relevant energy information between nodes in order to gather this state information, but it is impractical to deploy such algorithms in networks containing a large number of sensor nodes. In addition, localised routing algorithms do not have feature that includes the direct communication with the BS.

In the next section, the proposed protocols will be described. Using network topology control to keep the transmission distance low by adding the factor of implementing sequence layer for cluster formation (*k-means*) reduces energy consumption as well as the featuring of direct communication with the BS. Therefore, improving the network lifetime. In addition, the proposed protocols intended to improve the network converge.

3.4 Proposed protocols

The above literature survey presents reviews on the existing research in routing protocols for regular network topology in both Ad hoc networks and WSNs. Firstly, Energy-Adaptive Clustering Protocols (ECPs) for energy-efficiency in WSNs have been proposed; it uses clustering, by dividing an area into subsets of small grids. This clustering allows obtaining an efficient routing of the packets, Also the protocol uses three mechanisms based on the following hypothesis:

- All the nodes in the same cluster are able to communicate directly among them.
- At the time of clustering, a single node per cluster is designated as a leader of the cluster. It will be chosen, deterministically or randomly, among the normal nodes of the cluster.
- When any sensor node in a cluster wants to send data to a sensor node of another cluster, or to the BS, it sends its packets to the CH of its cluster.

ECP algorithms use global location information and have the effect of limiting emissions to long range in intra-cluster communication to CHs only. Nevertheless, communications over greater distances translate into countless energy consumption since more transmission power is necessary. In addition, ECP algorithms implement the *k-means* approach.

Furthermore, the ECP protocols are extended to demonstrate mobile node detection in Energy-Adaptive Clustering Protocols (*d*-ECP), which have the potency to work in any monitoring scheme or as a tool for the IoT. In a multi-hop context, the nodes away from the BS can overload the nodes close to it. The proposed protocols have the feature of tolerating direct communication with the BS. In this way, the network lifetime and the battery life of individual nodes will be extended. In terms of the range of communication, the mobile nodes (M-node), have capability of RFID (radio-frequency identification), in terms of the communication range. In a general view, novel mechanisms have the ability to contain a monitoring system.

3.5 Summary

In this chapter, the main routing protocols for both Ad hoc network and WSNs were summarized.

The review of the literature in routing protocols focused on cluster formation and showed that the centralized algorithm could use network topology information to form good clusters that require less energy for operation than the ad-hoc clusters formed. The proposed work considers this point to implement an added layer for cluster formation (*k-means*).

In addition, after presenting the protocol architectures and different challenges related to energy consumption both in this chapter and in previous chapter, the following points were presented in these chapters:

• WSNs have small, weak sensors in computing capacity, in memory and in battery, which communicate with each other over the air.

• The resource limitations of these sensors, which are also used in many applications, require from the deployment of the network to use algorithms and protocols adapted to their abilities.

• Clustered partitioning is a commonly used operation to facilitate and make the management of these networks more efficient.

• These networks are also subject to issues of resilience, as well as energy consumption, and availability of communications.

• There are many ways to assurance these properties, all with their advantages and disadvantages. Energy consumption is always a compromise between the expected performance and the additional cost involved by the mechanisms put in place. Applied to sensor networks, these solutions must naturally be economical in resources, and particularly in the energy needed. Provided with these resource constraints and requirements raised by energy consumption, in this work, we introduce new mechanisms to further preserve the energy consumption in WSNs.

Chapter 4

Performance Evaluation of Flat and Hierarchy Routing Protocols

In this chapter, performance evaluation of the routing protocols, AODV (Perkins et al., 2003), DSR (Johnson et al., 2001) and LEACH (Heinzelman et al., 2000) was carried out. This evaluation is based on energy consumption (network lifetime), routing packets of the network and Packet delivery fraction (PDF). Two configurations are considered for AODV and DSR protocols: Constant Bit Rate (CBR) and Exponential generator traffic, and their performance was compared with that of LEACH.

4.1 Related work

Many schemes and solutions have been proposed for both Ad hoc network and WSNs, many still largely open to research. Although other researchers have studied similar performance evaluation of these protocols, none of them has considered the exponential generator traffic model for data generation.

In an Ad hoc and WSNs networks, the size of a message depends on the applications that run on the network. The message size could be identified as large size, medium size or small size. The key challenge in selecting a routing protocol is to extend the lifetime of the network to its optimum value by the use of energy-efficient algorithms (Touray et al., 2012, Amadeo et al., 2015, Saxena et al., 2016).

Furthermore, in both Ad hoc network and WSNs applications, using the traditional Internet Protocols (IP) requires a huge amount of bandwidth in order to support high data demand. This places the ultimate demand on the battery capacity, which is not very easy to expand. An alternative way to optimize the network lifetime is to design optimized routing protocols that are energy-efficient (Touray and Johnson, Han et al., 2016, Ali and Ghani, 2016).

AODV combines the mechanisms of DSR and DSDV; also, AODV builds routes using a route request and route reply query cycle between the destination and source nodes with no prior information. It broadcasts a route request (RREQ) packet. Nodes receiving a RREQ will update their information and set up backward pointers to the source node. When the source node receives the RREP, it begins to forward data packets to the destination (Royer and Toh, 1999, Basurra et al., 2015).

DSR is designed to provide on-demand routing but not to track topology changes occurring at a high rate. The two main sources of bandwidth overhead in this protocol are route discovery and route maintenance. These occur when the discovered routes are unused or when the network topology changes and this overhead can be reduced by employing intelligent caching techniques in each node at the expense of memory and CPU resources. The remaining source of bandwidth overhead is the required source route header included in every packet. DSR is based on source routing, thus requires considerably greater routing information. In DSR, a route has to be discovered prior to the actual data packet transmission. This initial search latency may degrade the performance in interactive applications. Moreover, the quality of the path is not known prior to the call set-up. It can be discovered only while setting up the path. This quality of path needs monitoring by all intermediate nodes during a session (Johnson and Maltz, 1996, Sharef et al., 2014, Rao and Singh, 2014).

It increases the cost due to the additional latency and overhead. Due to source routing, DSR has a major scalability problem. Nodes use routing caches to reply to route queries. This results in “uncontrolled replies and repetitive updates in the hosts’ caches”. In addition, early queries cannot stop the propagation of all query messages, which have flooded all over the network. Therefore, when the network becomes larger, the control packets and message packets also become larger. This could degrade the protocol performance after a certain period of time (Abushiba and Johnson, 2015, Johnson and Maltz, 1996).

Several researchers use attribute mechanisms, which is called caching, or replication templates of data as a means of making information more accessible to mobile devices in MANET. Mechanisms proposed in these works use either the caching, or data replication, but never a hybrid approach combining these two techniques. A major design problem in most networks is that of the addressing of the nodes either by using attribution of identification or their location in the network; For instance, Phone numbers, IP addresses, postal address , etc. (Yang et al., 2004, Liu et al., 2017).

Many proposal works in WSNs offer allocation methods using clustering. CHs manage address allocation, and thus make this technique decentralized and more scalable. The effectiveness of these techniques only depends on their design as well as the number of signalling messages needed to obtain an address. The nature of data-centric applications in the WSN leads to addressing mechanisms which mainly have the role of helping at the collection and data processing rather than peer-to-peer communication (Yetgin et al., 2017).

To the best of my knowledge, there is no performance evaluation of the three protocols available in the literature in terms of energy-efficiency (network lifetime). Moreover, the comparison has not been made between using CBR and Exponential traffic generation of data in these protocols. In the following sections, both AODV and DSR protocols have been simulated for these two traffic generators using NS-2 and their performance evaluated in WSNs. The comparing of routing protocols, includes the key parameters of routing protocols such as energy consumption (network lifetime), routing packet (throughput) and PDF.

4.2 Simulation and performance analysis

In this section, a simulation of the three routing protocols, namely AODV (Perkins et al., 2003), DSR (Johnson et al., 2001) and LEACH (Heinzelman et al., 2000) consisting of static and mobile nodes is carried out. In the experimentation, random positioning of the sensor nodes will be adopted. In addition, the performance of the network is evaluated under mobile network scenario; nodes will be distributed randomly over the same sensing area. It is important to emphasize that each simulation will have a set of nodes: 100, 200 and 300 nodes randomly. Therefore, none of the simulations would have the same distribution, when the simulation is started, the performance evaluation will be carried out against the number of nodes in the network distributed (Touray et al., 2012, Abushiba and Johnson, 2015).

4.2.1 Implementation and experimental set up

The simulation environment is described in this section, and shows the results of the simulation for energy consumption distribution for each routing protocol. This simulation has been accomplished using the Network Simulator NS-2 version 2.34. The NS2 is a discrete event simulator that is used by many researchers and provides a flexible tool for network simulation. Using this tool it is easy to compare and study how various routing protocols perform with different network configuration and network topologies. Moreover, as a Medium Access Control (MAC) protocol, NS-2 simulation uses IEEE 802.11 wireless network, which is a standard definition for the Physical layer, IEEE 802.11 supports simple devices such as wireless sensor nodes and real-time traffic (Malik et al., 2015).

For all protocols, AODV, DSR and LEACH, the performance evaluation will be carried out using both static and mobile network models, Random Way Point (RWP) mobility model is used over a fixed area about (100 x 100) metres flat space for 600 seconds of simulation time. In order for fair comparisons between the protocols, the entire scenario takes the average of 10 runs of the simulator under identical environmental conditions composed with the exact time of the simulation .

CBR and Exponential traffic models were used in AODV and DSR. In CBR traffic, the nodes will have the maximum number of connections set up between nodes. Applications in exponential generator traffic, the connections between the nodes will have an Exponential ON/OFF distribution. Packets are sent at fixed rate during ON periods.

Considering, the interval time to be the same in CBR as the burst time in Exponential application parameters, it is assumed that the start time for transmissions will be 5 seconds after the simulation begins as well as the stop time of traffic generation to be 5 seconds before the simulation stops. The following performance metrics have been chosen to compare the performance of the routing protocols:

- Energy Consumption (Network lifetime): It is the total time that the all nodes stay alive, which measures the average of the lifetime of the network.
- Routing packets: It is the total number of routing packets transmitted during the simulation.
- Packet delivery fraction (PDF): It is the ratio of data packets delivered to BS. Packet delivery fraction is a measure of the efficiency of the protocol (Zhang et al., 2014, Abushiba and Johnson, 2015), and is calculated as follows:

$$Packet\ delivery\ fraction\ = \frac{(Packets\ delivered\ )}{(Packets\ Sent)} \tag{4.1}$$

4.2.2 Performance results of static sensor network

In this section, the simulation results are presented for the static network based on a network configuration consisting of CBR and Exponential traffic communicating over an 802.11 wireless network; performance values are a comparison between all of the protocols (AODV, DSR and LEACH) in terms of the lifetime of the nodes, the routing packets (throughput) and PDF.

Results related to the lifetime of the sensor nodes in the network are shown in Figures 4.1 and 4.2, when using CBR and Exponential traffic respectively. These Figures are shown the difference of network lifetime performance between all protocols.

Figure 4.1 and 4.2 represents the network lifetime in seconds while network size is increasing (number of nodes) for each protocol. The simulation was deemed completed, when there was no more communication between nodes. The simulation were carried out and averaged to get value point. Furthermore, the entire scenario takes the average of 10 runs of the simulator under identical environmental conditions composed with the exact time of the simulation.

Figure 4.1– Network lifetime performance with CBR traffic

Figure 4.2– Network lifetime performance with Exponential traffic

Results related to the routing packets in the network are shown in Figures 4.3 and 4.4, when using CBR and Exponential traffic respectively.

Figure 4.3 and 4.4 represents the routing packet performance in seconds while network size is increasing (number of nodes) for each protocol. The simulation was deemed completed, when there was no more communication between nodes.

The simulation were carried out and averaged to get value point. Furthermore, the entire scenario takes the average of 10 runs of the simulator under identical environmental conditions composed with the exact time of the simulation.

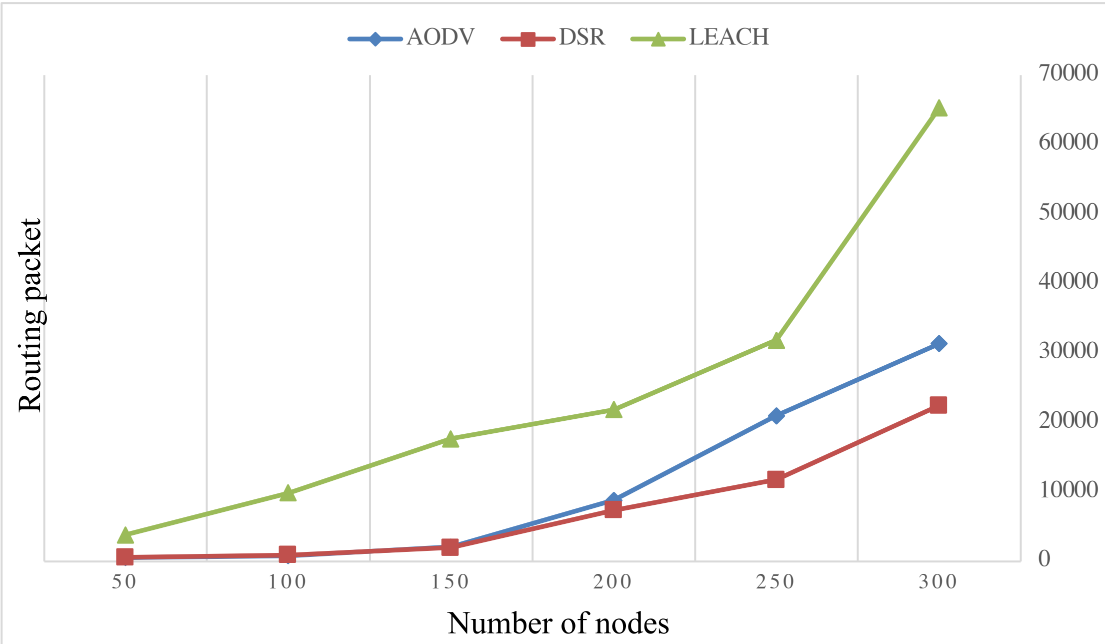

Figure 4.3– Routing packet performance for the protocols with CBR traffic

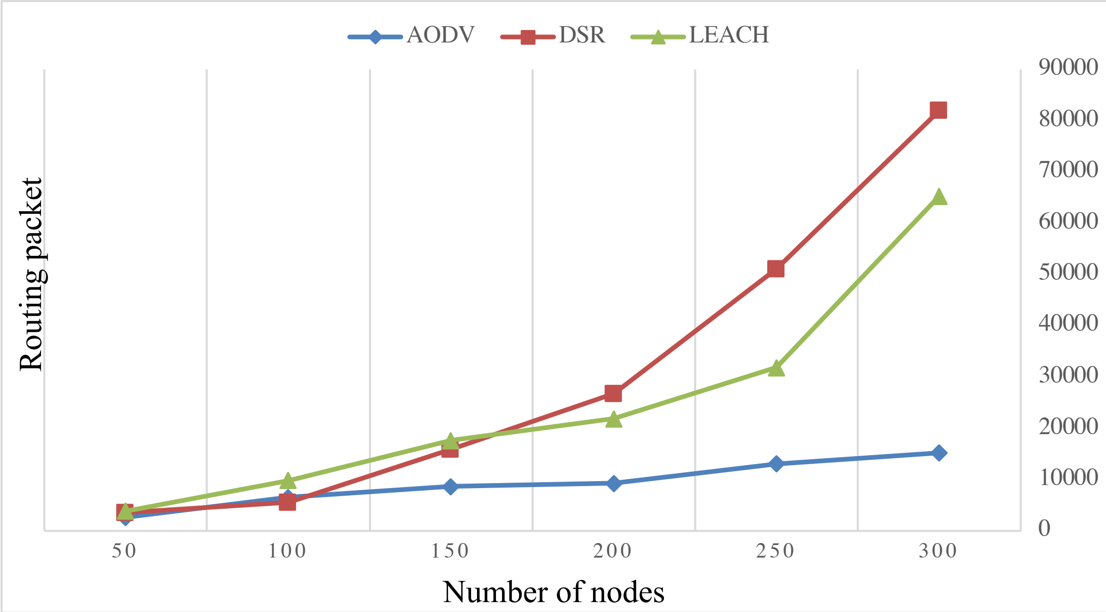

Figure 4.4– Routing packet performance for the protocols with Exponential traffic

Figure 4.5 and 4.6 represents the PDF while the network size is increasing (number of nodes) for each protocol. The simulation was deemed completed, when there was no more communication between nodes. The simulation were carried out and averaged to get value point. Furthermore, the entire scenario takes the average of 10 runs of the simulator under identical environmental conditions composed with the exact time of the simulation.

Results related to the PDF in the network are shown in Figures 4.5 and 4.6, when using CBR and Exponential traffic respectively.

The PDF rate is expressed in terms of the ratio of the total number of packets that reach the destination node to the total number of packets that were sent from the source node. From the average results, there are less packet losses for the LEACH protocol. In addition, in the Exponential traffic. The DSR protocols perform better, when the network size (number of nodes) was less than 200 nodes.

The packet delivery fraction is always above 89%, or higher number under CBR traffic type and the Exponential traffic, the packet delivery fraction on all protocol performed well, though the CBR seems to be better.

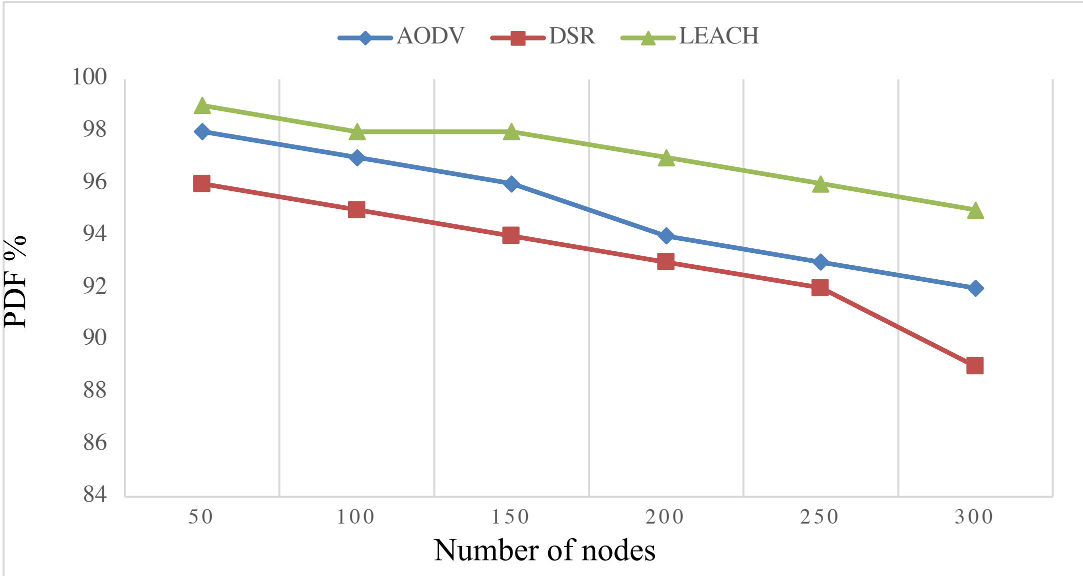

Figure 4.5– PDF % of the protocols with CBR traffic

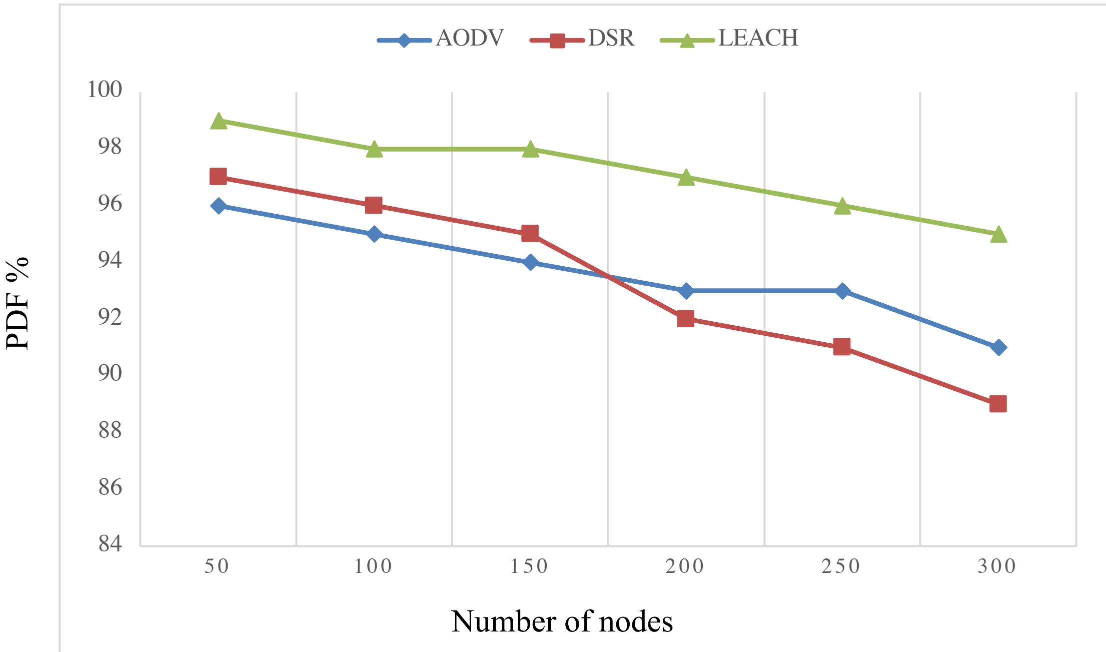

Figure 4.6– PDF % performance of the protocols with Exponential traffic

4.2.3 Performance results of mobile sensor network

Integrating mobility in WSNs motivates researchers to design and improve protocols. This section will present the results obtained, when the sensor nodes have a mobility factor. The mobile sensor nodes move according to the random waypoint mobility model (RWPM) (Abed et al., 2014, Cong et al., 2015), since it is a well-known mobility model (Mitsche et al., 2014). As in the previous section, the lifetime of the nodes, the routing packets (throughput) and PDF for all protocols will be evaluated.

Figure 4.7 and 4.8 represents the network lifetime in seconds while the network size is increasing (number of nodes) for each protocol. The simulation was deemed completed, when there was no more communication between nodes. The simulation were carried out and averaged to get value point. Furthermore, the entire scenario takes the average of 10 runs of the simulator under identical environmental conditions composed with the exact time of the simulation.

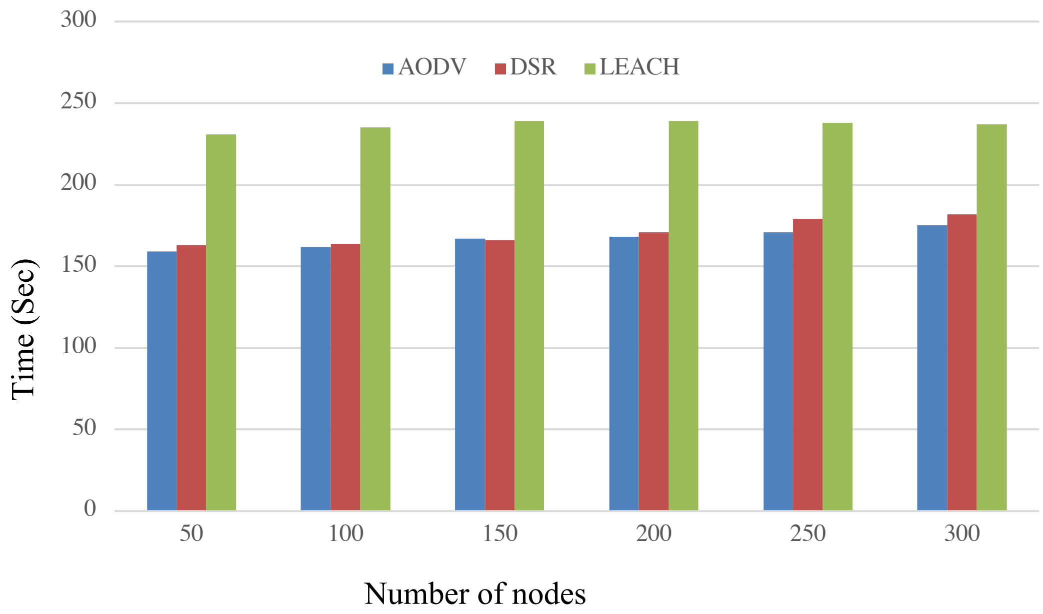

Figure 4.7– Network lifetime performance with CBR traffic

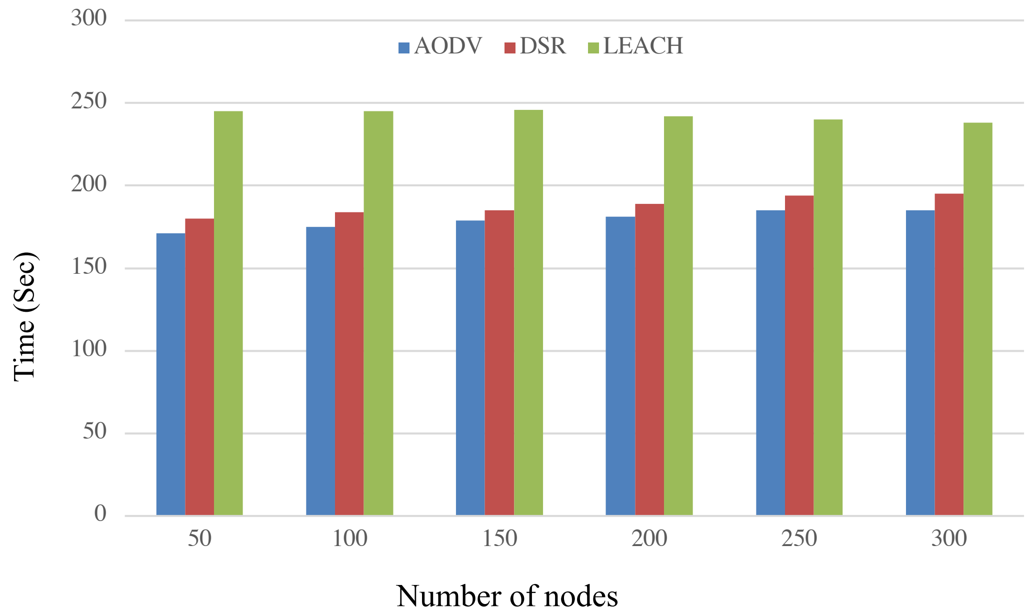

Figure 4.8– Network lifetime performance with Exponential traffic

Results related to the routing packets in the network are shown in Figures 4.9 and 4.10, when using CBR and Exponential traffic respectively.

Figure 4.9 and 4.10 represents the routing packet performance in seconds while network size is increasing (number of nodes) for each protocol. The simulation was deemed completed, when there was no more communication between nodes.

The simulation were carried out and averaged to get value point. Furthermore, the entire scenario takes the average of 10 runs of the simulator under identical environmental conditions composed with the exact time of the simulation.

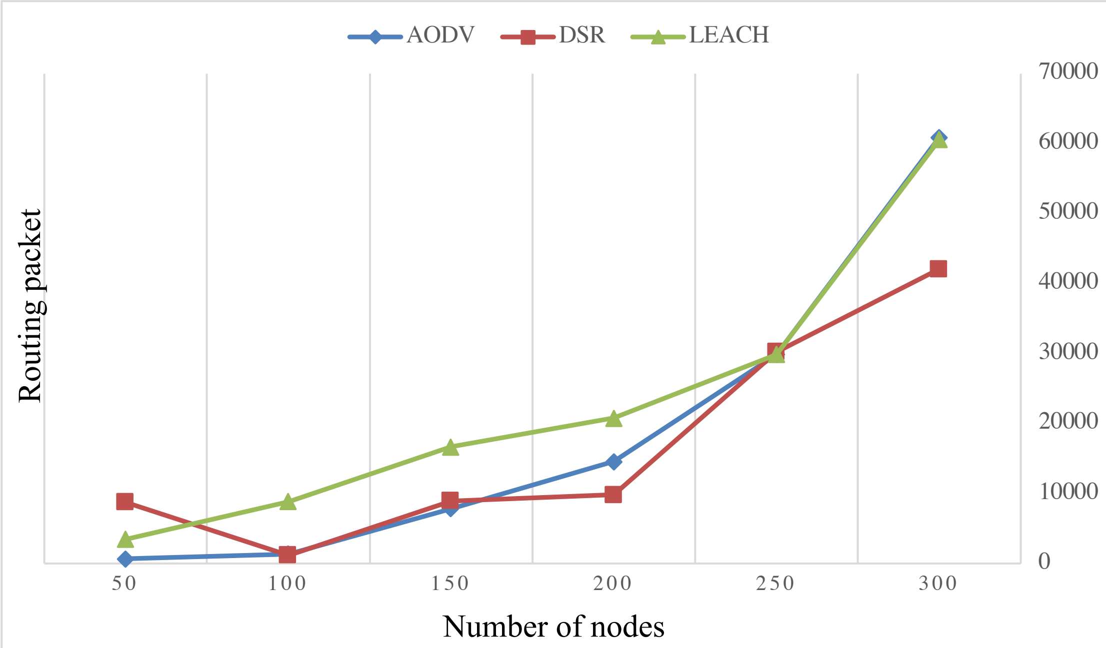

Figure 4.9– Routing packet performance for the protocols with CBR traffic

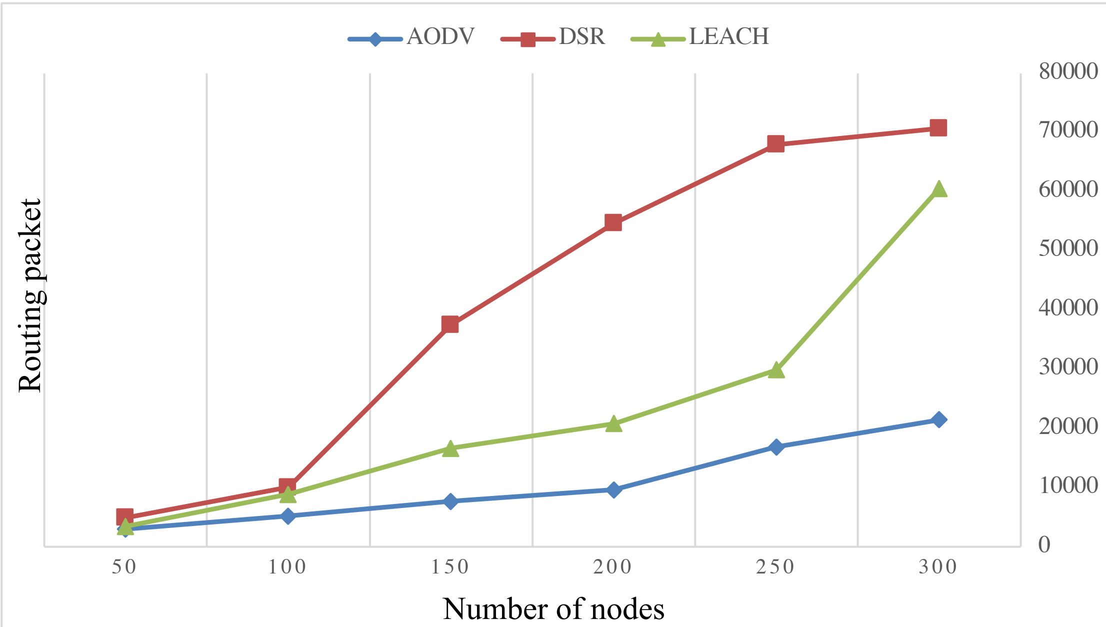

Figure 4.10– Routing packet performance for the protocols with Exponential traffic

Results related to the PDF in the network are shown in Figures 4.11 and 4.12, when using CBR and Exponential traffic respectively while the network size is increasing (number of nodes) for each protocol. The simulation was deemed completed, when there was no more communication between nodes. The simulation were carried out and averaged to get value point. Furthermore, the entire scenario takes the average of 10 runs of the simulator under identical environmental conditions composed with the exact time of the simulation.

The packet delivery fraction is always above 83%, or higher number under CBR and the Exponential traffic. The DSR protocols perform better, when the network size (number of nodes) was less than 150 nodes.

The PDF for LEACH remains consistently above 87 % for varying network size, while AODV remains consistently above 86 % and DSR can be as low as 83%. This superior PDF performance of LEACH protocols is due to the clustering mechanism, which decreases the network depth and hence increases the probability of the packets reaching the BS.

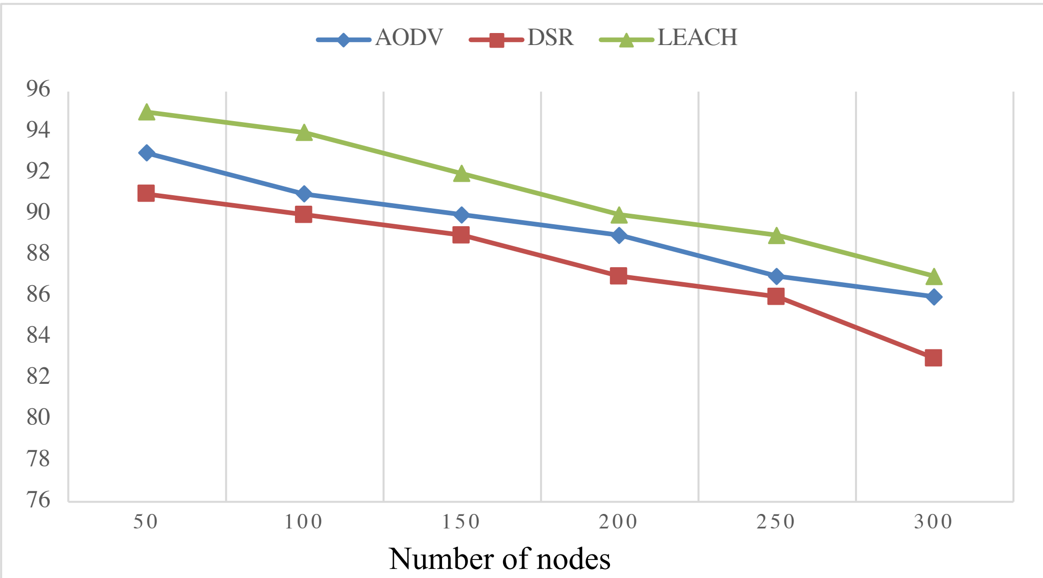

Figure 4.11– PDF % performance of the protocols with CBR traffic

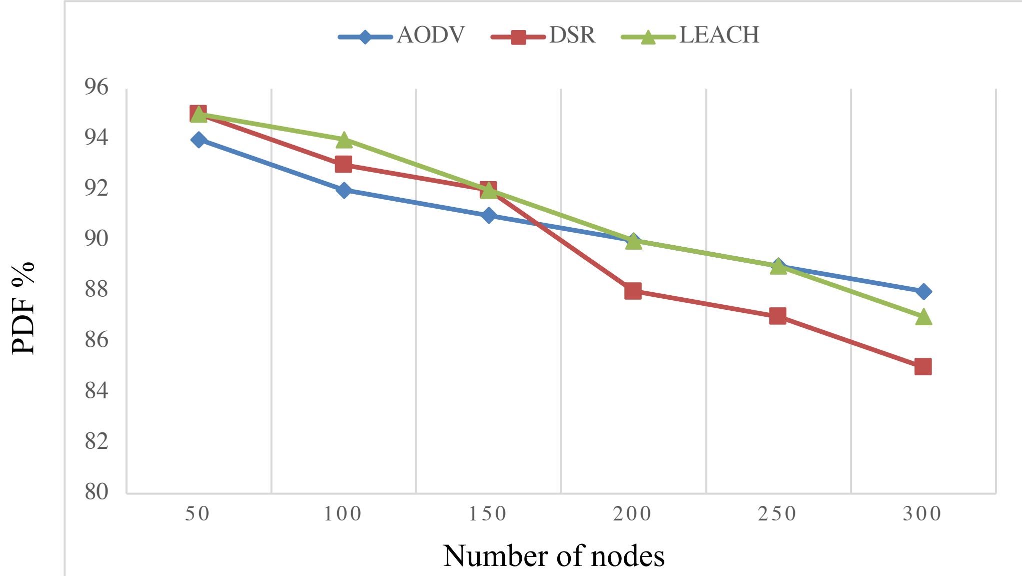

Figure 4.12– PDF % performance of the protocols with Exponential traffic

4.3 Summary and the reviews of the results

The motivation behind this chapter was the need to investigate the energy consumption of sensor nodes and the routing packets in routing protocols. This work was focused on AODV, DSR and LEACH routing protocols. An in-depth simulation study has been presented on these protocols.

By analysing a range of metrics. This analysing is based on energy consumption (network lifetime), routing packets of the network and Packet delivery fraction (PDF). Two configurations are considered for AODV and DSR protocols: Constant Bit Rate (CBR) and Exponential generator traffic, and their performance was compared with that of LEACH. LEACH performed better than the other protocols in terms of energy consumption, Therefor, applications where the energy conservation is important, LEACH should be the preferred protocol.

In addition, AODV and have better performance on static sensor network, whereas, LEACH protocol showed steady performance over most of the scenarios. Comparing these routing protocols under identical simulation conditions, for areas such as the energy conservation could be very crucial for the performance; it is clear that LEACH is the candidate.

Furthermore, for the PDF for all protocols is more than 83% for all network sizes (number of nodes). For network sizes of up to 150 nodes with Exponential traffic on mobile sensor network is better than that of AODV. Overall, the LEACH has better performance.

From the above results, it becomes clear that hierarchical protocols such as LEACH are the most efficient way of improving energy consumption in applications involving WSNs. However, as identified in the literature, (Afsar and Tayarani-N, 2014), there is area for improvement in LEACH.

In the following chapters, novel approaches for improving the network lifetime of WSNs are presented. The routing architecture called Energy-Adaptive Clustering Protocols (ECP) propose a range of modifications around LEACH for improving energy-efficiency in WSNs. Improving energy efficiency in WSNs is important because of the limited battery resources of the sensor nodes.

Chapter 5

Energy-Adaptive Clustering Protocols (ECP) for Energy-efficiency in Wireless Sensor Networks

In this chapter, Energy-Adaptive Clustering Protocols (ECP) for Energy-efficiency in Wireless Sensor Networks are proposed, and the simulation results have been compared with two well-known existing routing protocols LEACH (Heinzelman et al., 2000), DEEC (Qing et al., 2006), EE-LEACH (Arumugam and Ponnuchamy, 2015) and HT2HL (Alharthi and Johnson, 2016). The performance was measured by altering network parameters such as node density, number of clusters and so on. The evaluation scenarios successfully obtain the true behaviour and performance of the proposed routing algorithms. The proposed architectures have demonstrated improvement in network lifetime by average of 67 %, 17 %, 21 % and 8 % compared to LEACH, DEEC, EE-LEACH and HT2HL protocols respectively.

5.1 Related work

The use of poorly adapted algorithms in sensor networks not only contributes to decreasing network performance for increasing data processing speed, it also consumes more energy. It is essential to be economical with the use of the batteries in sensors that generally cannot be recharged or replaced readily. Therefore, lot of work has been carried out to reduce energy consumption as much as possible. On a more general level, the performance of each operation, whether it is the collection of data, their processing, their occupation in memory, and all the steps relating to their transmission, can be optimised in order to conserve energy. The protocols used, the sensor working cycle, and up to the very topology of the network can have an impact on the energy consumption of the nodes (Ovsthus and Kristensen, 2014, Dewan et al., 2014, Le et al., 2015).

For instance, initially WSNs used routing protocols developed for Wireless Ad hoc Networks, which did not systematically consider energy conservation as a factor; hence, the routing algorithms had to be specifically designed for WSNs. Thus, Energy-efficient Routing Algorithm to Prolong Lifetime (ERAPL), is based on the use of genetic algorithms as well as a data collection sequence to avoid loops and duplicates of transmission (Tian et al., 2015, Sucasas et al., 2016).

There are also solutions that offer energy savings by establishing a classification of the nodes for both single-path and multi-path routing, according to their priority or according to their importance to the user. Thus, priority packets are retransmitted more quickly, while those of lesser importance can wait for the traffic to be under conditions in which transmission should consume only a minimum amount of energy; the waiting phase can also allow the arrival in the buffer of the other packages and proceed with their aggregation (Kafi et al., 2014). In meanwhile, one of the key opportunities to reduce consumption in energy is the use of a hierarchically clustered architecture in the WSNs.

There are different ways to design cluster-based routing in WSNs. In flat routing methods, all neighbouring sensor nodes normally have the same data of the same event and each node transmits to BS individually, this results in energy consumption and the nodes will last for only a short time. Whereas, in the cluster-based routing only the CHs (CHs) transmit the data directly to the BS, but the other nodes will only transmit the collected data to the CH. Hence, the CH selection will determine the lifetime of the network (Handy et al., 2002, Ari et al., 2016).

The DEEC protocol (Qing et al., 2006), is designed for heterogeneous WSNs, where the CH selection is determined by probability according to the remaining energy of each node and average energy of the network. Nodes, which have more remaining energy, have more probability to become the CH than nodes having less remaining energy.

One of the most common clustering algorithms employed in WSNs is the LEACH algorithm. A dynamic algorithm, which performs new network clustering regularly over time, and sets up a simple but effective routing solution for packets in the network (Heinzelman et al., 2000).

There are also many other protocols, and some of them take into account two to three parameters, such as the residual energy of nodes, their distance to the potential CH or the number of neighbours, such as the HEED protocol. (Younis and Fahmy, 2004, Abbasi and Younis, 2007, Chourasia et al., 2015).

LEACH was developed, in order to address the unique necessity of WSNs. Most of the application protocol architectures in a sensor network have a main function which is to forward the data gathered by sensors to the BS. In order to avoid energy consumption many approaches have been proposed to achieve low energy consumption (Batra and Kant, 2016).

The main task for clustering-based routing protocols is to minimize global energy consumed by nodes. For this purpose, the load needs to be balanced across the network over time. Since the sensor nodes will connect to the appropriate CHs depending on signal strength, this methodology require the nodes that have the highest energy within the cluster to volunteer to be the CH and transmit the aggregate data to BS (Handy et al., 2002, Ahmad et al., 2014, Mahapatra and Yadav, 2015).

Researchers are continuously contributing to clustering algorithms. Several of them are even specifically adapted to WSNs, mostly based on LEACH whether to improve its performance or the LEACH security (Liu, 2015).

ED-LEACH (Hou et al., 2009), studied Euclidean Distance between nodes to improve location of CHs in a region, due to random deployment of the nodes which become placed close to or sometimes far away from each other. Chung-Shuo (2013) proposed a new cluster-head selection method for LEACH. Work proposed (Hou et al., 2009) takes into consideration the remaining energy of nodes and the protocol has two levels of operation. Similar to the LEACH protocol, ED-LEACH introduced a random delay before sending advertisement messages by CH nodes made it better for cluster to join the process. This process has resulted in 17%

reduction in the number of CHs, however potential unreachability of nodes is not addressed, though identified as an issue with this protocol.

In terms of LEACH-CE (LEACH-Centralized Efficient) (Tripathi et al., 2013) protocol, although the improvement is made to LEACH, still the nodes with the highest energy in a region will become a CH, because nodes with less energy in some round will die sooner. LEACH-CE in the set-up phase chooses the higher energy nodes as cluster-head in each round, and this will eliminate the average lifetime of the network. ME-LEACH (Chen and Shen, 2007), is also based on LEACH, and is more energy efficient compared to the original LEACH, by reducing the communication distances between sensor nodes, but this achievement comes by powerful radio which will not work efficiently on large scale networks.

Although, some research has already been done on clustering methods for WSNs using *k-means* algorithm in mining data and smart gird, these areas of researcher have received growing interest from researchers (Qin et al., 2016). Zou and Liu (2014) introduced a Distributed *k-mean* Clustering (DKC) method. This method is proposed for WSNs based on *k-means* algorithm. The idea behind DKC is to aggregate data based on the adaptive weighted allocation. The adaptive weighted data aggregation is used to process the network node data. In addition, DKC algorithm attempts to reduce data redundancy as much as closer to the sensor nodes in order to avoid the overloading of the network.

Although the information of neighbour nodes in same cluster is taken into account when establishing the clusters. However, the above mention work has some important results missing in the review due to space limitation. For instance, the authors have not covers the energy consumption in most of the cases.

In summary, the proposed work presented in the following sections, is based on an energy efficient strategy, while at the same time distributing the energy consumption of sensors to prolong network lifetime as much as possible. Comparison of the simulation results and analysis are made to a number of approaches.

5.2 Energy-Adaptive Clustering Protocols (ECP)

In this part of the thesis, novel strategies for both network topology and routing are proposed to maximize network lifetime. The proposed ECP architecture includes variants based on the way the sensor nodes communicate to the BS via CH. The three novel methodologies proposed in this research architecture are: 1) the sensor nodes are assigned to the CH closest to the centroid in their region. 2) The sensor nodes select the CH from the neighbouring region if the CH from their own region is farther than the neighbouring CH. In other words. The sensor nodes select CH from their neighbouring region if they are in closer proximity (in terms of signal strength) compared to their own CH; 3) the sensor nodes closest to the BS, choose to communicate directly to the BS.

This method allows the network to adopt the best scenario to extend the network lifetime, by adopting optimal routing path for the outlier nodes. The proposed methodologies enable the outlier nodes in any cluster region to choose one of the three optimum ways to transmit data to the BS. This is explained further in section 5.2.2. Also, see Figure 5.3 to 5.7.

ECP encompasses three novel techniques within the clustering methodology to transmit the aggregated data to the BS. The qualifying assumption is that all the nodes will transmit the sensed data to the BS via the CH in their region, or to the nearest CH in some scenario, and directly to the BS if the distance to the nearest CH is greater than to the BS. The number of clusters in the network is denoted by the term *k-cluster*:

$$(0 \leq k \leq \text{number of sensor nodes}) \tag{5.1}$$

The BS is considered stationary and resource high for fair comparison with previously published work. The proposed protocols are evaluated with BS located in three different positions in relation to the sensing environment: centre of the network, at the edge of the network and outside the sensing environment. The size of the data packet is large (4k bits) compared to the inquiry message packet size, which is common in sensor network. The main assumptions here are the sensing environment will be divided into the set number of regions and centroids identified for each region using *k-means* before the protocol starts.

5.2.1 Cluster head selection for ECP using *k-means* approach

The *k-means* algorithm has been the most used for classification of data points in the literature (Rodriguez and Laio, 2014, Rahman and Islam, 2014). Before the set-up phase, the system will have the sensing environment divided into an appropriate number of cluster regions as defined by the user, and centroids fixed for each region using the *k-means* approach. Dividing the sensing environment into equally sized cluster regions will result in clusters containing varying number of nodes and density. The proposed ECP protocol will then initiate the CH selection process as described in section 5.2.2 (de Amorim, 2016, Abushiba et al., 2017). The *k-means* method was implemented in this research as described below:

$X = xi; i = 1; \ldots\ldots\ldots\ldots n;$ a set of points in a space of n dimensions, which are to be classified as K classes, $C = ck, k = 1, \ldots\ldots\ldots, K$. The *k-means* algorithm, tries to find the correct partition such that the quadratic error between the empirical center of the class and all the points belonging to it is minimal.

The equation (5.2) below describes the process for *k-means* algorithm:

$$\sum_{j=1}^{k} \sum_{Xi \in Si} \|Xi - Cj\|^2 \qquad i = 1, \ldots\ldots\ldots\ldots N \tag{5.2}$$

- Generate k points cluster centre, the number of the cluster-required k.
- Set the data points. In this case the data points will assign to location of the nodes, in every cluster area required
- The cluster centre (centroid) in each area will assign to nearest node by calculating the mean value of the nodes location (data points) in each cluster.
- This node will become the cluster-head if it has enough energy, means above the threshold set.

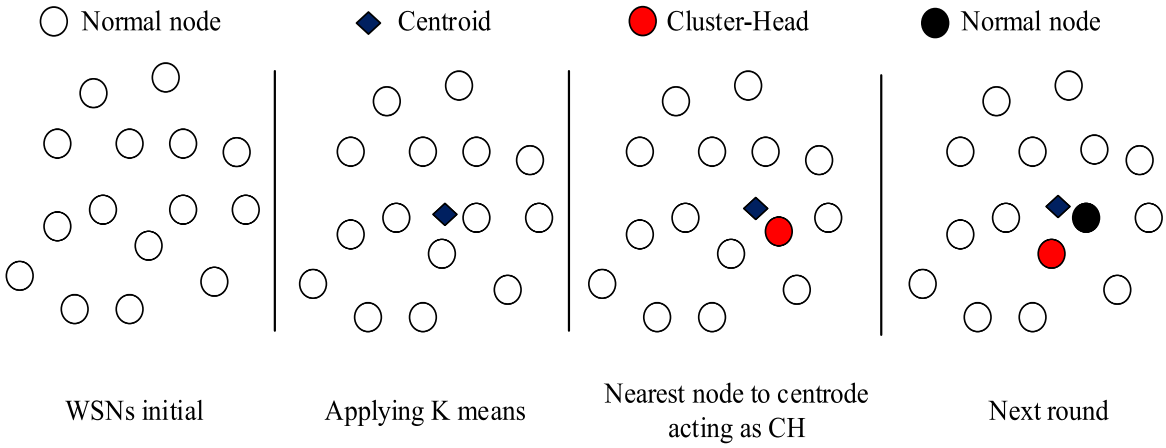

Figure 5.1– Formation schedule of the cluster-head in round.

Repeat the steps when the assigning node that is near to the cluster centre but not able to act as CH. According to (Drineas et al., 2004), the authors mention that the *k-means* algorithm risks converging towards a local optimum, but ensures very short execution times. In this case, the number of the clusters versus the gird area of the network will be tested to ensure the coverage will not be an issue.

In this context, the *k-means* algorithm is implemented where the number of classes correspond to the number of clusters in the sensing environment. In this research work, I have evaluated the algorithm for 6 different cluster group scenarios: 5, 10, 15, 20, 25 and 30. The clustering is followed by the identification of the centroid position in each of the cluster regions. This process is presented, in the next section along with the discussion on the how the *k-means* algorithm will be implemented as part of the proposed architecture. This process is shown in figure 5.1.

Set-up phase

Before the set-up phase begins, the k-means algorithm would have divided the sensing environment into a number of clusters as required by the user, and identified the centroid for each cluster region. Following this step, the ECP algorithm will start the process for CH nomination. During this process, the nodes in each region will compute their probability to become the CH using equation (5.4) as in LEACH. Then those nodes which are eligible to become CHs in this round will compare their energy levels with the threshold-energy set for the round. This threshold-energy is dynamically fixed at 60% of the remaining energy of the network for each round. The eligible CHs with node energy higher than this threshold-energy in each region will nominate themselves as CHs. Finally, the contending CH candidates will identify the CH nearest to the centroid for their region, following the process described in equation 5.2. The rest of the potential CHs will be stored in a database in the hierarchical order of their distance from the centroid. If there is more than one qualifying CH in a region with same energy levels and at same distance from the centroid, the algorithm selects one of them randomly.

The distance is calculated between the data points (the position of the sensor nodes) by using Euclidean distance (Danielsson, 1980).

$$Dist\ (X_1, X_2) = \sqrt{\sum_{i=2}^{n} (x_{1i} - x_{2i})^2} \tag{5.3}$$

The rest of the nodes forming the cluster will sense the data and transmit to the CH nodes to which they are assigned. The CHs will in turn transmit the data to the BS. A node will act as the CH as long as its energy is above the threshold.

When the energy level falls below the threshold value in the CHs, their status reverts to normal sensing nodes. Implementing *k-means* algorithm has forced the system to identify the optimum number of CHs for the field area and node density. This I believe has improved the network lifetime further.

$$T(n) = \begin{pmatrix} \dfrac{p}{1 - p\left(r \bmod \dfrac{1}{p}\right)} & , if\ n\ \in G \\ 0 & , otherwise \end{pmatrix} \tag{5.4}$$

Once the CHs are established, they inform their neighbouring nodes of their change of status using broadcast messages. For all node communications, the hello (inquiry) message packets were assumed to be in the range of 10s bits long, whereas the data message packets were fixed at 4k bits.

Other nodes, which have not designated themselves as CHs for the ongoing round, choose to join the CH cluster from which they received the data with the highest received signal strength (RSSI). Each node joins the cluster by sending a message to the CH.

This concludes the set-up phase. This will be followed by the steady phase where the data sensed by the nodes are transmitted to their regional CHs. This will use Time Division Multiple Access TDMA technique. Figure 5.2 below illustrates this principle.

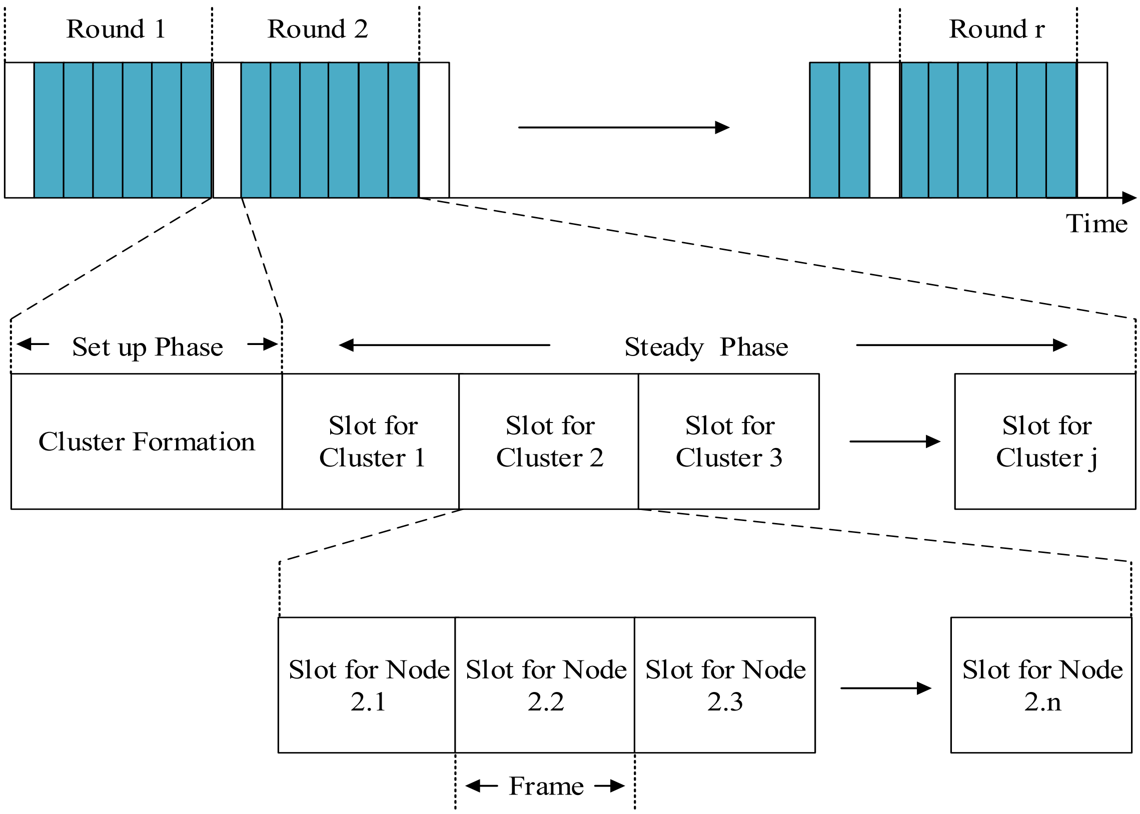

Figure 5.2– TDMA process sown in the timeline for the round.

This is followed by the data collection phase. CHs listen and receive the data from other sensor nodes in their cluster. The sensor nodes, which can be called Normal nodes, perform their mission, for instance, taking measurements of their environment, and sending their results to the CH, when it is their turn to do so. When it is not their turn to communicate, these nodes put their radio equipment on standby to save energy.

Steady state phase

Once the clusters are formed using the *k-means* implementation, the data transfer between the cluster nodes and their CH will start using TDMA process. The data packet will be comprised of the sensed data, the node id, coordinate position of the node, and the node's residual energy. After receiving the data from their cluster nodes, the CHs will process the data and transmit directly to the BS. As the sensed data is processed by the CH before forwarding onto the BS, this conserves the energy and bandwidth required for transmission. Once this operation is completed, the next round will begin. A new value for threshold-energy will be calculated every round (Average network energy x 0.6). The CHs will function as CHs as long as their residual energy is higher than the threshold value set for each round.

As soon as the residual energy of a CH falls below the threshold-energy, its status will revert to that of the normal sensing node. Then the next successor CH will be selected from the database of all CHs selected in the cluster region during the set-up phase.

5.2.2 Variants of Energy-Adaptive Clustering Protocols (ECP)

In this proposed architecture. There may be one or two variant scenarios that do not fit with the overall expected 'normal situation'. Normal situation, ECP (A1), where the sensor nodes are assigned to the CH closest to the centroid in their region.

ECP (A1)

In scenario 1, which is implemented as ECP (A1), the sensor nodes communicate to their regional CHs, and the CHs communicate to the BS.

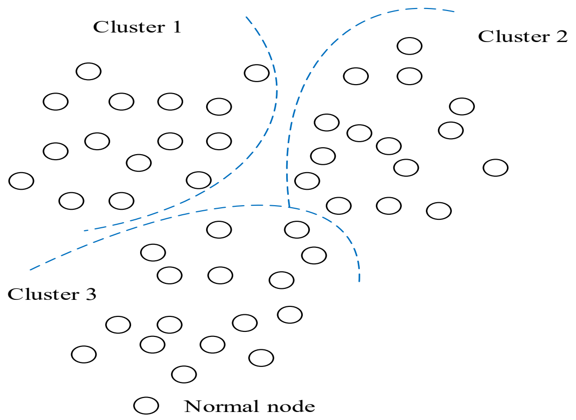

Figure 5.3– Initial of three clusters

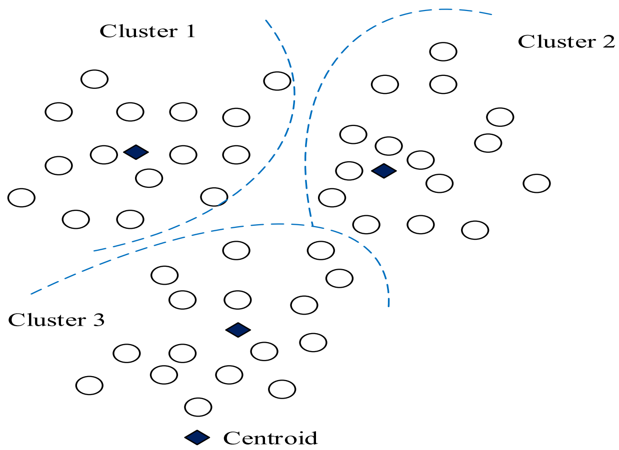

Figure 5.4– Establishing *k-means*

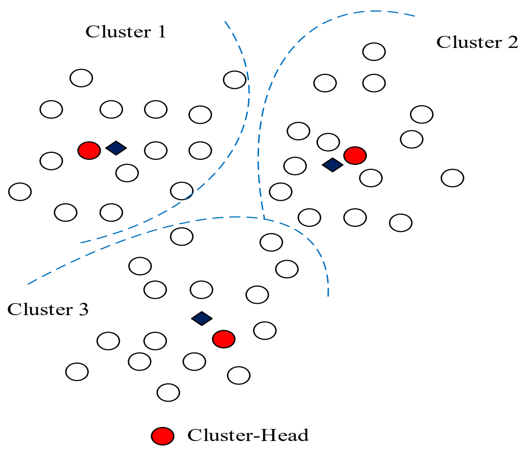

Figure 5.5– Nearest node to centroid acting as CH (A1)

In the following section (ECP (A2) and ECP (A3)), two such outlier scenarios have been considered to modify the proposed protocol to address issues arising in such situations. This method allows the network to adopt the best scenario to extend the network lifetime, by adopting optimal routing path for the outlier nodes. The proposed methodologies enable the outlier nodes in any cluster region to choose one of the two optimum ways to transmit data to the BS.

ECP (A2)

As the proposed routing architecture divides the sensing environment into clustering regions and the CHs are selected close to the centroid, it is possible to have outlier nodes in some or all of the regions. The outlier nodes may be too far away from the calculated centroid of their region. This may mean that the communication between these nodes and their CH will consume a huge amount of energy and the nodes will die much earlier than other nodes. In order to address this situation, a variant of the ECP (A2) has been implemented where the outlier nodes in a cluster region will assign themselves to a CH from the neighbouring region to which they are in close proximity.

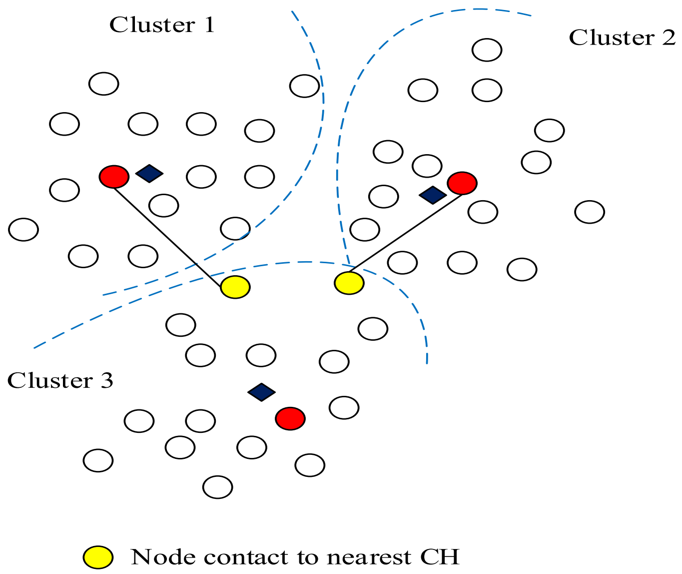

Figure 5.6– Nodes finding the nearest active CH (A2)

ECP (A3)

The second such scenario is where the normal sensing nodes are closer to the BS than the CH of their region; energy may be unnecessarily spent in communication between the sensor nodes and the CH. So, a variant of the ECP (A3) is proposed where the sensing nodes closer to the BS will communicate directly to the BS to conserve energy thus extending the network lifetime.

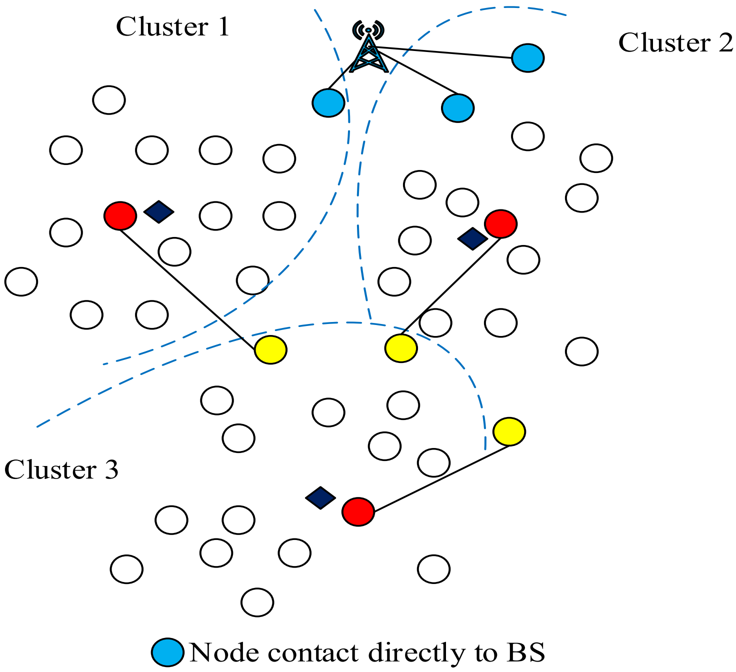

Figure 5.7– Nodes communicating with the BS directly (A3)

5.3 Simulation and performance analysis

In this section, the ECP routing protocols along with the variants have been implemented via simulation using Matlab.

The performance of the proposed approach is compared with that of LEACH (Heinzelman et al., 2000), DEEC (Qing et al., 2006), EE-LEACH (Arumugam and Ponnuchamy, 2015) and

HT2HL (Alharthi and Johnson, 2016). The parameters considered for the simulation are given in Table 5.1.

5.3.1 Experimental set-up and proposed network model

For the experimentation, sensor networks with numbers of nodes 100, 200 and 300 (as shown in Figure 5.8) were considered.

It was assumed that all nodes are randomly distributed over the 100*100 m of sensing area, where all the nodes are homogeneous which means every node has the same identical sensing, communication capabilities and same initial energy. Three different locations (x=50, y=50), (x=50, y=100) and (x=50, y=150) have been selected for the BS (sink) position. This was to ensure fair comparison between various scenarios. All of these parameters are summarized in Table 5.1.

Table 5.1– Parameter Values for the Simulation

Parameter	**Value**
Network Size (m*m)	100*100
Location of BS	(50, 50), (50, 100) and (50, 150)
Number of Nodes	100, 200 and 300
CH Probability	0.1
Initial Energy	0.5 *J*
E_{TX}	50 *n J/bit*
Number of k-means Cluster k-means	5, 10, 15, 20, 25 and 30
The Data Packet Size (bits)	4000
Each data point was generated by averaging 10 simulation results.	

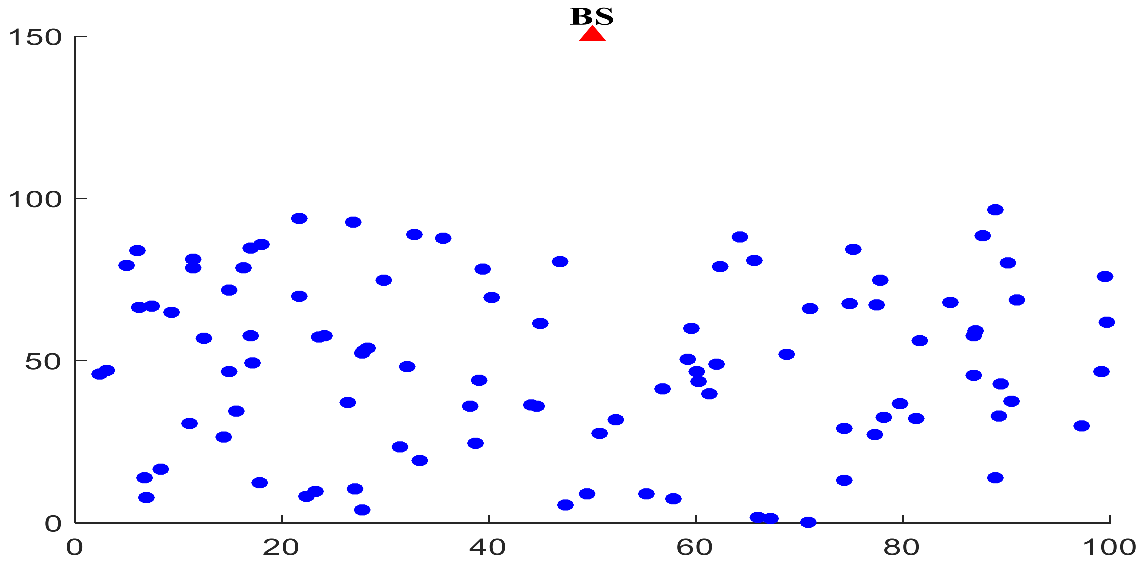

Figure 5.8– 100 nodes randomly distributed over the 100*100 m (BS x=50, y=150).

5.3.2 Simulation results

To evaluate the performance of three scenarios using ECP, the following performance metrics were used:

- The Network Life Time, the time period of sensor nodes still keeping active, which means transmitting and receiving data, assuming over 90 % of nodes have not enough energy to do so in the case when 100 nodes were deployed in the network. In the case where 200 and 300 nodes were deployed, the network will be considered being expired, when 95 % of nodes has died.
- Energy consumption, during the operational sensors network, the amount of energy the nodes will dissipate in transmitting and receiving data between normal nodes and CH nodes.
- The Effective Data sent, the performance of the network, can judge by the total of the transmission during the course of the network process, as an indicator of the overall energy consumption (network lifetime).

5.3.2.1 Energy consumption in ECP

The study of the energy consumption of the proposed method is essential to appreciate the effect produced on the battery of the sensors. The numerical results presented in this subsection were obtained by running a simulation, whose parameters are presented in Table 5.1.

Figure 5.9 to 5.11 shows the residual average energy as a function of the number of nodes in the three variants (A1, A2 and A3) of the ECP comparing to LEACH, DEEC, EE-LEACH and HT2H protocols.

In figure 5.9 where, the number of the rounds is represented on the x-axis and the average consumed energy on the y-axis, the performance of ECP shows that the energy consumption in the network using the ECP (A1) protocol is less compared with that of LEACH, DEEC, EE-LEACH and HT2H protocols.

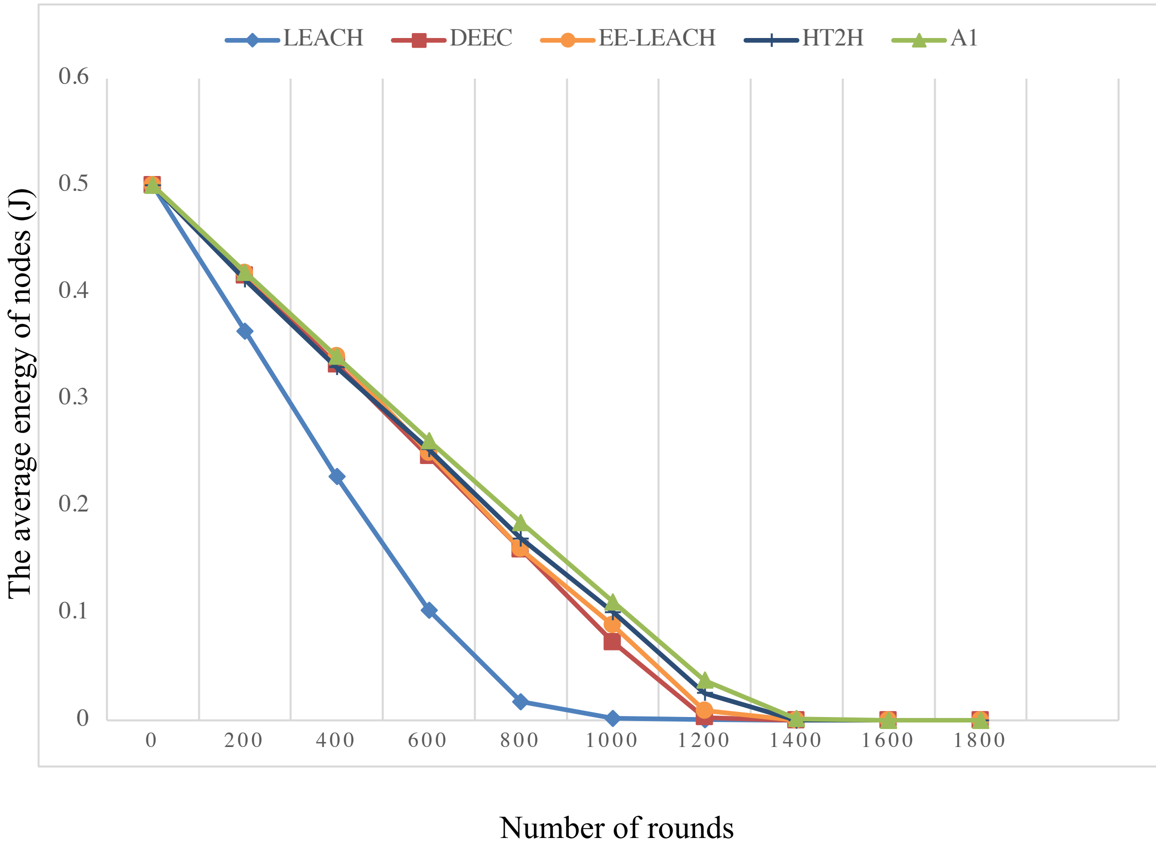

Figure 5.9– Energy consumption comparison to A1, (100-nodes, cluster number 10, BS (50, 50))

In figure 5.10 where, the number of the rounds is represented on the x-axis and the average consumed energy on the y-axis, the performance of ECP shows that the energy consumption in the network using the ECP (A2) protocol is less compared with that of LEACH, DEEC, EE-LEACH and HT2H protocols.

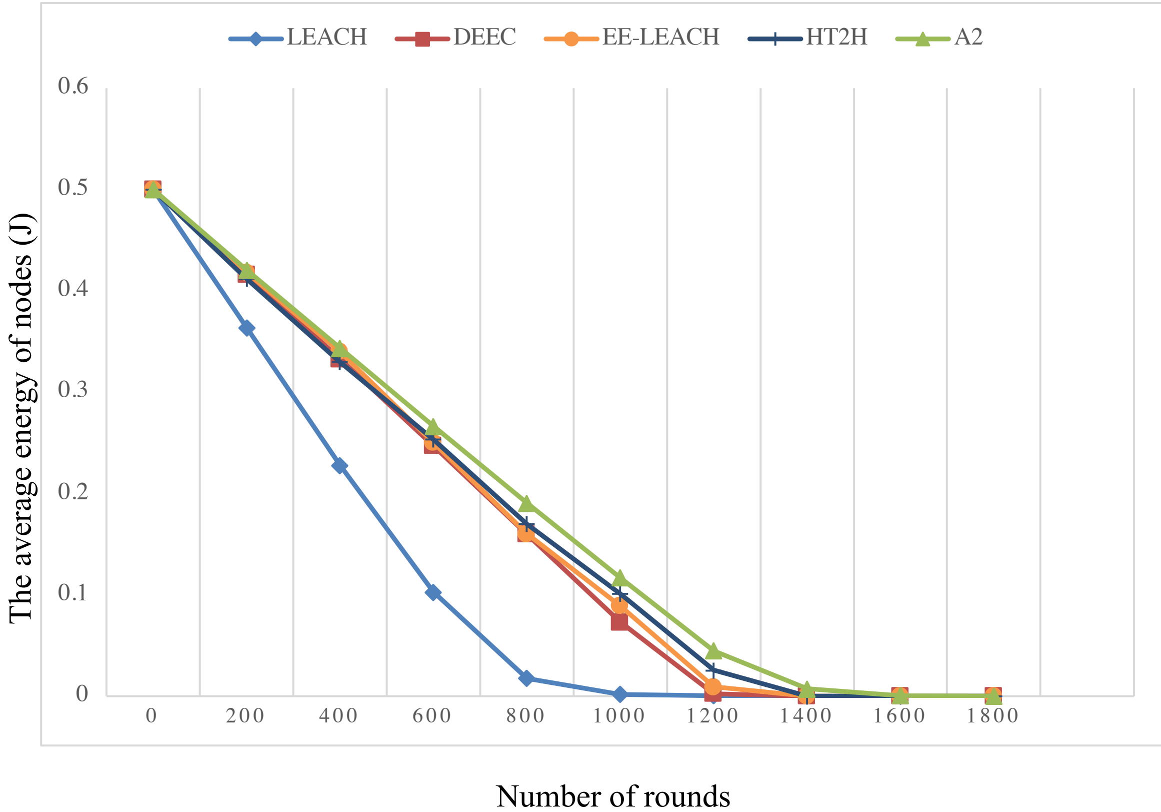

Figure 5.10– Energy consumption comparison to A2, (100-nodes, cluster number 10, BS (50, 50))

In figure 5.11 where, the number of the rounds is represented on the x-axis and the average consumed energy on the y-axis, the performance of ECP shows that the energy consumption in the network using the ECP (A3) protocol is less compared with that of LEACH, DEEC, EE-LEACH and HT2H protocols.

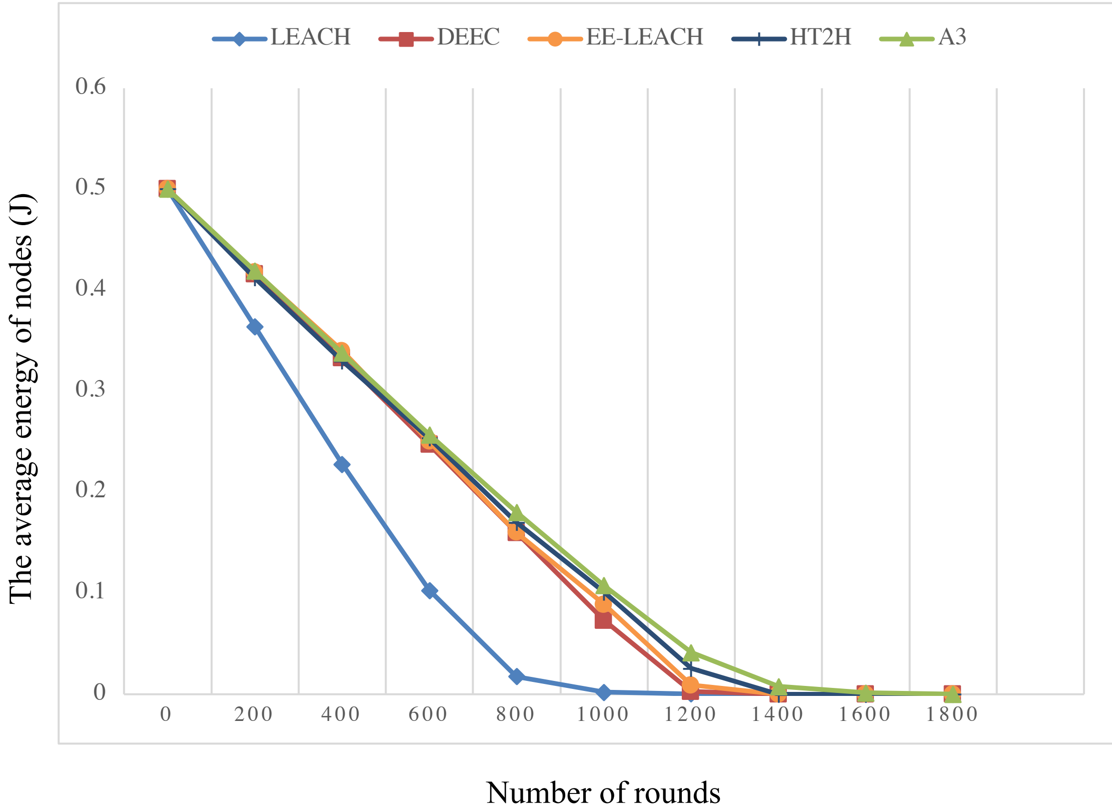

Figure 5.11– Energy consumption comparison to A3, (100-nodes, cluster number 10, BS (50, 50))

Essentially, the average energy consumed in the entire network is very low in most of the scenarios. Thus, in ECP, the sensor nodes can save up to 22 % of their energy compared to the LEACH, DEEC EE-LEACH and HT2H protocols.

The most energy conservation happens in the scenario ECP (A3). The main reason being the sensor nodes closer to the BS communicated directly to the BS without having to go through the CH.

5.3.2.2 Network lifetime

Figures 5.12 to 5.14 illustrate the simulation results for the network lifetime as histograms, by examining the performance of same network density (same number of nodes) in these graphs the BS was set on different positions.

Figure 5.12– The network lifetime of 100-nodes (BS at location x=50, y=50).

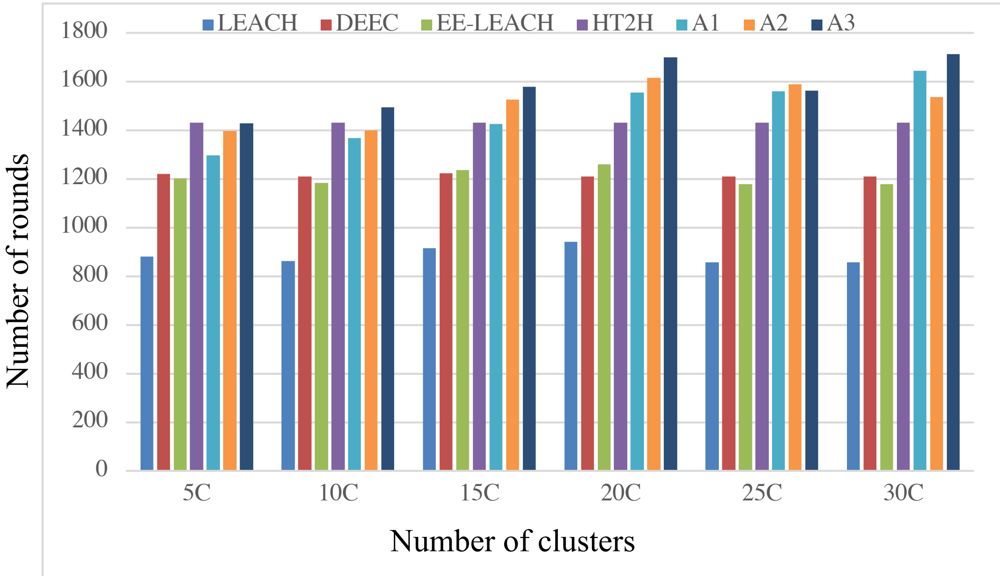

Figure 5.13– The network lifetime of 100-nodes (BS at location x=50, y=100).

Figure 5.14– The network lifetime of 100-nodes (BS at location x=50, y=150).

Figure 5.12 show the highest number of nodes still active when the BS was set on position of (x=50, y=50). Nevertheless, the network lifetime in all sets of cluster whatever the number of clusters was that EPC protocols have a very low energy consumption compared to LEACH, DEEC EE-LEACH and HT2H protocols.

Figure 5.13 show when the BS was set on position of (x=50, y=100). The performance EPC protocols have less network lifetime comparing when the BS was set on (x=50, y=50), but still the network lifetime of EPC protocols have a very low energy consumption compared to LEACH, DEEC EE-LEACH and HT2H protocols.

Figure 5.14, shows the results when the BS was placed at (x=50, y=150), when the far away from the network, the results showed how stable still the proposed protocols are.

Simulations varied the location of the BS with respect to the network (when BS is located within the network or the far away). In addition, comparing the evidence from the histogram presented for the different numbers of CHs in the area. The over all of the network lifetime, it can be noticed that there are differences when the number of clusters increases.

On the other hand, comparing the standard deviations to all positions of the BS, notable differences are found. They are evident on the histogram presented in every figure, which presents, for different percentages for the network lifetime. Observe all levels of the networks and compare; they give clear improvement of the proposed algorithms.

In all Figures, it can be noticed that the energy consumed per node increases with the cardinality of the network. This is perfectly normal because as cardinality increases, so does the degree of connectivity of the nodes. Therefore, the node receives more packets and therefore consumes more power. Also, observe that the A3 approach is helping to extend the lifetime of the network because a node consumes on average 7% less energy than in the A1 and A2 approaches.

The improvement percentage will be presented and analysed in detail in the next section. The energy spent on average by one node in each round; in all scenarios where it is difficult to reach the BS, it is important to propose an energy efficient algorithm that can extend the lifetime of the network and ensure its operation.

5.3.2.3 Performance evaluation summary

In this section, a summary of performance evaluation is presented. This comparative analysis involves the improvement percentage of the average lifetime; the total number of packets sent to BS (throughput) and the stabilized number of CHs in clusters.

Firstly, Tables 5.2 to 5.4, the percentages of average lifetime are presented, from the results observed in the previous section; these have shown that the ECP performed more efficiently. This finding indicates that the extended version of the following results are dedicated to the representation all sorts of event distributions, and the significant reduction in consumption energy during all communication phases extended the network lifetime. Furthermore, it allows visualization as demonstrated by the values obtained by simulation, and shows the full average network lifetime for the proposed protocols the over LEACH, DEEC EE-LEACH and HT2H protocols.

Table 5.2 – Performance of the ECP protocol as the BS location is varied, 100 nodes.

BS Location	Protocol	Average Network Lifetime	Improvement (%)			
			LEACH	DEEC	EE-LEACH	HT2H
(x=50, y=50)	A1	1519	63	22	18	6
	A2	1578	70	27	22	11
	A3	1642	76	32	27	12
(x=50, y=100)	A1	1475	66	21	22	3
	A2	1510	70	24	25	5
	A3	1579	78	30	30	10
(x=50, y=150)	A1	1334	91	15	31	9
	A2	1336	91	15	31	9
	A3	1361	95	17	33	11

Table 5.3 – Performance of the ECP protocol as the BS location is varied, 200 nodes.

BS Location	Protocol	Average Network Lifetime	Improvement (%)			
			LEACH	DEEC	EE-LEACH	HT2H
(x=50, y=50)	A1	1442	50	11	9	0.09
	A2	1497	55	15	13	3
	A3	1622	68	25	22	12
(x=50, y=100)	A1	1402	49	10	11	1
	A2	1451	54	14	15	4
	A3	1587	68	24	25	14
(x=50, y=150)	A1	1316	79	9	25	8
	A2	1324	80	10	25	8
	A3	1459	99	21	38	19

Table 5.4 – Performance of the ECP protocol as the BS location is varied, 300 nodes.

BS Location	Protocol	Average Network Lifetime	Improvement (%)			
			LEACH	DEEC	EE-LEACH	HT2H
(x=50, y=50)	A1	1419	40	8	10	0.08
	A2	1486	47	13	15	4
	A3	1649	63	25	28	16
(x=50, y=100)	A1	1400	39	7	5	2
	A2	1472	47	12	11	7
	A3	1693	58	21	20	16
(x=50, y=150)	A1	1344	72	7	22	10
	A2	1335	71	7	21	9
	A3	1454	87	16	32	19

In the following part, the throughput of the network is evaluated by considering the total number of packets sent to BS from CHs.

For all BS locations simulated, with regard to the delivery rates achieved with the total number of packets sent to the BS via the CHs, ECP has higher delivery rates compared to those of LEACH, DEEC, EE-LEACH and HT2H protocols. Table 5.5 to 5.7 summarize the performance comparisons.

Table 5.5 – Throughput: The average total number of packets sent to the BS via CHs, 100 nodes.

BS Location	LEACH	DEEC	EE-LEACH	HT2H	A1	A2	A3
(x=50, y=50)	14264	17750	19018	19040	55045	61440	64008
(x=50, y=100)	13149	16380	17532	17800	51008	53483	56211
(x=50, y=150)	10644	12333	14644	14888	36900	36108	36480

Table 5.6 – Throughput: The average total number of packets sent to the BS via CHs, 200 nodes.

BS Location	LEACH	DEEC	EE-LEACH	HT2H	A1	A2	A3
(x=50, y=50)	13669	28590	17940	18055	50886	62273	69435
(x=50, y=100)	13544	24825	17776	18022	48090	53783	60178
(x=50, y=150)	12570	19811	16498	17540	40895	37790	40873

Table 5.7 – Throughput: The average total number of packets sent to the BS via CHs, 300 nodes.

BS Location	LEACH	DEEC	EE-LEACH	HT2H	A1	A2	A3
(x=50, y=50)	13669	33380	18073	19512	49800	67918	78666
(x=50, y=100)	13621	32178	18014	18801	48155	53620	57388
(x=50, y=150)	12711	28821	16811	17845	42208	41696	42718

Finally, since the clusters are pre-set, obtaining a poor clustering set-up during a given method will not greatly affect overall performance of the ECP. In figure 5.14, sharing the stability of the cluster number of the proposed protocols, these results lead to observations similar to those obtained on the grid topology with all EPC protocols of the network (A1, A2 and A3). However, the proposed protocols showed most efficiency wherever the BS was placed and regardless of the number of clusters in the sensing area.

5.4 Summary

The significant aspect of the ECP protocol is that it reduces the energy consumption and extends the network lifetime for the WSNs, in the proposed scheme, by using *k-means* algorithm to select the CHs, for a certain number of nodes as these nodes are nearest to the centroid in their cluster region.

The simulation results (Figures 5.12 to 5.14) showed that the performance of the ECP protocols greatly exceeds that of LEACH, DEEC EE-LEACH and HT2H protocols. In terms of energy conservation, and the network lifetime has improved by 67 %, 17 %, 21 % and 8 % compared to LEACH, DEEC, EE-LEACH and HT2HL protocols respectively.

The proposal is effective in terms of duration of network life, and rate of reception of data by the BS. As shown in Tables 5.5 to 5.7, the performance of ECP protocols is much higher than the compared protocols, with the average throughput level of the packets. Thus, the performance of the ECP can be explained by the fact that this algorithm significantly decreases the number of packets that collide in the entire network, thus increasing the flow of receiving packets. For example, applications uses such as critical zone monitoring, habitat monitoring and agriculture intelligent, rather have requirements in terms of energy consumption, coverage area of interest and connectivity of the network. As the nodes that have already been chosen before have energy under the threshold, then the CH will be updated by choosing another node, these steps are dependent on the location of the nodes, which are randomly deployed. In addition, more Figures are given in the Appendix B.

Chapter 6

Evaluation of Energy-Adaptive Clustering Protocols for mobile node detection in WSNs (*d*-ECP)

In this chapter, the performance of the Energy-Adaptive Clustering Protocols (ECP) has been evaluated under conditions of mobility. The mobile nodes, which will be introduced in the WSNs, have the same characteristics of the static nodes, with a communication range the same as an RFID tag. Potential applications for this research could be wildlife monitoring, condition monitoring in industrial applications, IoT application etc.

6.1 Related work

Sensors are known to regularly produce erroneous, inaccurate and incomplete measurements, without it being possible to predict exactly when these incomplete measurements will appear (transient faults). Specific detection techniques, correction or mitigation of errors must be implemented, in particular in a multi-sensor environment (Harrison et al., 2016).

In recent years, the critical applications of WSNs have been given great attention among the researchers. These applications could be of use in areas such as health care, military, industry, natural world monitoring, wildlife monitoring and IoT, which require the use of mobile sensor nodes within the sensing area. In addition, a prerequisite of critical applications are a reasonable use of the sensor's battery (Krishnan and Kumar, 2016, Ali et al., 2017).

Furthermore, using sensors to collect a set of information, position, current activity (running, cycling, etc.), the mood or environment (noisy, populous, rain, etc.) of an individual in the purpose of automatically sharing this information. By extension, allow users and organizations to share information of their large-scale systems to contribute collaboratively to various analytical tasks, road traffic, population flows, conditions climatic conditions, etc. (Liu et al., 2015, Meng et al., 2016). The smart sensor, which obtains and transmits data, could be used in health sector, Ullah et al. (2016) have a vision of a framework for e-Health using body sensors to obtain, process and transmit patient health related data to a centralized storage.

In addition, sensors are also use to collect the information in self-regulate environment settings in homes and offices (temperature, brightness, humidity, energy consumption, etc.) and control access to certain resources based on context (e.g. presence or not of a manager). In the context of smart cities, analyses in real time is essential for the different parameters (noise, pollution, road traffic) and also, the connectivity of different elements for urban infrastructure to improve its management (Zanella et al., 2014).

Make possible tracking in real time and space of any object, for little that it is identified, for instance with an RFID tag. This scenario is today implemented by the industry for tracking objects in a natural world monitoring. The tracking in time for wildlife monitoring are extremely high on energy consumption for WSNs depending on the network requirements (Dominguez-Morales et al., 2016).

Furthermore, the tracking in real time for wildlife monitoring and other applications have errors measures, it is usually impossible to predict when these errors will occur as transient faults, and their causes are difficult to determine in a specific way (the position of the node). It may be hardware failures, such as a short circuit or a damaged sensor, or an effect due to battery discharge as noise input, software failure, or a calibration error. These are very widespread and can corrupt the results in different ways, for example by introducing a constant shift (offset fault), a constant gain (gain fault) or a variation of these two properties over the course of time (drift fault). These faults are also difficult to detect because all measures are affected and, in fact, maintain a certain coherence with regard to the phenomenon measured. For example, a constant offset on a temperature sensor would not disturb not the coherence of the day-night cycle (Gună et al., 2014, Peng et al., 2017).

In the next section, The Energy-Adaptive Clustering Protocols (ECP) have been evaluated under conditions of mobility to have an impact on discovery, and collection of information in terms of the position of mobile nodes (M-nodes). For example, considering a scenario, which consisted the analyses of the subject movement. In these scenarios, all available sensors could be very large, which including the static sensors installed in the sensing area. Therefore, to evaluate the proposed approaches, a number of tests were conducted; including the precise distance of the M-nodes position on the sensing area.

6.2 Mobile node detection in Energy-Adaptive Clustering Protocols (*d*-ECP)

The main goal of this work is to introduce node mobility within the WSNs and evaluate the ECP for the following metrics: network throughput, network lifetime, mobile node detection. In general, in applications related to tracking subjects, such as wildlife monitoring, near communication (NC) detection is used except when high-resolution cameras are used for that purpose.

6.2.1 The overview of the approach

The approach is based on detecting the position of an M-node, which in this proposed work is RFID. The detection range for mobile nodes to be detected by a static node is considered as 30 feet (9.14 meters) (Floyd, 2015). This means, a static node will be able to track and count the mobile subjects within the radius of 30 feet (9.14 meters) (Floyd, 2015).

For evaluation purposes, scenarios with either one mobile node (M-node) or 10 mobile nodes are used. The three variants of ECP (A1, A2 and A3) are evaluated for these two scenarios. When implemented, as in the ECP architecture, the network goes through the procedure for the 'set-up phase' where using *k-means* it divides the sensing environment into given cluster regions, identifying the centroid and CH for each region. This is followed by the 'steady-phase', where the sensor nodes start transmitting the sensed data to the BS using A1, A2 or A3 techniques. The only difference in the *d*-ECP protocols is that the sensed data will be the position of the mobile node introduced into the network. The mobile nodes were introduced at the very start of the entire procedure. The mobile nodes had been assigned with steady speed and random direction as mobile nodes passed through the sensing environment. The mobile nodes kept transmitting their position, which was detected and transmitted by the static sensor nodes. The *d*-ECP protocols detected all 10-mobile nodes at least 85% of the time.

The procedure of the algorithm is as follows:

Algorithm: The Procedure of *M-node* location
Read location information from all *M-node* in each round
for *m* = 1 **to** *N* **do** (mobile index)
  while (*d*<9.14)
    Select measurements related to ***M-node***
    Extract all the measurements from static nodes within the clusters
      if there are only one static node that detects events for ***M-node*** **then**
        detection event
        Select reference location information according to the selected measurements
        Display the position on the map
        Upload the position of the ***M-node***
        CHs data aggregation after each round, and transmission to BS
          Else
            if there are one static or more than nodes that detect events for ***M-node*** **then**
              Calculate the average distance position of position ***M-node*** location according to the latest
              Select reference location information according to minimum distance
              Select reference location information according to maximum distance
              Display the position on the map
              Upload the position of the ***M-node***
              CHs data aggregation after each round, and transmission to BS

end if

end if

removes dead nodes from all lists

repeat

end while

end for

until stop

6.2.2 Evaluation and performance analysis

The effectiveness of the proposed *d*-ECP (A1, A2 and A3) approach to detect M-nodes in the mobile sensing environment, has been evaluated under two scenarios, one with just one mobile node and the other with 10 mobile nodes. Matlab simulation was used for this experimentation. The simulation conditions are presented in the following Table 6.1.

Two performance metrics were used to evaluate the performance of the *d*-ECP under mobile environment: 1) percentage of error in detecting the mobile node. 2) their positional tracking through the sensing field.

Table 6.1 – Parameter Values for the Simulation

Parameter	Value
Network Size (m*m)	100*100
Location of BS	(50, 50)
Number of Nodes	100
CH Probability	0.1
Initial Energy	0.5 *J*
E_{TX}	50 *n J/bit*
Number of Cluster K-means	30
The Data Packet Size (bits)	4000
M-node speed	2 m/sec
Each data point was generated by averaging 10 simulation results.	

The detection rate in percentage for the mobile nodes is evaluated, in terms of how many M-nodes were not detected by the static stationary nodes. This aspect is presented as a percentage, as given below:

$$e = \frac{n}{T} * 100\ \% \qquad (6.1)$$

Where e is the error and n number of times the M-nodes were not detected, and the T is the time or total number of rounds.

The second parameter is the mobile node's position tracking. In order to achieve this, the distance of each mobile node from the static nodes involved is plotted. The distance is presented as the minimum distance, the average distance and the maximum distance. In the case of just one static node detected the M-node, all three distances will be equal. Figure 6.1; illustrates the scenario.

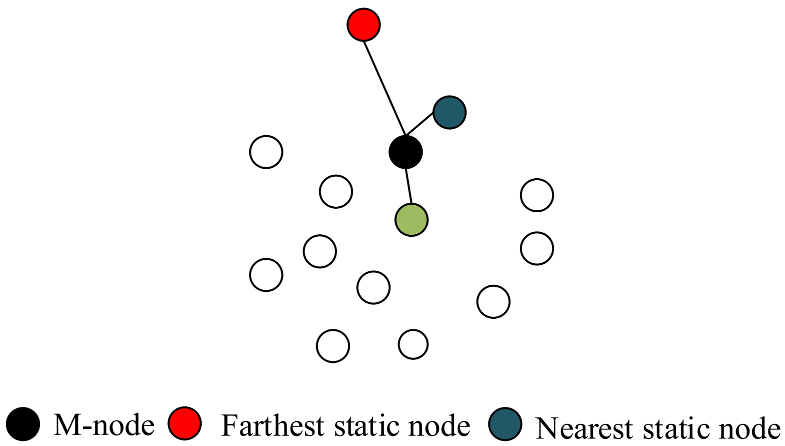

Figure 6.1– Example showing of how the distance is calculated.

Figure. 6.1 shows the example of the farthest and the nearest distance between the M-node and static nodes, where three static nodes are assumed to have detected the M-node. The Euclidean distance between a static node and the mobile node is calculated using equation 6.2.

$$d(x, y) = \sqrt{(y_1 - x_1)^2 + (y_2 - x_2)^2} \qquad (6.2)$$

According to equation (6.3), the average of the three distances will be calculated.

$$d = \frac{\sum D_{1:n}}{N} \tag{6.3}$$

Where d is average distance and N equal the number of the static nodes, which detect M-nodes, and the D is the distance between the M-node and static nodes.

6.2.3 Performance analysis for 1 M-node

The simulation is performed for the *d*-ECP protocols to examine the effectiveness of the approaches, in terms of both the accuracy of the M-nodes' detection and the distance. The simulation parameters are similar to the ECP protocols and specified in Table 6.1 above. The simulation is performed with the BS located at (50, 50), and 100 stationary nodes and the number of the cluster is 30.

Firstly, the simulation with one mobile node is as observed from Figures 6.2 to Figure 6.10. The simulation model consists of 100 nodes. These sensor nodes are distributed randomly into 30 clusters; each cluster has CHs, in a sensing area of size 100x100 meters. The range of the detection signal transmission is 30 feet (9.14 meters) RFID range.

In this simulation, performance indexes are compared for all three scenarios, A1, A2 and A3 as in the previous chapter. The performance evaluation of these protocols has been carried out under the same simulation environments, the same condition source, the same network loads, and the same parameters. Figures 6.2 to Figure 6.4 show the simulation result of distance rate for the first 50 rounds about 2.5 % of the time for running the simulation.

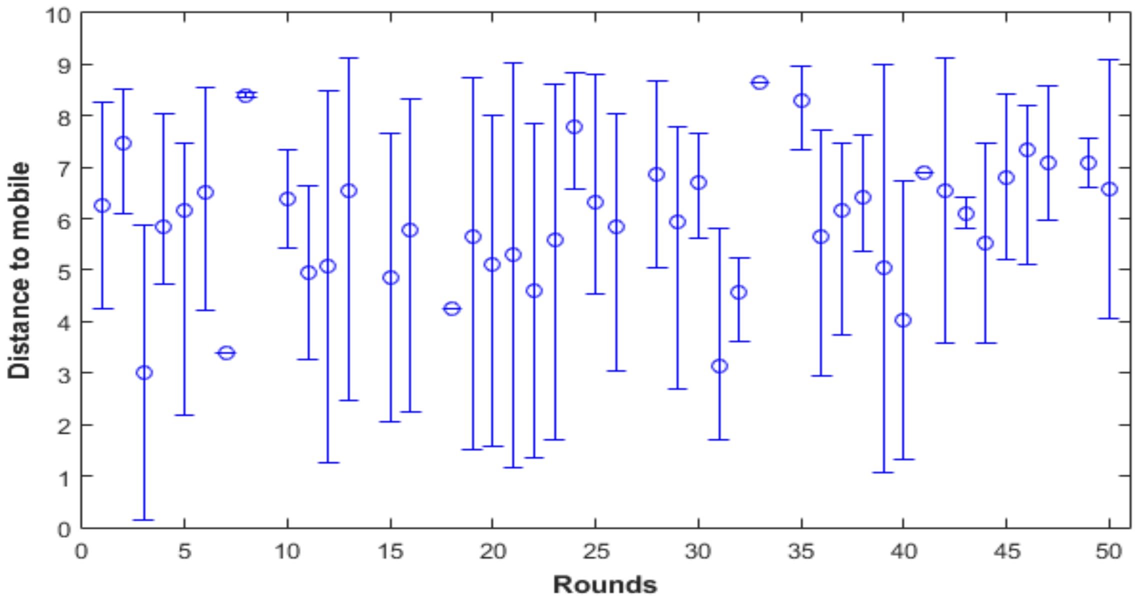

Figure 6.2– Distance variation of M-node from the static nodes (The first 50 rounds, A1).

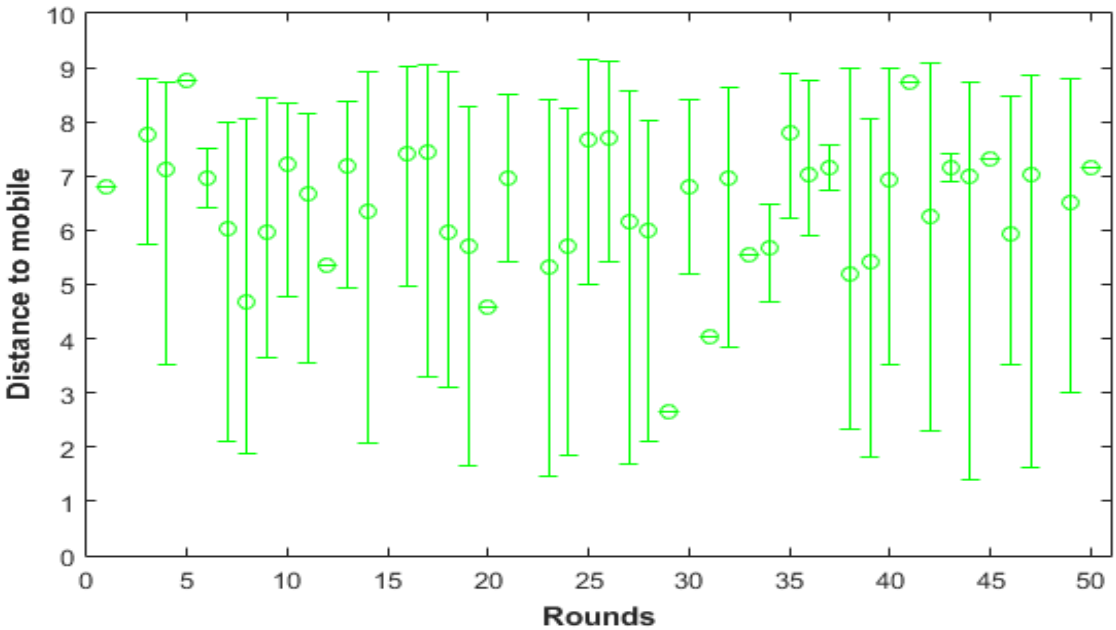

Figure 6.3– Distance variation of M-node from the static nodes (The first 50 rounds, A2).

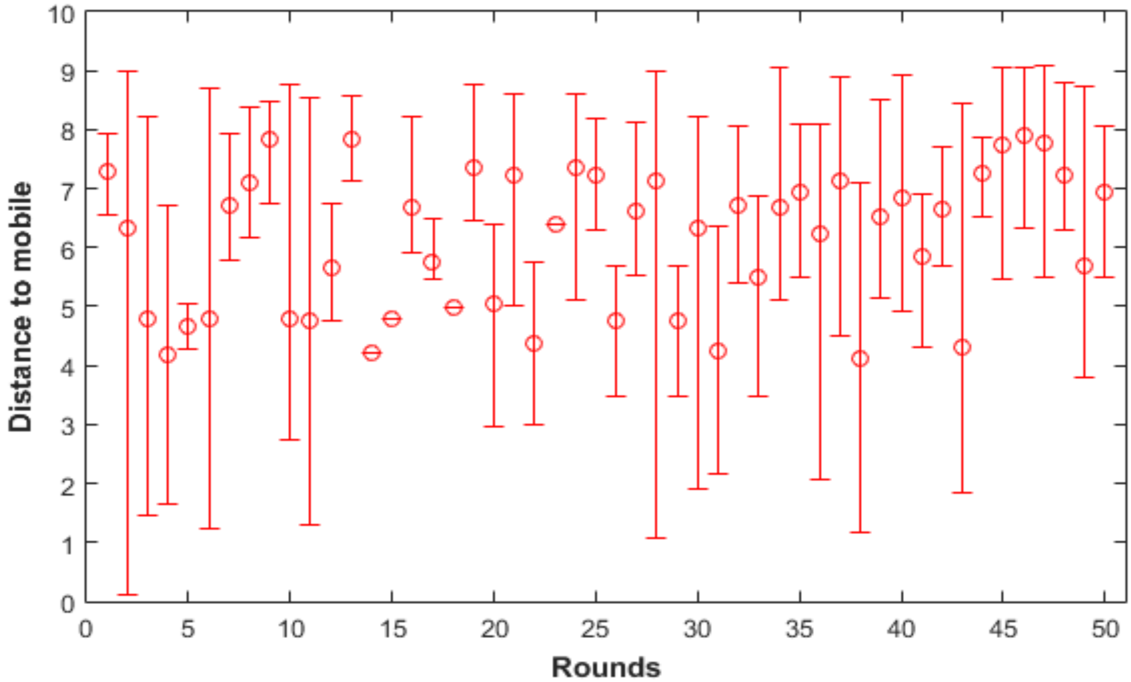

Figure 6.4– Distance variation of M-node from the static nodes (The first 50 rounds, A3).

It is obvious from the Figures that all three (A1, A2 and A3) techniques have achieved within the range in terms of detection, all of the techniques have detected the M-node at most of times in the first 50 rounds, due to the distance is bigger than 9.14 meters. Also, the when the M-nodes were detected the distance calculation is different from one to another.

Consequently, assuming the simulation will run until approximately 90 % of static nodes have enough energy in the network (transmitting and receiving data), after this point, the simulation will stop. Therefore, after calculating the available distance between the statics nodes and the M-node, techniques will select the maximum, the minimum and average distance value.

For fair comparison, in the following Figures (from Figure 6.5 to Figure 6.10), the simulation results for the distance variation of the time at middle and at end of simulation processes are shown.

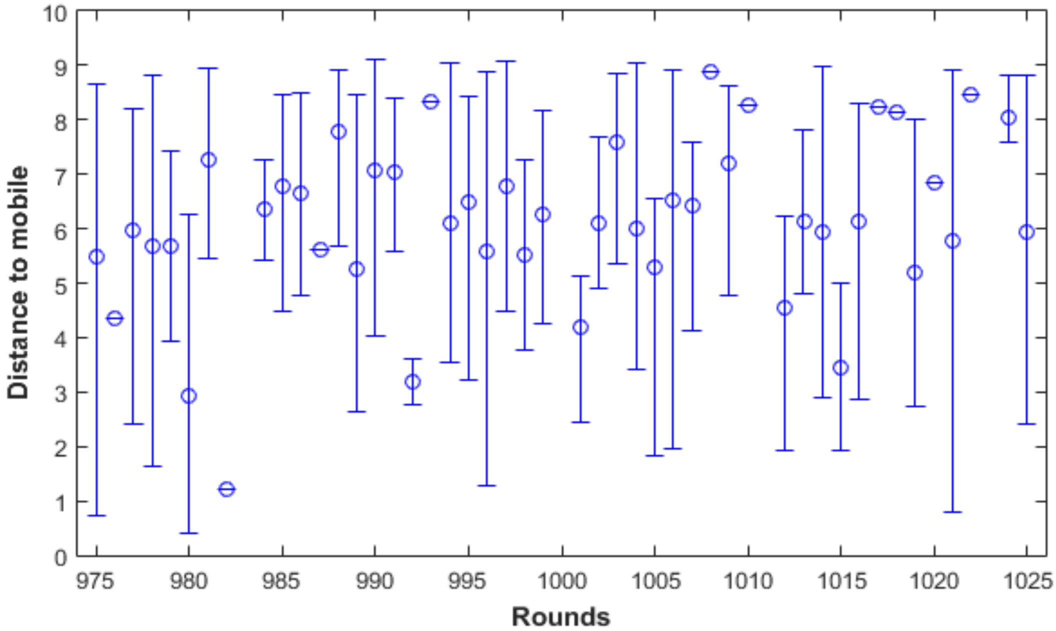

Figure 6.5– Distance variation of M-node from the static nodes (at the middle of the simulation, A1).

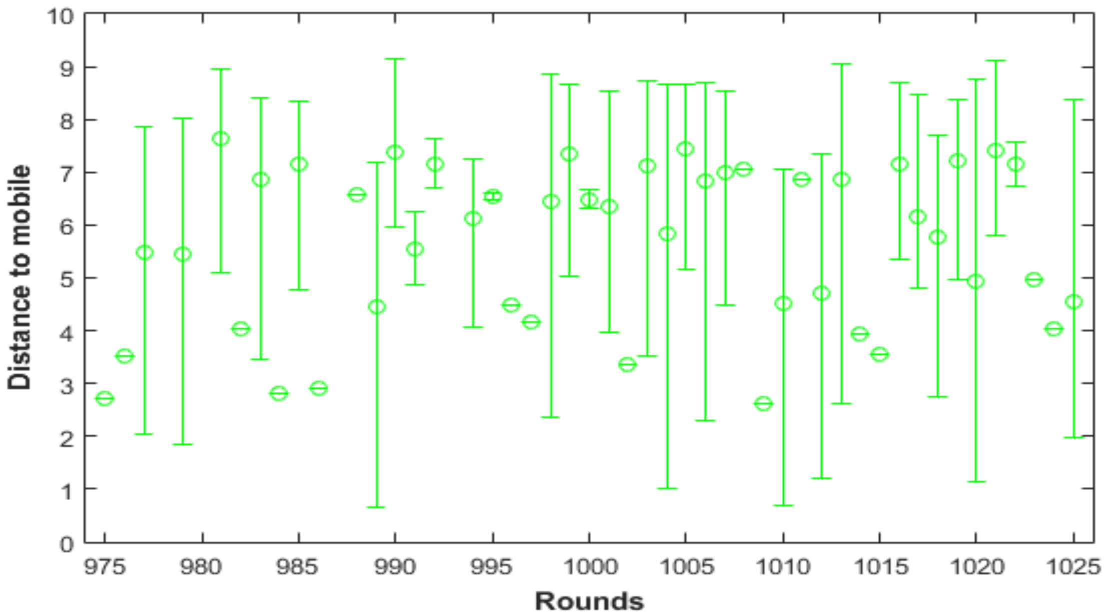

Figure 6.6– Distance variation of M-node from the static nodes (at the middle of the simulation, A2).

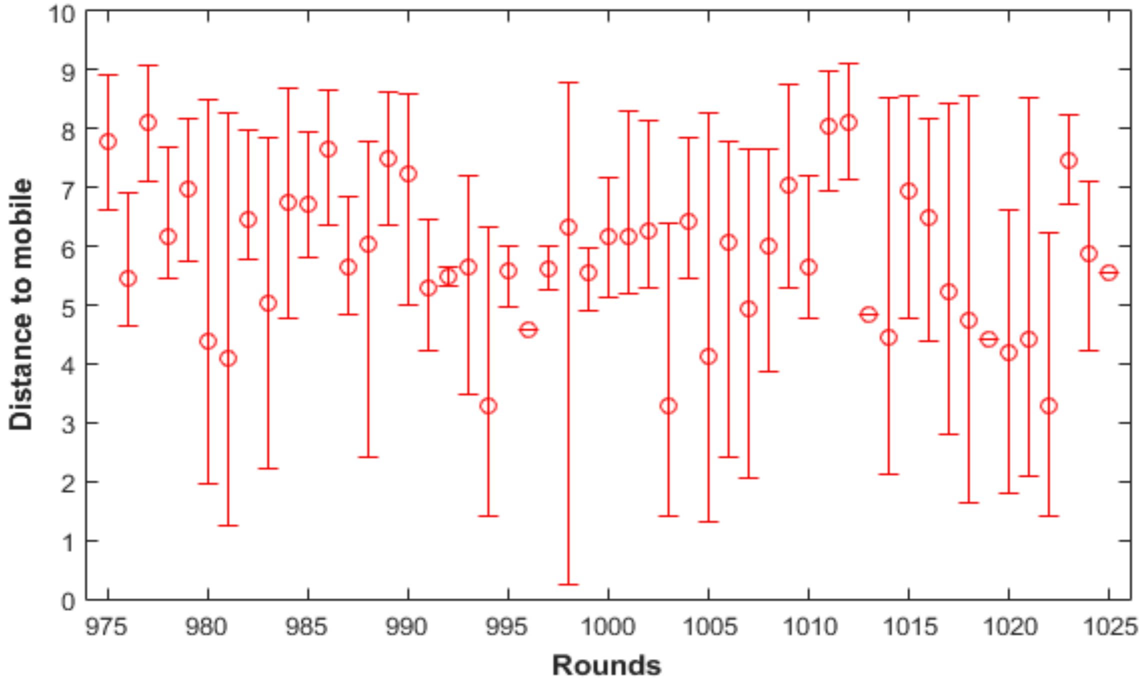

Figure 6.7– Distance variation of M-node from the static nodes (at the middle of the simulation, A3).

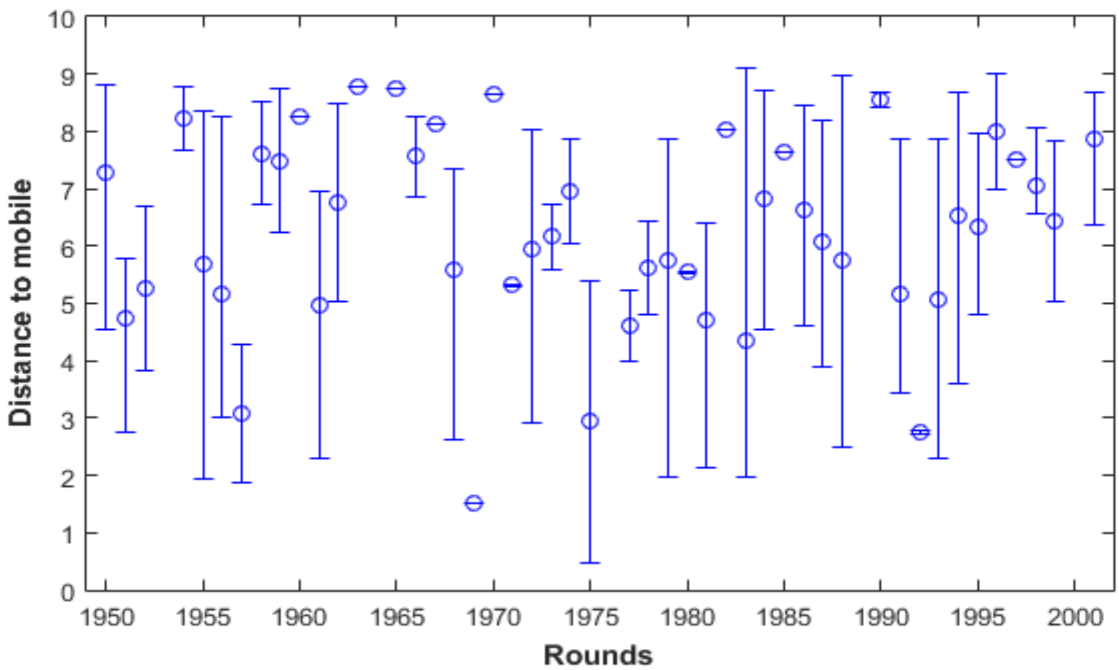

Figure 6.8– Distance variation of M-node from the static nodes (at the end of the simulation, A1).

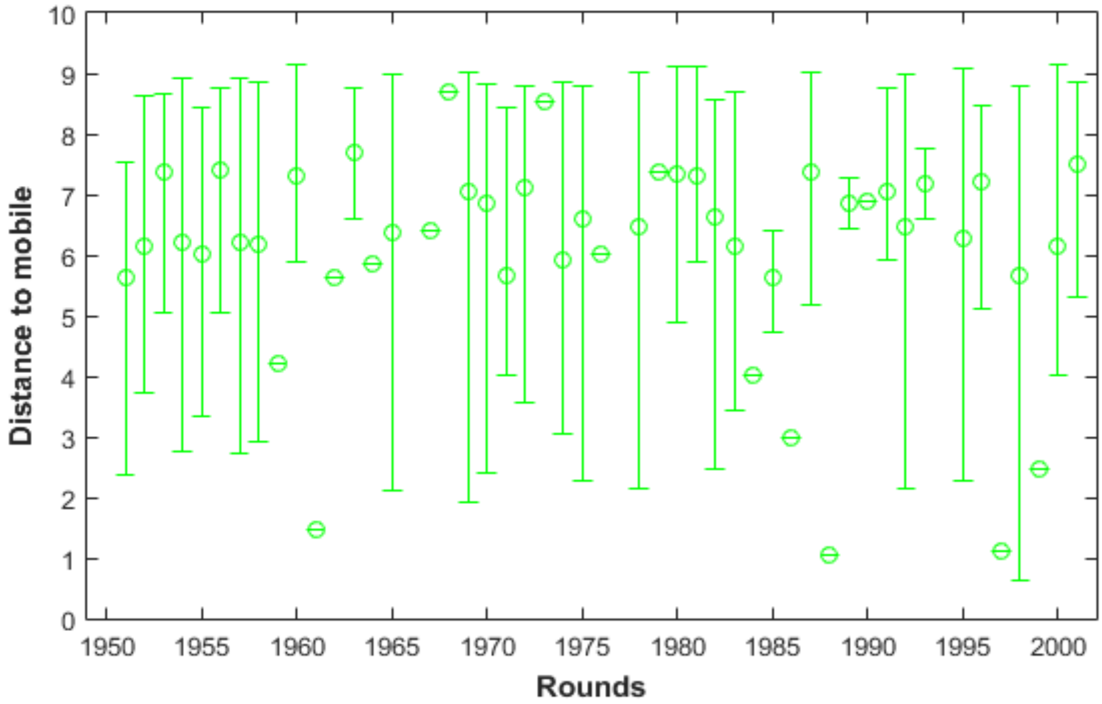

Figure 6.9– Distance variation of M-node from the static nodes (at the end of the simulation, A2).

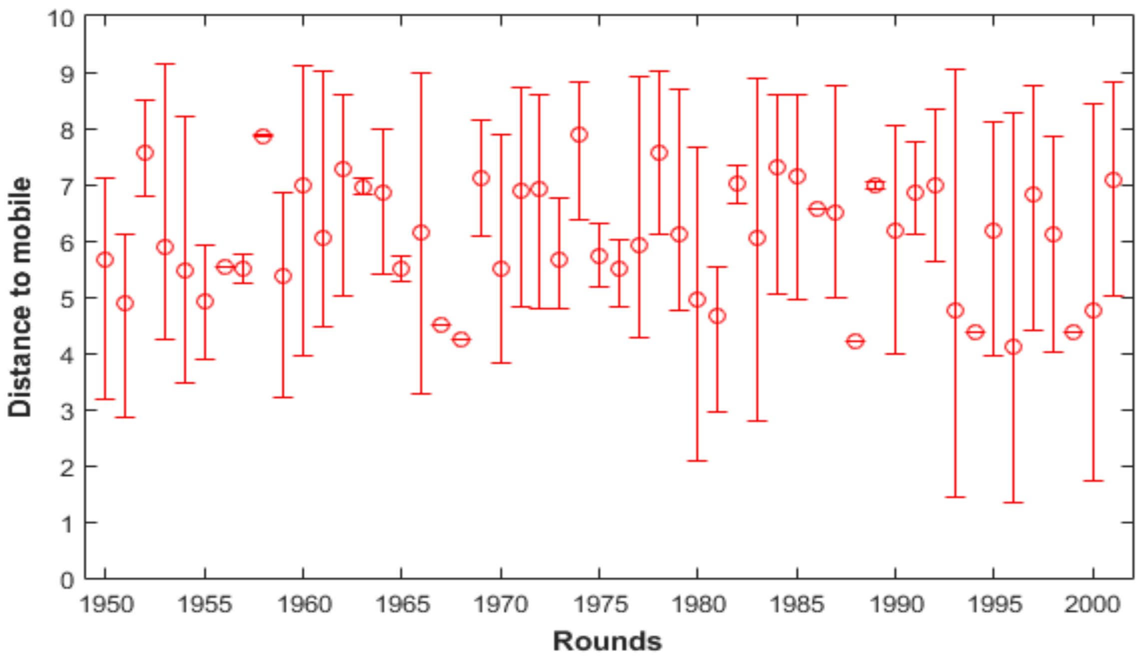

Figure 6.10– Distance variation of M-node from the static nodes (at the end of the simulation, A3).

Figures 6.11 to 6.13 show the distance variation of the M-node from the static nodes at middle of running the simulation time. It is obvious from the Figures that all three (A1, A2 and A3) techniques have over 90 % detection rate. The distance recorded by the static nodes as shown in the following Figures falls within the coverage range of RIFD tags.

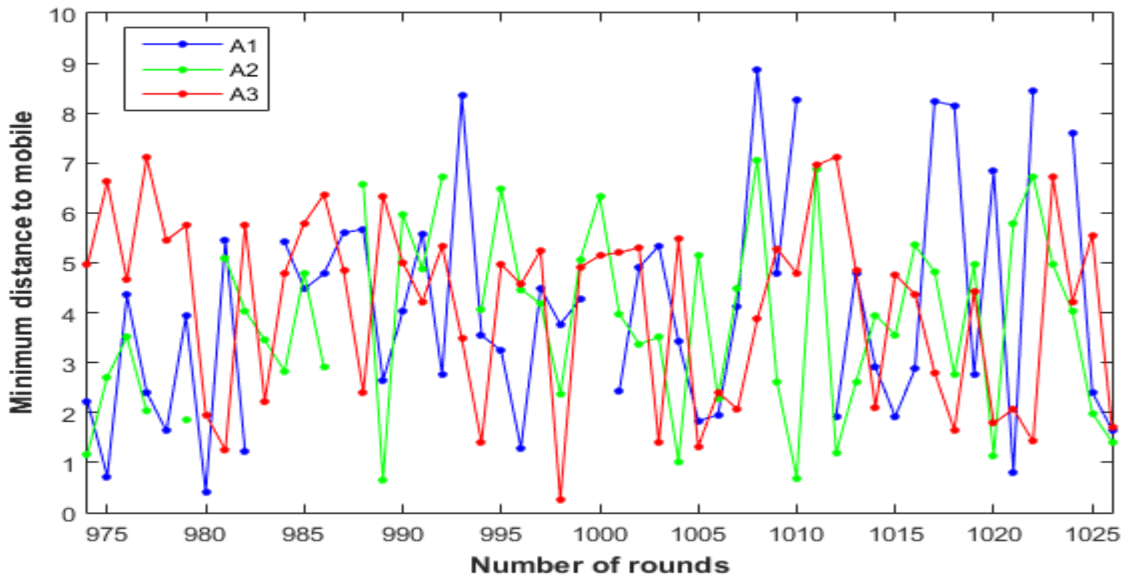

Figure 6.11– Minimum distance of M-node from the static nodes (at the middle of the simulation).

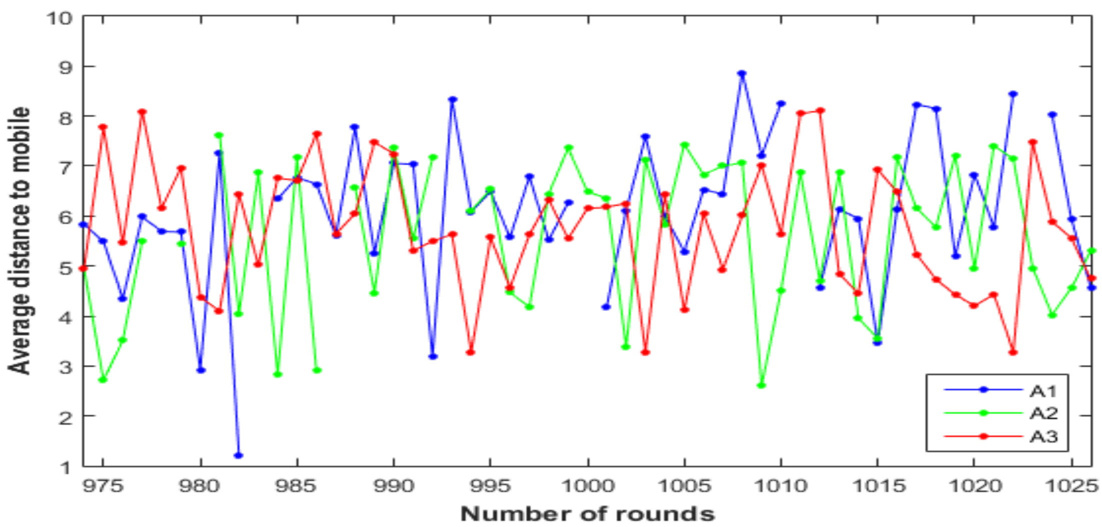

Figure 6.12– Average distance of M-node from the static nodes (at the middle of the simulation).

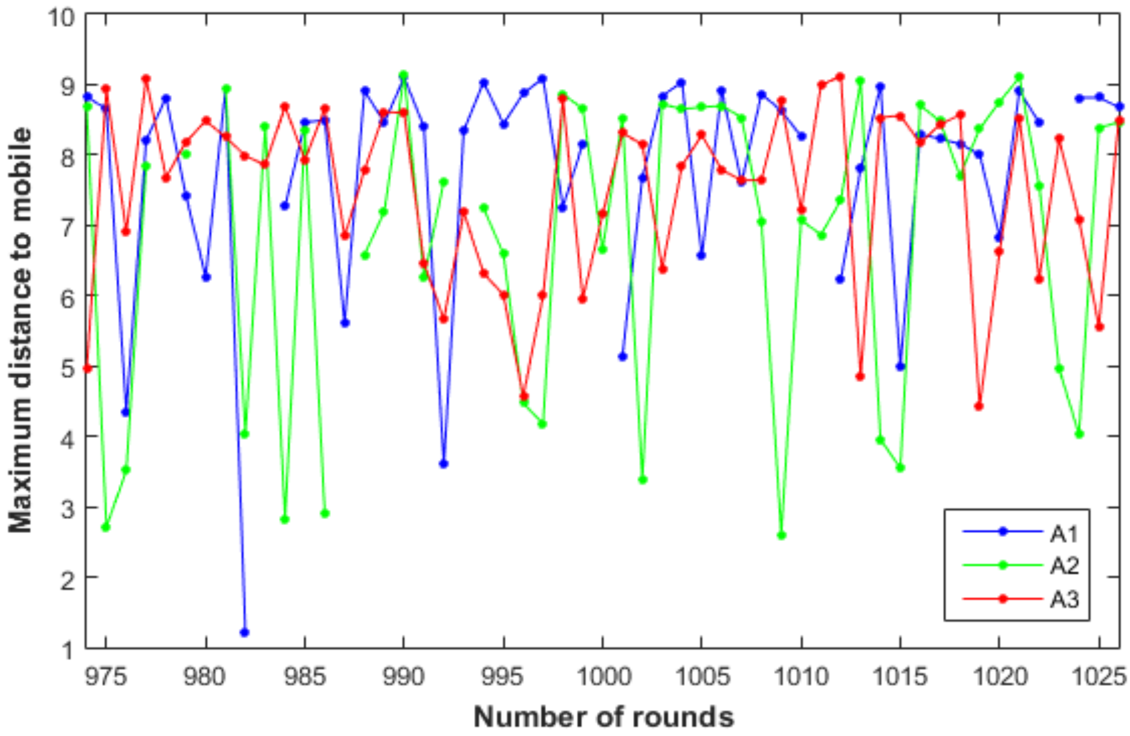

Figure 6.13– Maximum distance of M-node from the static nodes (at the middle of the simulation).

6.2.4 Performance analysis of 10 M-nodes

As in the previous section, the simulation is performed for the *d*-ECP protocol to examine the effectiveness of the algorithms, in terms of both the accuracy of the M-nodes detection and the distance. In this section, the simulation is performed for 10 mobile nodes.

The same simulation environment is used. The three mechanisms are verified; therefore, it is imperative to distribute the surplus generated by this burden between different CHs to test the balance, in terms of the energy consumption and therefore the service lifetime of the network.

In the context of the whole network, considering all the three mechanisms (A1, A2 and A3), introducing 10 mobile nodes will increase the number of transmission packets in the network. This in turn will increase the number of data packets between the nodes and their CHs, which in turn will result in increased energy consumption, collision and loss of data etc. This constitutes for approaches are to examine the stationary nodes process of detecting an event in their covered area and execute assigned tasks while it has enough energy.

The functional tasks are distributed and executed among its individual, local, global, environment, and BS constituents, to execute a task, with more mobile nodes in the sensing area.

Moreover, the achieved results should not only perform identification and tracking of M-nodes within the sensing area, but demonstrate the appropriateness power usage of the proposed system to provide power-effective and minimised assigning optimum values to effective network lifetime with collection of information required.

The highlights of distance variation output for the simulation results for one round are shown in the following three Tables 6.2 to 6.4; each mobile node is presented individually.

Table 6.2 – The performance of the A1 protocol with 10 M-nodes and distance variation output

Time/Rounds	M-node ID	Min distance	Average distance	Max Distance
900	101	3.01	6.62	8.90
900	102	2.59	4.58	6.57
900	103	3.67	5.76	7.86
900	104	4.08	4.08	4.08
900	105	0.64	2.32	4.00
900	106	2.59	2.59	2.59
900	107	3.20	4.41	5.63
900	108	8.82	8.82	8.82
900	109	5.34	6.64	7.94
900	110	8.64	8.64	8.64

Table 6.3 – The performance of the A2 protocol with 10 M-nodes and distance variation output

Time/Rounds	M-node ID	Min distance	Average distance	Max Distance
900	101	2.88	6.11	8.83
900	102	4.64	5.56	6.21
900	103	4.44	6.61	8.77
900	104	6.37	7.21	8.06
900	105	5.73	7.68	9.03
900	106	5.53	6.03	6.52
900	107	0.46	4.54	8.70
900	108	3.95	5.50	6.72
900	109	6.05	7.36	8.09
900	110	3.58	3.58	3.58

Table 6.4 – The performance of the A3 protocol with 10 M-nodes and distance variation output

Time/Rounds	M-node ID	Min distance	Average distance	Max Distance
900	101	7.65	7.85	8.04
900	102	1.69	4.91	7.94
900	103	4.49	6.62	8.75
900	104	6.69	6.69	6.69
900	105	5.05	5.60	6.19
900	106	3.15	5.55	8.13
900	107	4.84	6.07	7.29
900	108	1.98	4.01	6.04
900	109	2.44	5.10	7.68
900	110	3.39	4.06	4.72

It is obvious from the tables that the failure of detection has not occurred, all three protocols have detected the M-node at all times in the given round, but in terms of the distance, vary from one to another.

However, the failure of detection occurs, over time, and Figures 6.14 to 6.16, show the histogram of the distance variation for the all-mobile nodes over the first 100 rounds. From the Figures, it can be noticed that average distance is around 6 metres for A1; also it can be noted that average distance is around 6.2 metres for A2, but in Figure 6.16 for A3, the average distance is spread from 5.3 to 7.6 metres.

In the next section, the failure of detection is compared, in detail to address how the different numbers of mobile nodes cost the network, in terms of network lifetime.

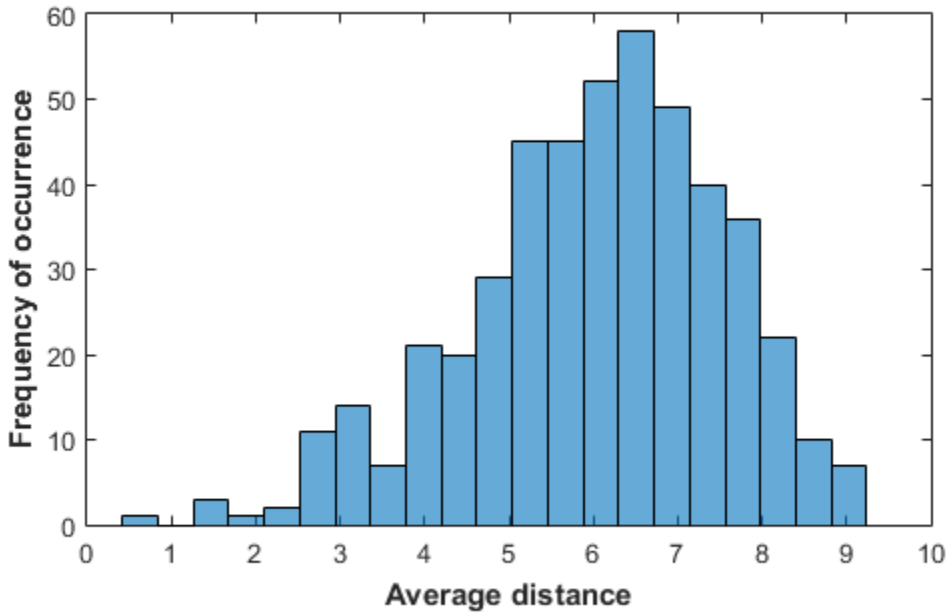

Figure 6.14– Average distance variation of All M-nodes (over the first 100 rounds, A1).

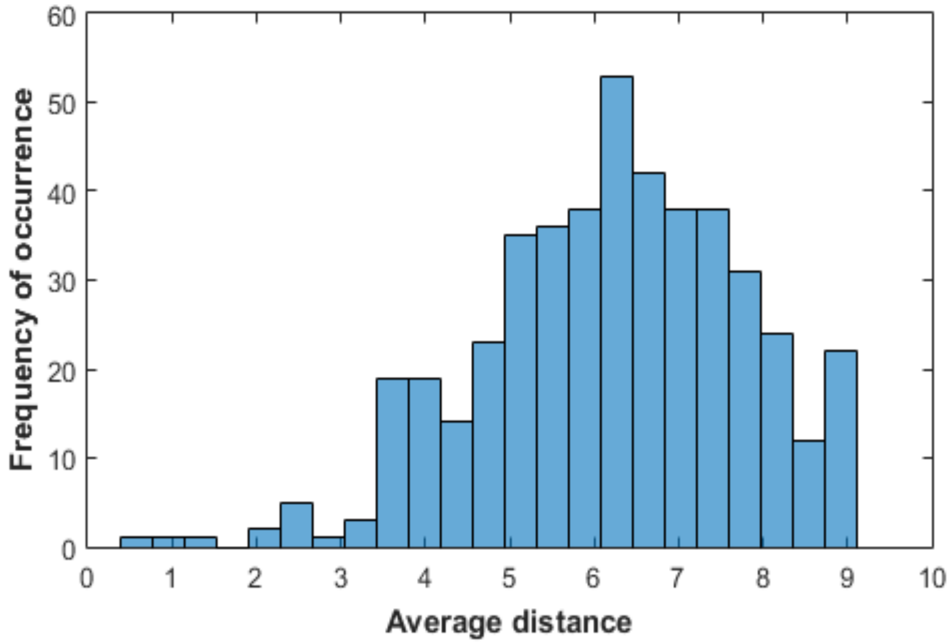

Figure 6.15–Average distance variation of All M-nodes (over the first 100 rounds, A2).

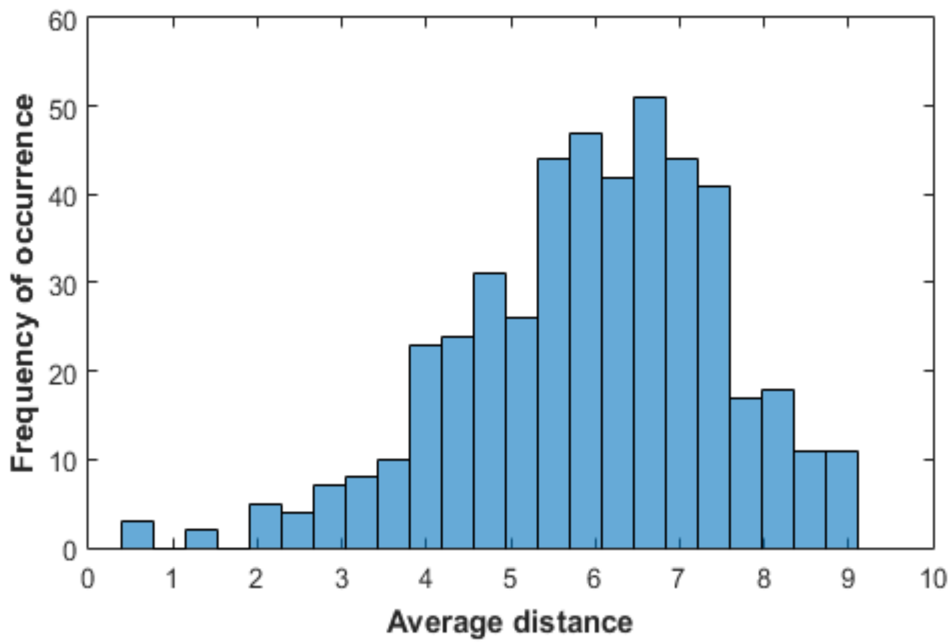

Figure 6.16– Average distance variation of All M-nodes (over the first 100 rounds, A3).

6.2.5 Discussion of the results

This section outlines the solutions obtained for the *d*-ECP protocols, the focus will be on the error detection which means what percentage of the static nodes fail to detect the mobile nodes within the setting range (RIFD range = 9.14 meters).

The detection of these errors is a complex task in normal times, but becomes critical at the scale of the IoT where the volume of data is such that it is neither desirable nor necessarily possible to store them for much time. In the same way as the temporal nature of the information produced by sensors requires that one is interested in a representation of the data in the form of flow, error detection and correction processes must be able to be applied continuously.

In addition, heterogeneity plays a role here too, since in a family of sensors the measuring properties may vary from one to another: accuracy, resolution, sensitivity, measuring range, response time, etc. Similarly, the probabilities of occurrence of certain errors will be dependent on sensor technologies used.

Table, 6.5 presents the results for *d*-ECP in terms of detection and percentage of failure during the simulation time. It is clear from the table that the mobile nodes have been detected at least 90 % of the time in all scenarios in the simulation.

Considering all the three mechanisms (A1, A2 and A3), the network lifetime has not been affected, when the number of the mobile nodes has increased in the grid area.

Additionally, the percentage of detection varies from 90 % to 98.41 %, the increase in the number of transmission packets has not affected the network lifetime. The average distance is well balanced at all times in all scenarios, regarding the average of the maximum distance, and is approximately under 2 metres from the maximum distance range.

Table 6.5 – The performance of the (A1, A2 and A3) protocols comparison (1 and 10 M-nodes)

Protocols	Network lifetime / Rounds	Number of M-node	Average Min distance	Average distance	Average Max distance	Percentage of detection
A1	1709	1	4.37	5.96	7.34	90 %
A1	1701	10	4.53	5.96	7.25	93.07 %
A2	1890	1	4.26	6.09	7.41	92.55 %
A2	1850	10	4.65	6.04	7.27	91 %
A3	1780	1	4.55	6.09	7.66	98.5 %
A3	1760	10	4.40	5.92	7.29	98.41 %

6.3 Summary

This chapter presents views of different levels of infrastructure that make up distributed systems and corresponding scheduling strategies were described. In order to deploy and integrate static wireless sensors to detect mobile sensors within a certain range which can be deployed in many monitoring scenarios, such as infrastructures, people and animals. These scenarios also can be used in the monitoring of atmospheric pollution, natural world monitoring and wildlife monitoring depending on architecture: RFID, Smart Sensors and the IoT,

A very important part of this chapter represents the analysis on networks where different mobile nodes generate heterogeneous traffic toward the static nodes. This analysis is given for efficiency of the network. Based on the results obtained, the network has not been affected. The detection distance is sufficient to get the optimal schedule range. The systems are homogeneous, highly dynamic and open to the appearing and disappearance of mobile nodes detection. The system can be composed of different numbers of mobile nodes deployed on the network area.

Chapter 7

Conclusions and Future Work

7.1 Summary and conclusions

In this thesis, I have developed routing strategies to extend the network lifetime of WSNs, by addressing the issues around energy consumption in the network layer. This is especially important for applications including remote condition monitoring, agriculture, IoT and habitat monitoring. One of the main problems of WSNs is that the nodes are powered by batteries, where in most of the typical applications, it may not be feasible to recharge them due to the nature of their deployment.

Therefore, it is very crucial for the survival of the network that the limited node energy is used efficiently. One way of achieving this is by developing energy efficient routing algorithms to provide the mechanism and policies of data transmission within the WSNs. The main goal was to propose mechanisms for the extension of network lifetime in WSNs, while satisfying the constraints mentioned above. This is described by the main aim of the thesis, as addressed by this research which is conserving energy of the individual nodes in the presence of mobility, thus enhancing the network lifetime to levels that the proposed work is most efficient for maximising the network lifetime. Novel clustering protocols designed in this research extend the lifetime of the network comprising static and mobile nodes, by conserving energy consumption for data transfer. Moreover, the design and architecture of the protocols enable effective detection of mobile nodes in the network with minimal update time, and work seamlessly with increased scalability of mobile nodes.

To achieve this aim, the following research objectives were identified for this thesis:

- To evaluate the existing routing protocols applicable for both Ad hoc and WSNs, namely, AODV, DSR and LEACH. These protocols were selected for their ability to support reactive routing, node mobility and energy conservation.

- To design a novel clustering protocol (ECP) for WSNs, based on LEACH to improve network lifetime. The performance of ECP has been evaluated against LEACH for energy-efficiency of the network (network lifetime) and throughput. A novel feature in the proposed protocol is the ability to pre-select the number of clusters depending on the network size allowing for further improvements in network lifetime. This feature contributes to the better performance of ECP over LEACH.

- To enhance ECP (*d*-ECP) to support mobile nodes in the WSNs for enhanced network lifetime. The *d*-ECP has been demonstrated to effectively detect the mobile nodes in the network. The network was demonstrated through extensive simulations, to preserve the improved network lifetime in the face of increased mobility.

As a first step, a comprehensive literature survey was carried out examining the state-of the art research in the area of flat and hierarchical routing protocols for WSNs. It gives a review of proactive and reactive routing in Ad-hoc Networks, Flat and hierarchical routing protocols in WSNs, including network topologies connected with proposed work techniques. An effort has been made to present all the algorithms in a general form. However, review of this state of the art has led to the conclusion that there are still open issues in this domain.

The literature review identified multiple strands for potential improvement in the network layer that included flat vs. hierarchical protocols.

Therefore, the first objective of performance evaluation between selected flat and hierarchical routing protocols was carried out.

In Chapter 4, the performance evaluation of the routing protocols, AODV, DSR and LEACH, was carried out using Simulation. The evaluation was based on energy consumption (network lifetime) and routing packet. Two configurations were considered regarding AODV and DSR protocols: Constant Bit Rate (CBR) and Exponential generator traffic. Their performance was compared with that of LEACH.

While LEACH protocol performed better than the two flat protocols in terms of energy conservation and network lifetime in turn, several potential strands for improvement in LEACH were identified that could optimise the lifetime further. For example, selection of CH could affect the network coverage, options for data transmission paths from a sensor node to the sink could affect the network lifetime. This has led to the proposal of a novel routing strategy that leverages both the hierarchical routing structure and centralised process for CH selection and data transmission paths in order to achieve enhanced network lifetime in WSNs.

In Chapter 5, novel strategies for both network topology and routing are proposed to maximize network lifetime. ECP Energy-Adaptive Clustering Protocols (ECP) for energy-efficiency in WSNs is presented. The proposed ECP architecture includes variants based on the way the sensor nodes communicate to the BS via CH. In this proposed architecture, there may be one or two variant scenarios, which do not fit with the overall expected 'normal situation'. Two such outlier scenarios have been considered to modify the proposed protocol to address issues arising in such situations. ECP could be easily adapted to these situations.

The significant aspect of the ECP protocol is that it reduces the energy consumption and extends the network lifetime for the WSNs. An important property of this approach is its ability to cluster the entire network by using *k-means* algorithm to select the CHs , for a certain number of nodes as these nodes are nearest to the centroid in their cluster region.

The ECP approach is based on reachability of nodes in the network. ECP introduced three techniques within the clustering methodology to transmit the aggregated data to the BS. The qualifying assumption is that all the nodes will transmit the sensed data to the BS via the CH in their region, or to the nearest CH in some scenarios, and directly to the BS if the distance to the nearest CH is greater than to the BS.

The proposed techniques have been simulated and analysed and further compared to well-known algorithms such as LEACH, DEEC, EE-LEACH and HT2H protocols. The simulation results were compared to those of similar algorithms based on certain parameters, such as network lifetime. The experimentation was conducted for a combination of network conditions, such as number of nodes, number of CHs etc.

The simulation results showed that the performance of the ECP protocols greatly exceeds LEACH, DEEC, EE-LEACH and HT2HL in terms of energy conservation, and the network lifetime has improved by an average value of 67 %, 17 %, 21 % and 8 % compared to LEACH, DEEC, EE-LEACH and HT2HL protocols respectively.

The next research objective was to demonstrate mobile node detection in Energy-Adaptive Clustering Protocols (*d*-ECP), where the ECP strategy was shown to successfully detect mobile nodes without sacrificing the network lifetime when introduced into the sensing environment. This was dealt with in Chapter 6, where the performance of the *d*-ECP was evaluated under conditions of mobility. The mobile nodes introduced in the WSNs had similar characteristics to those of the static nodes, with a communication range the same as an RFID tag. This approach is based on detecting the position of an M-node, which in this proposed work was RFID. The *d*-ECP was evaluated for a range of metrics: Network throughput, network lifetime and mobile node capture.

The Simulation results demonstrated the performance of the *d*-ECP protocols for their effectiveness in terms of both the accuracy of the M-nodes' detection and the distance, with one and ten mobile nodes.

To conclude, the proposed ECP and *d*-ECP are novel techniques for routing in WSNs, which can be deployed in environmental monitoring scenarios. The proposed algorithms are very efficient in terms of the energy consumption. Some specific potential applications for this research work could be in wildlife monitoring, condition monitoring in industrial applications, IoT application etc.

The research work described in this thesis has resulted in the submission of Journal and International Conference publications, which are listed in Appendix A.

7.2 Suggestions for future work

The issues related to tracking wildlife over long distances has resulted in the development of a variety of tracking technologies. The choosing of the appropriate tracking system, which has low cost will be extremely useful in the designing of these practical applications.

The proposed ECP routing strategy has been evaluated for its energy performance using extensive simulations. However, there are ways this could be developed further, especially for real-life applications. Below are some suggestions to take this work through further investigations.

In particular, I intend to extend the studies and analysis on the following specific points:

- In this work, only the direct communication between the CHs and the BS has been taken into consideration. However, the proposed ECP algorithm can be extended to incorporate multi-hop between the CHs communication, which may improve the algorithm in its energy efficiency.
- In deploying the sensor nodes randomly as proposed in this work, the nodes often do not get perfect placement within the network. This means, in real-life applications, the energy-efficiency may not be optimum. Therefore, for future work, the nodes could be placed using a deterministic process in order to optimise the node position and thus optimise the network lifetime further.
- The freedom of the nodes where each node does not have only one possible clustering and nodes can belong to multiple clustering in the proposed approach has resulted in expended the network lifetime. However, a further direction is to extend the ECP approach to be able to contain set up a self-adaptive MAC layer to enable self-organization sensor nodes to ensure complete coverage.

In *d*-ECP, approaches have the following aspects, which are worth investigating further:

- Mobility factor, in *d*-ECP the speed of the M-node were 2m/sec, increasing the speed may lead to some useful future study of the protocols as well as increasing the number of the M-nodes.

- *d*-ECP used random walk mobility. Another interesting suggestion for further work is to propose Controlled Mobility Models that may result in enhanced network lifetime. This may be especially suitable for some applications where the movement can be predictable.
- Modelling the trajectory of the M-nodes' movement from their positions in the network over time. This model could help to predict the position of the M-nodes when the static nodes fail to detect the M-nodes and may improve the detection efficiency of the algorithm.

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Appendix A Publication

A.1 Conference

ABUSHIBA, W. & JOHNSON, P. Performance comparison of reactive routing protocols for Ad hoc network. e-Technologies and Networks for Development (ICeND), 2015 Forth International Conference on, 2015. IEEE, 1-5.

ABUSHIBA, W., JOHNSON, P., ALHARTHI, S. & WRIGHT, C. An energy efficient and adaptive clustering for wireless sensor network (CH-leach) using leach protocol. Computer Engineering Conference (ICENCO), 2017 13th International, 2017. IEEE, 50-54.

A.2 Academic journals

Walid Abushiba and Princy Johnson “Energy-Adaptive Clustering Protocols (ECP) for energy efficient in Wireless Sensor Networks’’. The journal Sensors (ISSN 1424-8220) "Battery-free Smart Sensors". Special Issue. Submitted

A.3 Permission for Performance Comparison of Reactive Routing Protocols for Ad hoc Network

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Figure. A.1 Permission performance comparison of reactive routing protocols for Ad hoc network.

A.4 Permission for An Energy Efficient and Adaptive Clustering for Wireless Sensor Network (CH-leach) using Leach Protocol

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Figure. A.2 Permission of An Energy efficient and adaptive clustering for wireless sensor network (CH-leach) using Leach protocol.

Appendix B Additional Results

B.1 Additional Results for ECP Chapter 5

Table B.1 – Network Lifetime Comparison for 100 Nodes, Location of BS (50, 50)

Number of Cluster	LEACH			DEEC			A1			A2			A3		
	First Node	50 % of the Nodes	90 % of the Nodes	First Node	50 % of the Nodes	90 % of the Nodes	First Node	50 % of the Nodes	90 % of the Nodes	First Node	50 % of the Nodes	90 % of the Nodes	First Node	50 % of the Nodes	90 % of the Nodes
5	381	747	962	802	1175	1228	532	1212	1314	594	1263	1399	650	1269	1603
10	381	747	946	802	1174	1228	693	1289	1387	613	1331	1466	681	1313	1665
15	421	760	881	920	1177	1249	688	1347	1468	699	1368	1488	695	1305	1482
20	381	759	930	921	1164	1228	750	1379	1590	741	1370	1584	692	1328	1575
25	381	750	946	802	1174	1228	727	1427	1626	787	1459	1645	727	1409	1747
30	411	756	906	933	1183	1259	827	1481	1710	766	1472	1891	775	1369	1780

Table B.2 – Network Lifetime Comparison for 200 Nodes, Location of BS (50, 50)

Number of Cluster	**LEACH**			**DEEC**			**A1**			**A2**			**A3**		
	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes
5	477	742	932	731	1200	1280	556	1187	1375	433	1254	1433	578	1257	1462
10	376	759	968	729	1200	1295	530	1234	1370	581	1272	1498	603	1248	1570
15	400	744	964	583	1207	1303	550	1275	1385	590	1289	1506	618	1271	1643
20	378	759	968	719	1200	1295	670	1291	1446	640	1302	1483	627	1263	1818
25	376	759	968	728	1200	1295	666	1329	1494	690	1337	1485	643	1370	1547
30	377	759	968	718	1200	1295	689	1346	1583	689	1350	1580	626	1318	1693

Table B.3 – Network Lifetime Comparison for 300 Nodes, Location of BS (50, 50)

Number of Cluster	**LEACH**			**DEEC**			**A1**			**A2**			**A3**		
	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes
5	452	746	1012	662	1221	1312	434	1167	1419	644	1247	1483	574	1260	1545
10	358	982	995	641	1218	1312	553	1216	1392	565	1230	1430	598	1231	1845
15	465	746	982	612	1213	1314	594	1240	1398	580	1255	1492	558	1255	1602
20	346	748	1024	604	1208	1312	602	1265	1427	647	1278	1551	591	1239	1591
25	346	748	1024	607	1208	1312	642	1284	1422	656	1293	1428	567	1267	1557
30	347	748	1024	607	1208	1312	664	1302	1406	658	1316	1535	586	1280	1757

Table B.4 – Network Lifetime Comparison for 100 Nodes, Location of BS (50, 100)

Number of Cluster	LEACH			DEEC			A1			A2			A3		
	First Node	50 % of the Nodes	90 % of the Nodes	First Node	50 % of the Nodes	90 % of the Nodes	First Node	50 % of the Nodes	90 % of the Nodes	First Node	50 % of the Nodes	90 % of the Nodes	First Node	50 % of the Nodes	90 % of the Nodes
5	353	644	882	901	1126	1221	595	1201	1297	648	1209	1397	497	1215	1428
10	323	637	863	823	1135	1210	615	1270	1368	620	1245	1400	517	1226	1493
15	336	625	915	857	1118	1223	674	1289	1425	670	1310	1526	645	1239	1579
20	351	624	940	919	1118	1210	627	1312	1555	671	1341	1616	706	1240	1700
25	321	637	858	825	1135	1209	677	1307	1560	838	1332	1590	658	1249	1562
30	322	637	858	826	1135	1209	663	1328	1645	688	1310	1535	672	1272	1712

Table B.5 – Network Lifetime Comparison for 200 Nodes, Location of BS (50, 100)

Number of Cluster	LEACH			DEEC			A1			A2			A3		
	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes
5	416	658	967	603	1157	1277	478	1172	1365	515	1216	1412	556	1209	1484
10	326	643	942	676	1165	1268	597	1209	1347	568	1213	1374	495	1199	1642
15	354	655	919	793	1160	1253	623	1230	1366	573	1245	1490	557	1216	1534
20	326	643	941	675	1165	1268	628	1251	1425	610	1271	1426	582	1248	1517
25	326	643	935	675	1165	1268	614	1269	1466	641	1296	1477	629	1233	1608
30	326	640	944	898	1159	1297	654	1281	1447	661	1292	1532	609	1247	1740

Table B.6 – Network Lifetime Comparison for 300 Nodes, Location of BS (50, 100)

Number of Cluster	LEACH			DEEC			A1			A2			A3		
	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes
5	353	649	965	571	1183	1309	551	1174	1414	571	1208	1510	514	1207	1532
10	332	664	1029	530	1177	1309	478	1206	1377	555	1223	1464	404	1199	1646
15	372	657	951	670	1173	1303	548	1224	1386	557	1234	1475	567	1204	1604
20	332	663	1029	531	1176	1308	596	1241	1383	605	1239	1470	602	1220	1606
25	371	646	1015	664	1183	1316	640	1252	1400	613	1257	1460	606	1230	1553
30	332	664	1029	531	1176	1308	610	1277	1443	578	1272	1456	565	1238	1615

Table B.7 – Network Lifetime Comparison for 100 Nodes, Location of BS (50, 150)

Number of Cluster	LEACH			DEEC			A1			A2			A3		
	First Node	50 % of the Nodes	90 % of the Nodes	First Node	50 % of the Nodes	90 % of the Nodes	First Node	50 % of the Nodes	90 % of the Nodes	First Node	50 % of the Nodes	90 % of the Nodes	First Node	50 % of the Nodes	90 % of the Nodes
5	169	426	711	693	966	1152	538	1102	1259	553	1085	1242	478	1059	1378
10	136	370	706	691	980	1154	360	1089	1310	426	1117	1266	355	1094	1291
15	154	377	707	713	976	1167	315	1030	1350	370	1055	1391	363	1025	1299
20	135	398	667	645	968	1161	256	1065	1318	398	991	1345	669	987	1397
25	136	370	695	692	980	1151	328	890	1381	368	958	1421	218	938	1473
30	137	370	695	692	980	1172	247	867	1389	259	765	1352	230	950	1333

Table B.8 – Network Lifetime Comparison for 200 Nodes, Location of BS (50, 150)

Number of Cluster	**LEACH**			**DEEC**			**A1**			**A2**			**A3**		
	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes
5	140	398	720	680	1029	1204	577	1122	1309	494	1128	1308	394	1029	1300
10	114	387	716	669	999	1021	559	1135	1282	482	1142	1304	486	1077	1398
15	149	426	772	708	1047	1192	381	1128	1305	432	1127	1320	448	1082	1415
20	114	386	716	712	999	1199	474	1140	1327	438	1053	1316	449	1055	1513
25	139	429	760	721	1027	1211	301	1099	1315	336	1101	1331	373	1026	1553
30	115	386	716	672	999	1199	302	1067	1361	297	1052	1370	387	1048	1577

Table B.9 – Network Lifetime Comparison for 300 Nodes, Location of BS (50, 150)

Number of Cluster	LEACH			DEEC			A1			A2			A3		
	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes	First Node	50 % of the Nodes	95 % of the Nodes
5	136	415	800	639	1029	1245	518	1127	1381	483	1144	1339	388	1115	1373
10	137	397	791	697	1038	1238	575	1140	1350	542	1132	1319	416	1121	1402
15	134	419	818	643	1039	1255	487	1130	1333	508	1119	1323	414	1118	1461
20	133	397	755	684	1039	1237	438	1137	1320	488	1111	1307	448	1109	1439
25	137	368	779	708	1024	1262	429	1120	1321	436	1126	1348	421	1096	1513
30	132	397	755	684	1038	1238	440	112	1359	361	1121	1324	363	110	1537

B.2 Additional Figures for ECP Chapter 5

Figures B.1 to B.6 illustrate the simulation results for the network lifetime as histograms. By examining the performance of various network sizes and densities in these graphs.

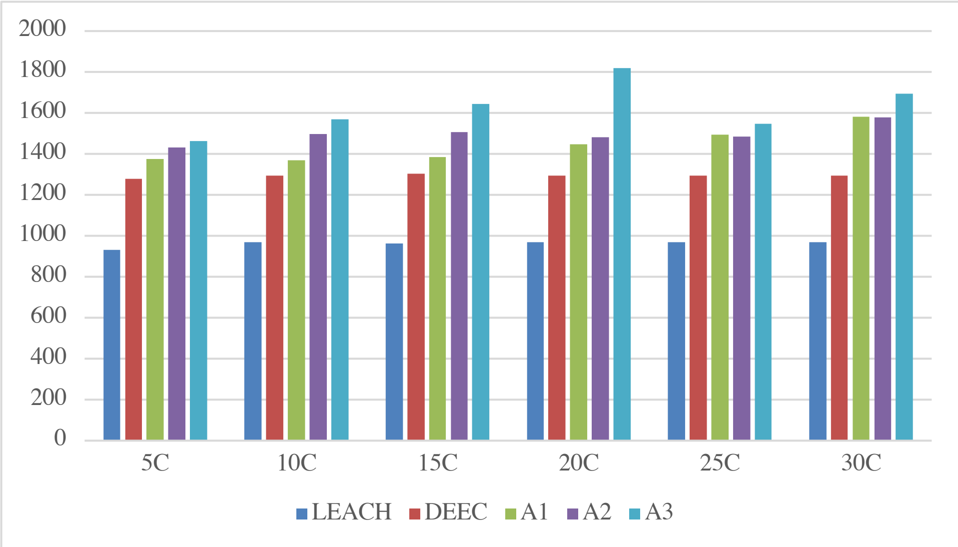

Figure B.1 – The network lifetime of 200-nodes (BS at location x=50, y=50).

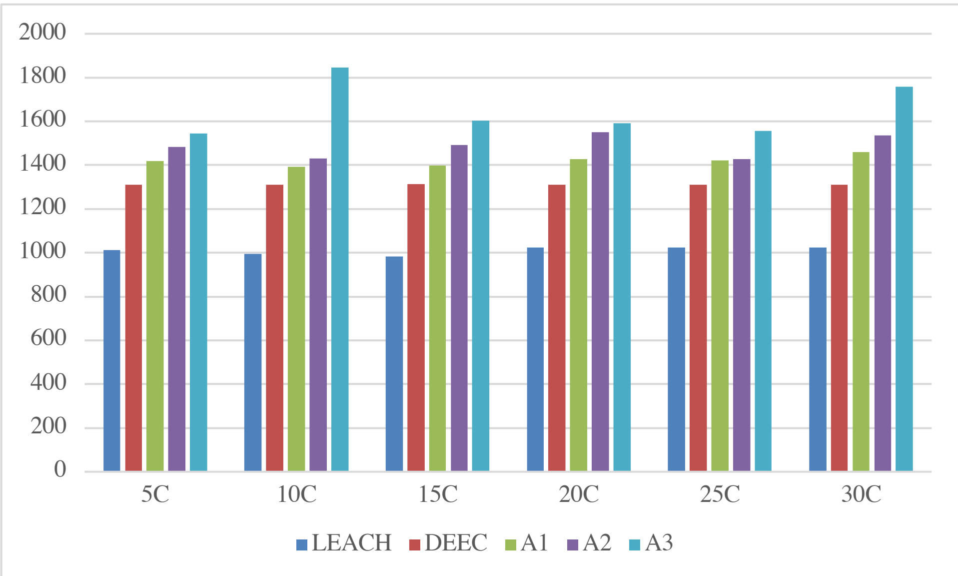

Figure B.2 – Network Lifetime Comparison for 300 Nodes, Location of BS (50, 50)

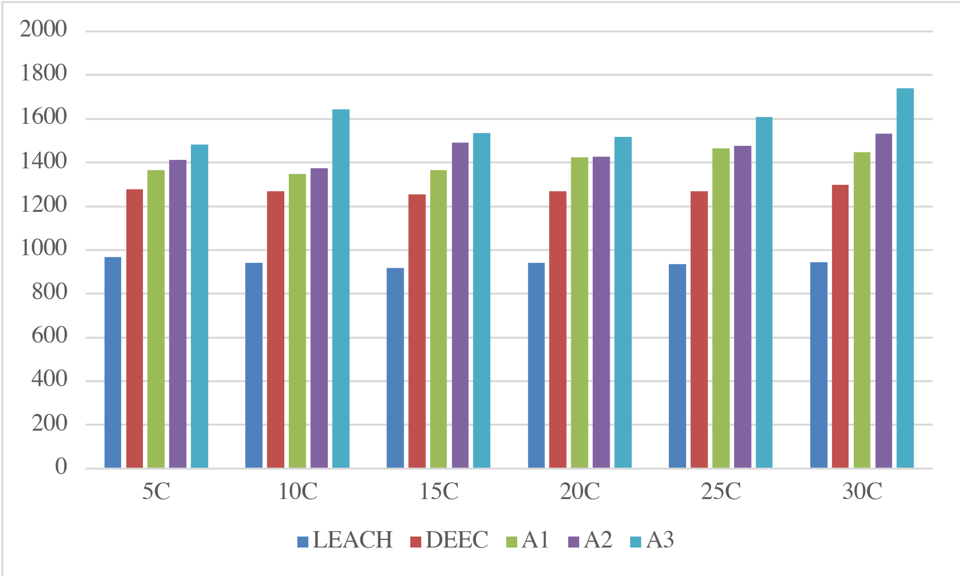

Figure B.3 – The network lifetime of 200-nodes (BS at location x=50, y=100).

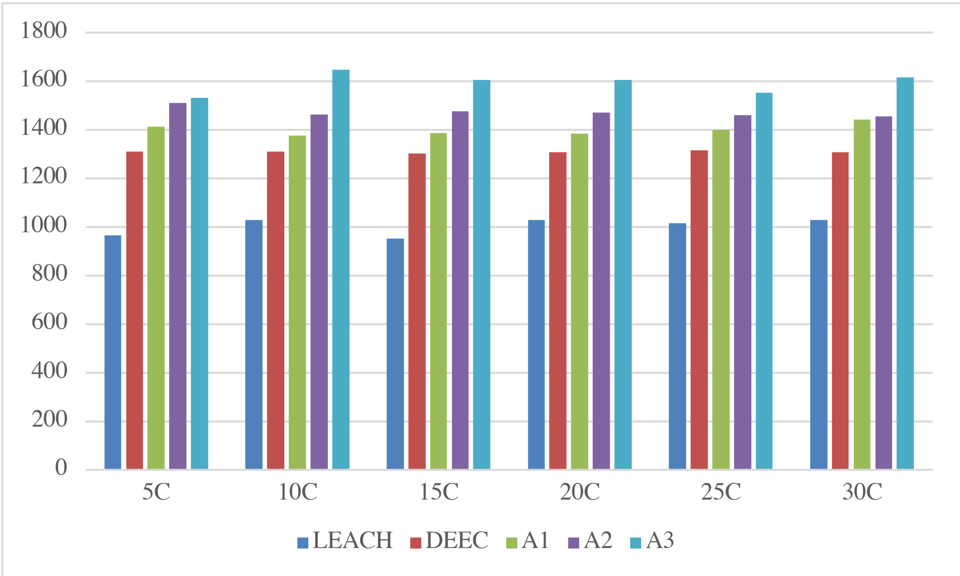

Figure B.4 – Network Lifetime Comparison for 300 Nodes, Location of BS (50, 100)

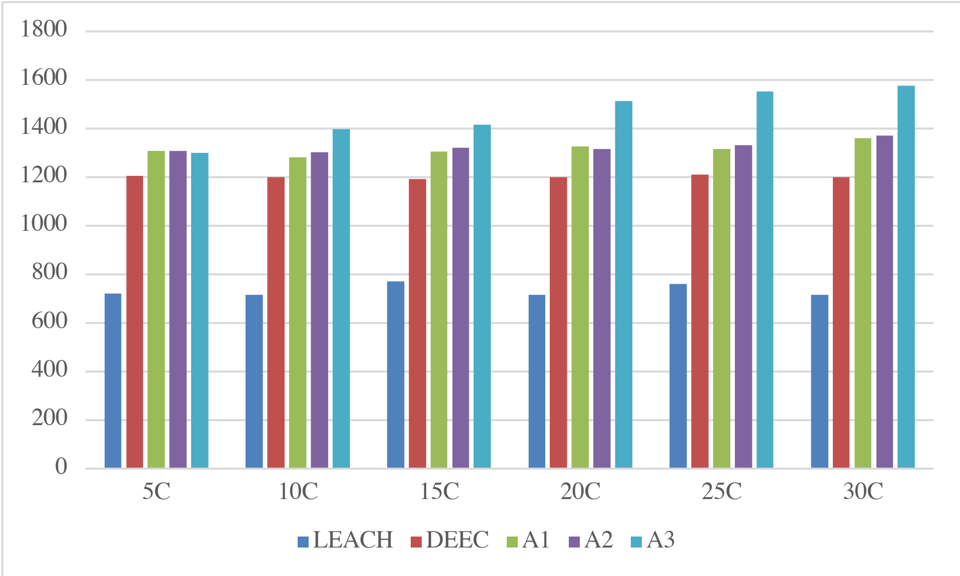

Figure B.5 – The network lifetime of 200-nodes (BS at location x=50, y=150).

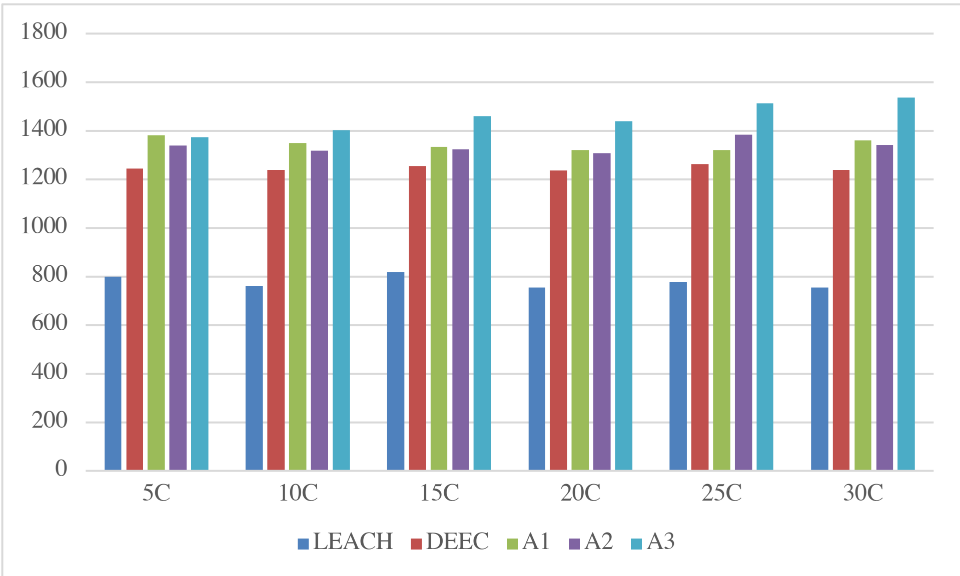

Figure B.6 – Network Lifetime Comparison for 300 Nodes, Location of BS (50, 150)

Appendix C Consumption Parameters of Widely used Sensor Node Platforms

Table C.1 – Consumption Parameters of Widely used Sensor Node Platforms.

Node Name	Radio standard	Power-Down (µA)	Transmit Mode (mA)	Receive Mode (mA)	Supply Voltage	Batteries Required	Indoor Range (m)	Outdoor Range (m)	Operating Temperature (C)
XBee3™ Zigbee 3.0	IEEE 802.15.4/ZigBee	1.7	40	15	2.1-3.6	--	Up to 60	Up to 1200	-40° to +85°
IRIS	IEEE 802.15.4	8	8	16	2.7-3.3	2 AA	> 50	> 300 m	--
MICAz	IEEE 802.15.4	<15	8	19.7	2.7-3.3	2 AA	20-30	75-100	--
IMote2	IEEE 802.15.4	387	31-53	44-66	3.2 - 4.5	3 AAA	--	30	0° to +85°
SunSpot	IEEE 802.15.4	40	40	40	4.5-5.5	--	--	--	--
WiSMote	IEEE 802.15.4	<2	2.2	18.5	2.2-3.6	2xAA	>50	>100	-40° to +125°
WiSMote mini	IEEE 802.15.4	--	--	12.5	1.8-3.6	CR2016	>50	>100	-40° to +125°