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Department of Electrical-Electronic Engineering

IMPROVEMENT OF CLUSTER HEAD SELECTION IN LEACH PROTOCOL TO REDUCING ENERGY CONSUMPTION IN WIRELESS SENSOR NETWORKS

Master Thesis

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Supervisor
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yoğunluğa sahip olması ve iletişimde çok fazla fazlalık olması. Diğeri, iletişimin güvenlik yönlerini göz önünde bulundurarak sensör ağının ölçeklenebilirliğini artırmaktır. Sensör düğümleriyle ilgili sorunlardan biri, ağ ömrünü sınırlayan pil kısıtlamasıdır. Düşük Enerji Uyarlama küme Hiyerarşisi (LEACH) adı verilen bir toplama tabanlı yönlendirme algoritması, güç tüketimini azaltmak için en iyi çözümlerden biri olarak önerilmiştir. Bu algoritmanın performansını analiz etmek için Matlab simülatörü kullanılarak uygulanan (LEACH) algoritması hakkında bir çalışma yapılmıştır. Matlab, bu araştırma sırasındaki diğer öykünücülerden farklı olarak, bu proje için iyi yetenekler sağladığı için bir öykünücü olarak seçilmiştir. (LEACH) algoritmasında, daha iyi performans için iyileştirilmesi gereken bazı kusurlar gözlemlendi. Mevcut çalışmada, Matlab simülatörünü kullanan ve nihayetinde IV-LEACH protokolünü kullanan LEACH protokol uygulaması, LEACH protokol performansını iyileştirmek için seçilen küme kafalarının ağ üzerinde tek tip olarak dağıtılmasını sağlar. Daha sonra, WSN'lerde kullanılmaya uygunluklarını doğrulamak için Ortalama ömür, enerji tüketimi, Ortalama iş hacmine göre sonuçlar analiz edildi. Ağ verimine göre LEACH protokolünden de daha iyi performans gösterdi. IV-LEACH, 150 düğümde enerji tüketimini yaklaşık% (49) ve verimi% (50) artırdı.

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DECLARATION

I hereby declare that during the preparation of this thesis, the scientific ethical rules were followed, the works of other individuals were referenced in accordance with scientific norms whenever utilized, there has not been any falsification in the used data, any part of the thesis wasn’t submitted to this university or any other one as a different thesis.

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SUMMARY

Sensor nodes (motes) are randomly dispersed in wireless sensor network (WSN) fields. Motes in WSNs coordinate for producing information of high quality and each scattered mote routes that information back to fixed or mobile BSs. One of the problems with sensor nodes is battery constraints that limit network life; the motes contain limited power depending on size, battery life and memory. The aggregation-based routing algorithm, the low energy adaptive clustering hierarchy (LEACH), is suggested as a highly sufficient solution to reduce power consumption. This study's fundamental aim is to optimise the LEACH protocol. There have been 2 reasons for exploring hierarchical routing. The first is that sensor networks have high density, and a large amount of redundancy has been present in communications. The second is increasing the sensor network's scalability considering the communication's security aspects. A recent study utilised the LEACH algorithm by analysing WSN performance with a MATLAB simulator, however, some flaws were noted in the algorithm. These flaws must be improved upon for better network performance. As in previous studies, MATLAB is the chosen emulator as it demonstrates good capability for this project's parameters. This study utilises MATLAB and IV-LEACH protocol for LEACH protocol implementation to ensure that the selected cluster-heads of motes are going to be distributed in a uniform manner over the network for the purpose of improving the LEACH protocol efficiency. Average lifetime, consumption of energy, and throughput are analysed to determine the motes suitability for use in WSNs. The IV-LEACH protocol improves the consumption of energy by approximately 49% and improves the throughput by 50% in 150 nodes, outperforming the LEACH protocol.

Key Words: Clustering, Fixed Round Time, LEACH, Energy Efficiency, Wireless Sensor Network.

ÖZET

Sensör düğümleri, kablosuz sensör ağlarında (WSN'ler) rastgele dağıtılır. Sensör düğümleri (parçacıklar olarak adlandırılır) genellikle sensör düğümlerinin kullanıldığı bir alan olan sensör alanında dağıtılır. Bu sensörler boyuta, pil ömrüne ve belleğe bağlı olarak sınırlı ve küçük güç içerir. Bu ağlardaki motlar, yüksek kaliteli bilgi üretmek için koordine olur ve dağılan bu motların her biri, mobil veya sabit olan BS'leri hemen toplayabilir ve yönlendirebilir. Çalışmanın temel amacı LEACH protokolünü optimize etmektir. Hiyerarşik yönlendirmenin araştırılmasına neden olan 2 neden vardır. Birincisi, sensör ağlarının yüksek yoğunluğa sahip olması ve iletişimde çok fazla fazlalık olması. Diğeri, iletişimin güvenlik yönlerini göz önünde bulundurarak sensör ağının ölçeklenebilirliğini artırmaktır. Sensör düğümleriyle ilgili sorunlardan biri, ağ ömrünü sınırlayan pil kısıtlamasıdır. Düşük Enerji Uyarlama küme Hiyerarşisi (LEACH) adı verilen bir toplama tabanlı yönlendirme algoritması, güç tüketimini azaltmak için en iyi çözümlerden biri olarak önerilmiştir. Bu algoritmanın performansını analiz etmek için Matlab simülatörü kullanılarak uygulanan (LEACH) algoritması hakkında bir çalışma yapılmıştır. Matlab, bu araştırma sırasındaki diğer öykünücülerden farklı olarak, bu proje için iyi yetenekler sağladığı için bir öykünücü olarak seçilmiştir. (LEACH) algoritmasında, daha iyi performans için iyileştirilmesi gereken bazı kusurlar gözlemlendi. Mevcut çalışmada, Matlab simülatörünü kullanan ve nihayetinde IV-LEACH protokolünü kullanan LEACH protokol uygulaması, LEACH protokol performansını iyileştirmek için seçilen küme kafalarının ağ üzerinde tek tip olarak dağıtılmasını sağlar. Daha sonra, WSN'lerde kullanılmaya uygunluklarını doğrulamak için Ortalama ömür, enerji tüketimi, Ortalama iş hacmine göre sonuçlar analiz edildi. Ağ verimine göre LEACH protokolünden de daha iyi performans gösterdi. IV-LEACH, 150 düğümde enerji tüketimini yaklaşık% (49) ve verimi% (50) artırdı.

Anahtar kelimeler: Kümeleme, Enerji Verimliliği, Sabit Yuvarlak Zaman, LEACH, Kablosuz Sensör Ağları.

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ABBREVIATION

BS	**:**	Base Station
LEACH	**:**	Low-Energy Adaptive Clustering Hierarchy
CH	**:**	Cluster Head
WSNs	**:**	Wireless Sensor Network
PEGASIS	**:**	Power-Efficient Gathering in Sensor Information Systems
MAC	**:**	Medium Access Control
FND	**:**	First Node Death
LND	**:**	Last Node Death
TDMA	**:**	Time Division Multiple Access
P	**:**	Percentage of Cluster Heads
CURE	**:**	Clustering Using Representative
IV-LEACH	**:**	Improved LEACH
E-LEACH	**:**	Enhanced LEACH
TL-LEACH	**:**	Two level LEACH
HEED	**:**	Hybrid Energy-Efficient Distributed clustering
TEEN	**:**	Threshold sensitive Energy Efficient sensor Network

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PREFACE

Throughout the preparation and writing of the present thesis, I would like to express my thanks for my esteemed professor Assoc. Prof. Dr. Indrit MYDERRİZİ. Moreover, I would like to thank my friend Alaa H. ABDULAAL for all support that he has offered during the period of the study.

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INTRODUCTION

With technology improvements, sensors are in high demand for monitoring and surveillance applications. Small, autonomous and inexpensive sensors may be utilised for monitoring various parameters like chemical constitution, speed, voltage and temperature. Most of those sensors send measured parameters to a BS (i.e. a sink) wirelessly. Receivers and transmitters supply the sensors and enable wireless communication. Those autonomous sensors are distributed through an area and can communicate with one another, making up a WSN. WSNs are typically used to monitor applications in areas in which replacing or accessing sensor nodes is not possible or viable from an economic standpoint (e.g. in sub-stations of high voltage). To ensure these applications continue, sensors with short lifespans must function for longer periods. Transmissions from the sensor nodes in WSNs consume a considerable amount of energy. This is considered one of the fundamental causes of early failure of the nodes. Therefore, network lifetime and energy consumption are considered important concerns in WSNs. Because WSNs are increasing in popularity in the networking field, researchers utilise a wide range of energy-efficient approaches for reducing the nodes' consumption of energy and enhancing network lifetime. One reason for the popularity of WSNs is their flexibility. Despite their positive aspects, WSNs do have some constraints. To overcome these intractable problems, multiple algorithms have emerged over time to enhance network lifetime. These algorithms configure routes with minimum delay for the sensor broadcast and communications, reduce power cost, and enable sufficient, error-free data transmissions. Among them, LEACH algorithm (a clustering scheme) is enduringly popular. The LEACH algorithm is a cluster-based protocol of routing, so it performs well and is adaptable.

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CHAPTER ONE

PURPOSE OF THE THESIS

1.1.Literature Survey

Multiple studies were recently conducted concerning the issues of WSNs, particularly regarding control and communication protocols. These studies involved power consumption, energy management, communication structure, optimal clustering and topology. This section reviews some major researches that are related to this proposed work.

Yang et al. (2018) introduced wireless routing clustering protocol based on an IV-LEACH algorithm for selecting the head of the cluster depending on the remaining energy and the node's current position by using the SEP algorithm.

Bharti et al. (2015) introduced the energy efficient extended-LEACH algorithm with the use of multiple-input multiple-output (MIMO) channels for WSNs. The LEACH algorithm selects the shortest path for sending information from the sensors to the user by MIMO technology.

Sujee and Kannammal (2017) introduced the energy efficient adaptive clustering protocol based on genetic algorithms (GAs) and GA inter cluster communications for WSNs. This work gives the best probability threshold for the determination of the choice of cluster head.

Regmi *etal*. (2017) have proposed a modified LEACH algorithm for WSNs by proposing an improvement to the LEACH algorithm by selecting two cluster heads to ensure that one will operate if the other stops working.

Rahmadhani et al. (2018) presented LEACH routing protocol on WSNs via delay-tolerant networking. Power consumption and packet loss analysis were discussed so that the algorithm reduces packet loss and increases packet delivery rate when buffer capacity reaches 10 times the packet size.

Chen et al. (2018) suggested a LEACH algorithm based on a possible energy consumption balance that resulted in approximately twice the life cycle when compared with the conventional protocol.

Al Rasyid et al. (2019) provided LEACH-GA and LEACH performance analysis concerning energy efficiency, throughput and the age of the network in multiple situations with three central station locations (centre, angle and external locations of the network area).

Manzoor et al. (2019) provided an improved two level (TL)-LEACH protocol for routing large-scale applications of WSNs. This protocol considered blockhead selection based on residual power and latency in communications.

"Loscri et al. (2005) suggested A TL-LEACH protocol that allowed an increase of 20% in terms of delivery firmness and an increase of up to 30% in the network lifespan.

Patel & Jinwala (2014) have proposed E-LEACH: an improvement to the LEACH Protocol for the preservation of the privacy in the secure aggregation of the data in WSNs. This protocol provided robustness against node capture attacks since the keys have been created via seed value. In addition, a broadcasted BS was not persistent in memory. Therefore, following resetting of the node, the attacker could not gain seed-related information.

"Qiang et al. (2009) suggested multi-single (MS)-Leach, a routing protocol that combined multi-hop and single-hop transmissions. Multi-hop and single-hop transmissions were combined in clusters. In addition, a critical value of cluster area size was obtained and applied as a base for selecting multi-hop or single-hop transmissions.

1.2. Problem Statement

The energy consumption problem is very important in WSNs, so reducing power consumption and extending network life are vital. Among the most notable adopted routing protocols is LEACH. This protocol is characterised by saving energy, causing an increase in the network life via random selection of the HC. However, this protocol has some limitations; it doesn't take under consideration the remaining node energy in HC selection process, resulting in death of the node. In addition, the distance between BS and nodes is not considered in HC selection. The power consumption process of the HC further from the BS is higher than the power consumption of the nodes closer to the BS. These limitations must be considered when designing the WSN protocol. The main factor that must be considered is the amount of energy that is consumed by the sensor and how reducing that consumed energy would increase the network lifetime. Singh et al. (2009)

1.3. Aims and Objective

A WSN is a system of partly dispensed independent gadgets that rely upon sensors to observe ecological or physical conditions. Energy is typically provided to the sensors through non-rechargeable batteries. Since the sensors are dispensed randomly, in large numbers, all around the network, efficiently routing the information gathered via the WSN is an issue. There are multiple ways to address this problem, one of which is node clustering. This method attempts to maximise the power of the nodes in WSNs. The nodes are usually distributed heavily in WSNs, so they can be sorted for the minimization of the energy consumption of data transmission, and they can be clustered for avoiding the transmission of redundant data. Due to the fact that the sensor nodes are deployed randomly in the physical environment, there's a high probability that nodes that have been located in the same area generate similar data. This is yet another reason to cluster the nodes; data can be summed within a particular cluster and then transferred. This method minimises the contention of data transmission in the WSNs.

The main aims of the present study include the following:

1. Utilise a MATLAB simulator to simulate and implement for WSN.

2. Implement an improved LEACH algorithm to save energy in the WSN.

3. Improve the stability period of the LEACH protocol.

1.4. Thesis Organization

This dissertation contains five chapters, including the current one that provides a review of WSNs, an overview of scope of the study, discusses the research problem and introduces a way to solve that problem and the aims of this work. The fundamental topics of the five chapters are described as follows:

1. **Chapter One** includes the introduction of the LEACH protocol and WSNs, the study objectives, related works, general information and the problem statement.
2. **Chapter Two** presents an overview of WSN applications, design issues, routing protocols, the LEACH protocol and the literature that is most related to the proposed work.
3. **Chapter Three** describes the proposed algorithm and the benchmarks for comparing and evaluating the algorithm with previous works.
4. **Chapter Four** presents the simulation results of the WSN implementation with the suggested algorithm and compares it to LEACH routing.
5. **Chapter Five** contains the conclusion of this thesis and suggestions for future work.

CHAPTER TWO

THEORETICAL BACKGROUND

2.1. INTRODUCTION

To monitor the health status of patients, various WSNs are used (like those utilised in military applications, weather monitoring and medical applications). WSNs are groups of sensors that communicate with the monitoring unit through an BS. The sensor consists of small independent devices with specific limitations (i.e. battery power, computing capacity, and communication range and storage memory). These sensors contain transmitting and receiving devices that collect information and send it to the BS. The information obtained can be stored or made available to the user upon request.

2.2. THE MODEL OF WIRELESS SENSOR NETWORKS

WSNs contain many sensors that can perform calculations and communicate wirelessly with each other. These devices are distributed in specific environments that are far from the users, as is shown in Figure 1. A WSN is made up of the following three items:

1. Sensors: A group of nodes that make up the network. Their major function is to perform local actions via a separate system to create a wireless network in an un-attended environment. Subsequently, they collect and send data to central station.

2. The BS: A location within the area from which the information is transmitted. The data and information collected through the sensing field are sent to the central station via infrastructure under various conditions. The monitoring station is then contacted via the Internet or satellite.

3. The main monitoring station (the user): Functions to receive information from the BS [Carl and Willig (2005)].

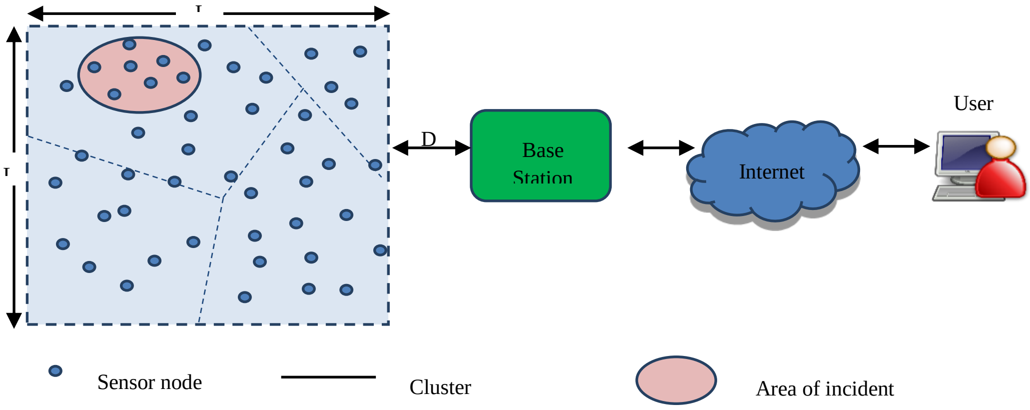

Figure 1. WSN Architecture

2.3.Type of Wireless Sensor Networks

Based upon the environment of the deployment (above ground, underground or underwater), there is a number of the WSN types [Liu and X (2015)].

- **Terrestrial**: A type of sensor network where the quantity of sensor nodes ranges from hundreds to thousands. The deployment of sensors is random over a specified area. Such WSN type is mainly utilised in a field where it monitors the environment. Energy management is a challenge in terms of the sustainability of the network.

- **Underground**: These sensor nodes are unique and expensive due to the logistics required for their maintenance and the pre-planning required for their deployment. These sensors are installed in soil for agricultural monitoring or inside mine walls to observe and monitor soil conditions. There is a land node, but its main duty is to retransmit the underground information to the BS.

- **Underwater**: This type of WSN presents a research problem because the environment can be hostile to the sensors and is usually only an area of exploration (not monitoring). While it is possible to deploy only a minimal number of nodes, they are more costly compared to the terrestrial sensors. In addition, the band-width is restricted, wireless communication is acoustic, the shortfall of signals is recurrent and broadcast postponements and management issues are enormous.

- **Multimedia**: such WSN type allows to monitor a tracker in the real-time events like the images, sound and videos. Those sensors are supplied by microphones and cameras. Emphasis has been placed upon good bandwidth, processing and data compression all of which imply high energy consumption. Advance planning is highly important for deploying those sensors.

- **Mobile**: which is the newest type of WSNs where nodes can reposition and autonomously reorganise the network. After their initial deployment, nodes disperse to collect data. A hybrid mobile network also exists that is a combination of mobile sensors and fixed ones.

2.4.Sensor Node

The sensor node itself is an appliance that gathers information and sends it on to the mote. Sensors commonly measure changes in their surrounding physical environment such as the temperature, amount of sunlight, wind speed and sound. Sensors can also measure changes in human health factors, such as heart rate and sugar levels. Logically, a sensor node must be small, expend energy efficiently, work in large volume densities, be independent (work unattended) and adapt to its surrounding environment. A diagram of the sensor node has been illustrated in Figure2. The sensor node consists of the following components [Pottie and Kaiser (2000)]:

• **Controller**

The controller performs several responsibilities. It manages the functional order of the sensor's components and processes the data. Different embedded systems use controllers due to their flexibility in connecting with other devices, their low consumption power, their low cost and ease of programming [Pottie and Kaiser (2000)].

• **Transceiver device**

The transceiver is a single device that performs both receiver and transmitter duties. Device transceivers do not normally have identifiers and have different operational states: receive, transmit, sleep and idle. The current generation of the transceivers have built-in state machines, so they perform a number of the operations automatically. Most of the transceivers that operate in the idle mode consume almost the same amount power that a transceiver in receive mode does. Therefore, instead of leaving a device in idle mode, it is better and more energy efficient for completely shutting down the transceiver. When changing the transceiver's mode from sleep to transmit to send a packet of data, a large amount of power is consumed [Chen et al. (2015)].

• **Sensors and Actuators**

Sensors are hardware devices. Their duty is to measure changes in physical parameters such as wind speed, amount of light and soil humidity. Sensors monitor parameters related to physical data. The sensor produces a continual analogue signal that is converted to a digital form through a digital converter. It is then sent to the controllers for more processing [Chen et al. (2015)].

• **Memory**

Memory types are based on storage objectives and are classified into two categories. The first type of memory is used for personally gathered data. The second type of memory is used for programming devices. The identification data of the gadget, if present, is included in the program memory [Chen et al. (2015)].

• Power supply

The sensor hub controls data detection, data transmission and information preparation. Power is supplied by either capacitors or batteries. Batteries, rechargeable as well as non-rechargeable, are primary source of energy for sensor hubs.

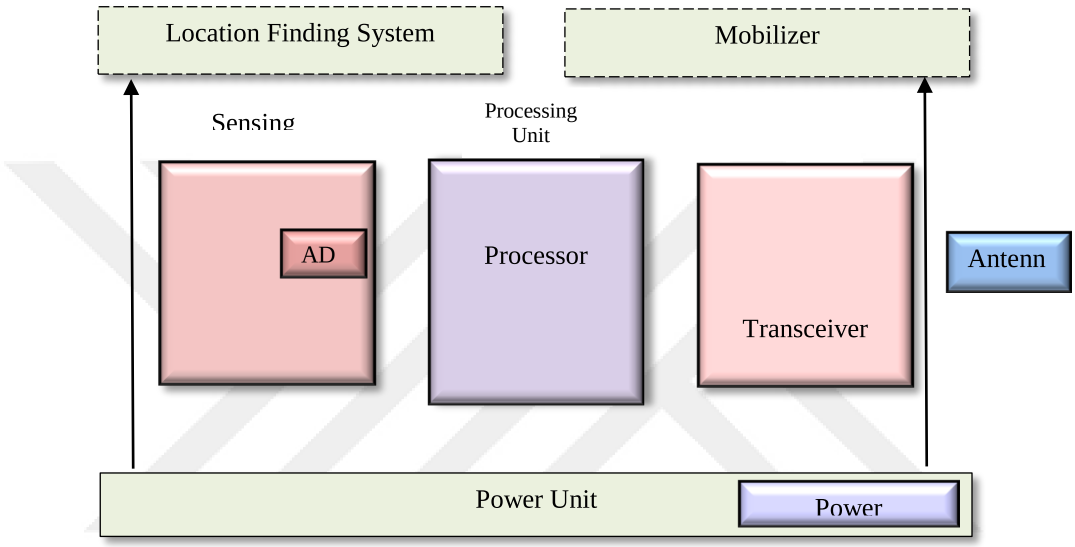

Figure 2. Block diagram of a sensor node

2.5. Wireless System Network Classification

WSNs can be categorised by operation and target application type. Network architecture is very important in the way that routing protocols work within WSNs. This section provides an explanation of these protocols. WSNs can be classified by type of deployed sensor: static WSNs and mobile WSNs (MWSNs). The MWSN concept was spurred by latest advances in the robotics technology and distributed computing.

2.6 Application Of Wsns

Research of WSNs is a rich, multidisciplinary area where several concepts and tools can be applied to address the variety of their applications. WSNs consist of a wide range of sensor types (e.g. magnetic, visual, thermal, infra-red, seismic and radar) that can monitor various conditions. The sensor nodes may be utilized for location sensing, continuous sensing, event detections and motion sensing. In addition, new application fields are being developed, including micro-sensing and wirelessly connected sensor nodes. Sensor node applications in WSNs are summarised in Figure 3.

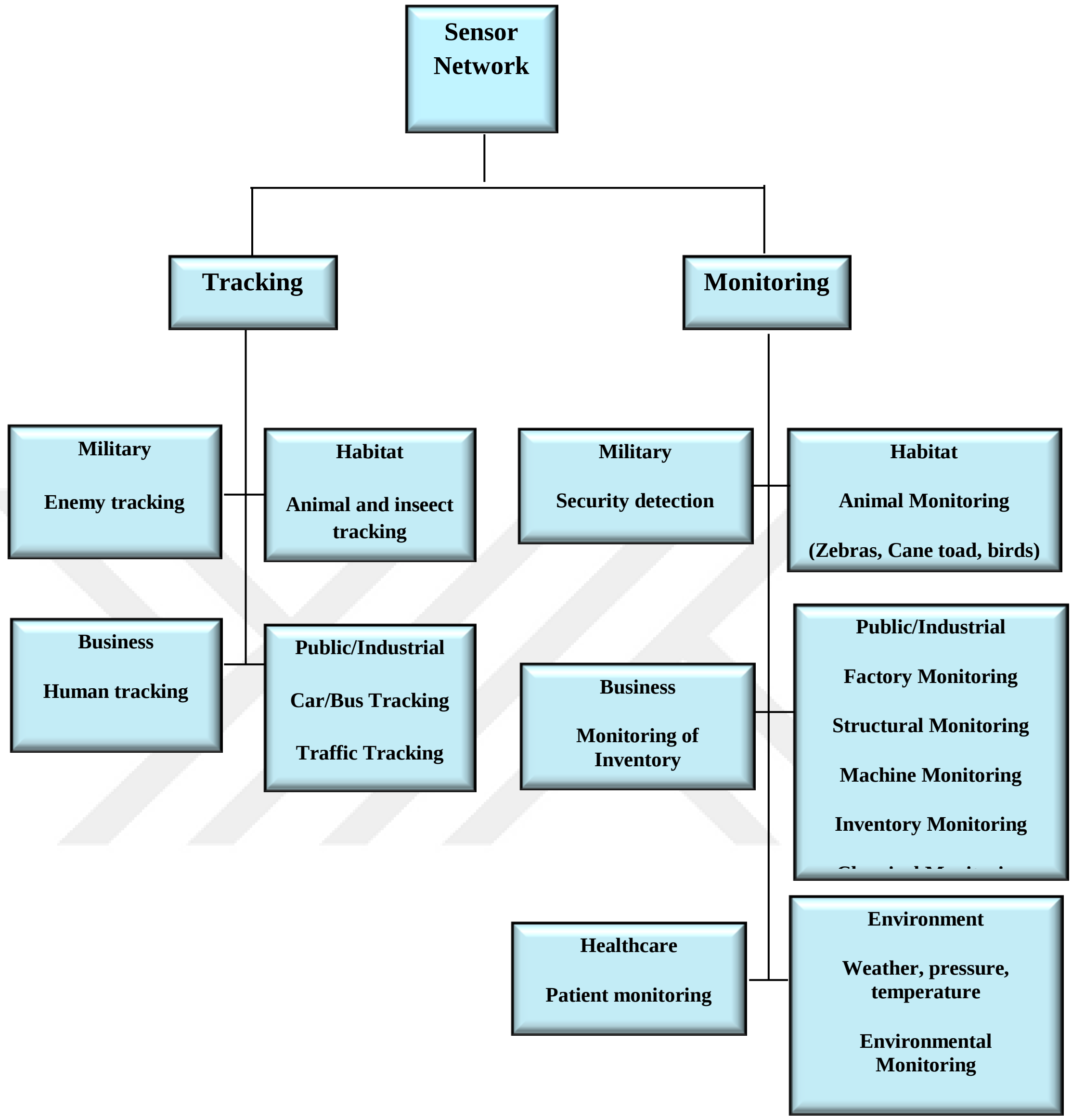

Figure 3. WSN applications

2.6.1. Applications of Area Monitoring

Area monitoring can be defined as one of the very common WSN applications. In area monitoring, WSNs are utilised where there are physical activities or phenomena that require monitoring. When a sensor detects an event that is being monitored (e.g. vibration or sound), it is reported to the BS. The BS then makes the correct action (for example, sending a message via Internet or satellite). In a similar manner, WSNs may be utilised in security systems for the detection of unwanted motion or in traffic control systems for the detection of high-speed cars. WSNs are also applied in the military field for surveillance, equipment and ammunition, monitoring friendly forces, reconnaissance of enemy forces, terrain evaluation, battle damage assessments and targeting [Fengjun and Yang (2010)].

2.6.2. Environmental Applications

Some WSN environmental applications include greenhouse monitoring, forest fire detection, air pollution detections, landslide detection and flood detection. They may also be utilised to track the movements of insects, small animals and birds. WSNs are used in the exploration of planetary movements, and to monitor the conditions of livestock and crops for irrigation facilitation [Fengjun and Yang (2010)].

2.6.3. Health Applications

Different health-care applications for WSNs provide interfaces for patients that are disabled. They can also provide diagnostic information, integrated patient monitoring, monitoring of internal processes, for drug administrations in the hospitals, telemonitoring of physiological information, and for monitoring and tracking doctors and patients within hospitals [Whitehouse (2003)].

2.6.4. Industrial Applications

Currently, WSNs are utilised in industrial applications (e.g. for machinery condition-based maintenance). Locations that were previously inaccessible, restricted or dangerous (such as rotating machinery or mobile assets) may now be reached with WSNs. They may also be utilised for measuring and monitoring the levels of water in ground wells as well as for monitoring the accumulation and removal of leachate [Whitehouse (2003)].

2.6.5. Other Applications

WSNs are also utilised in everyday applications such as vacuum cleaners, VCRs, refrigerators and microwaves. Other applications include the construction of smart spaces, monitoring the quality of products, managing inventory, factory instrumentation and much more.

2.7. Protocols Used in Wsns

The primary aim of routing a WSN is to provide high-efficiency, continuous networks. The flat direction, hierarchal direction and positional (location-based) direction are three possible classifications for the protocol based on the network's shape. All existing nodes in flat routing have fixed functions. Within a network, nodes operate differently in the serial direction. Data is routed in the positional direction based on node locations (as shown in Figure 4).

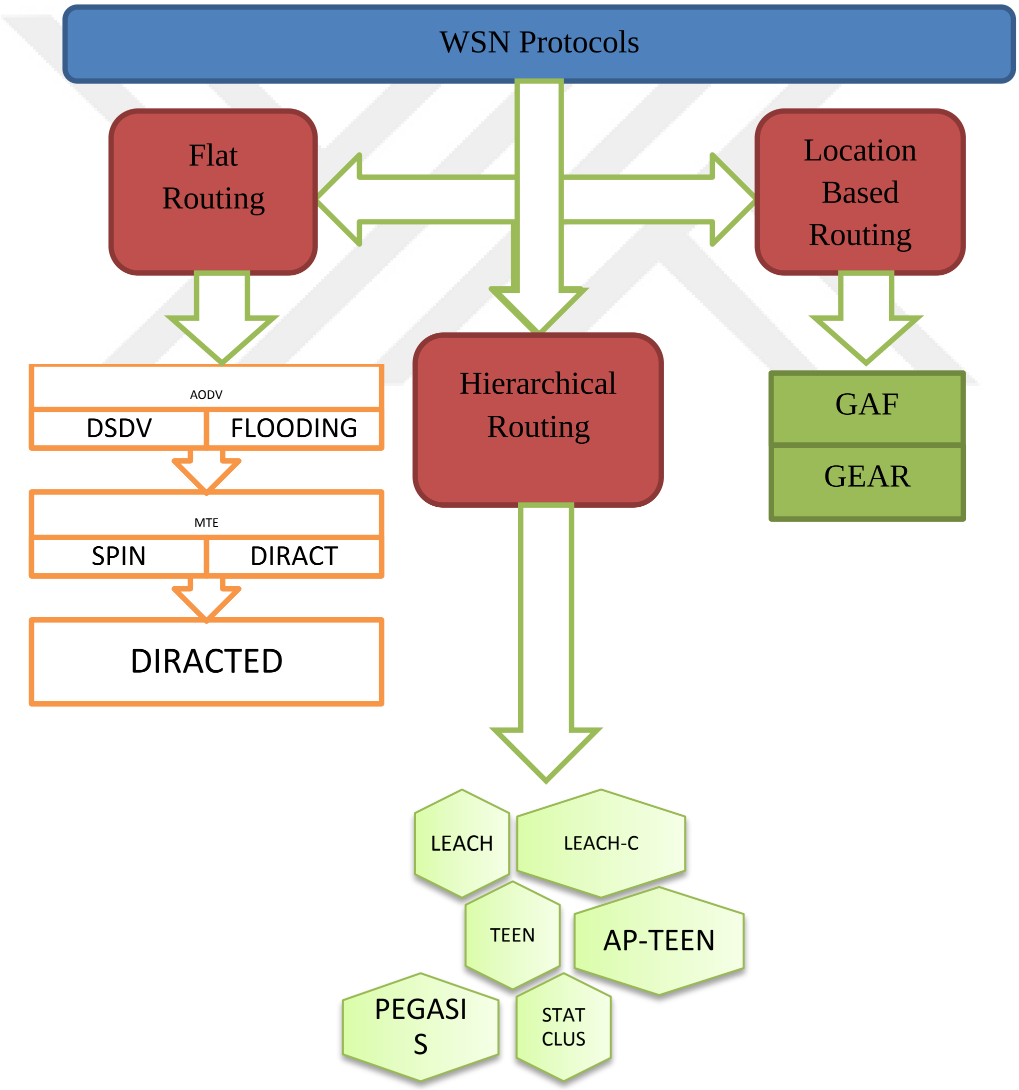

Figure 4. WSN protocols

2.7.1. Flat Routing Protocol

The flat protocol can be defined as a multi-hop protocol in which each node has a fixed functional role, all nodes participate in the operation to complete the sensing process, and each node cannot be identified individually as a result of the large number of nodes. The flat routing protocol consists of several protocols as shown in Figure 5: ad-hoc on-demand distance vector, Destination Sequenced Distance Vector, flooding, minimum transmission energy, sensor protocol for information through the negotiation, direct transmission and directed diffusion.

The BS sends a request to a specific area and then waits for the response from the sensor, doubling its focus on the information path. Multiple protocols can be found in the routing protocol, as is shown in Figure 5 [Kulik et al. (2002)].

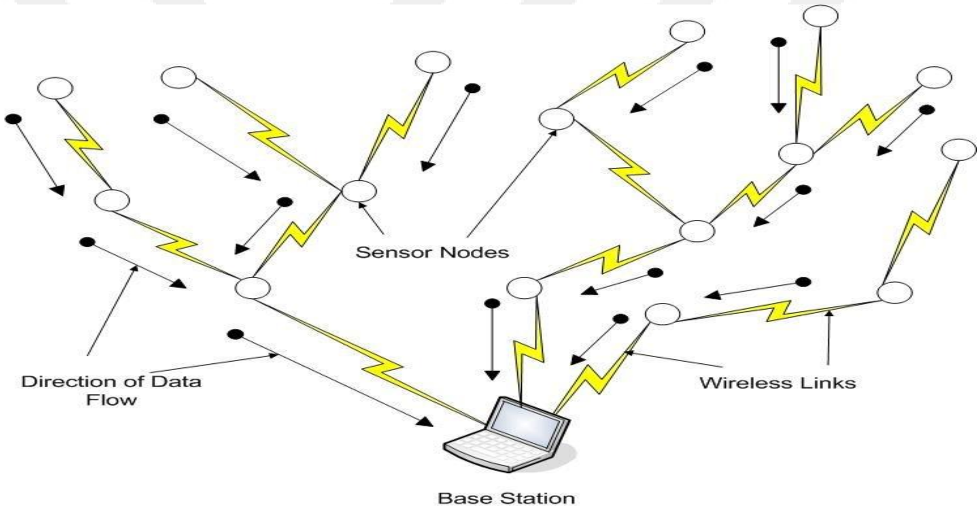

Figure 5. Flat routing in sensor networks [Bari (2005)]

2.7.2. Hierarchical Routing Protocol

The hierarchical orientation is made up of two layers, the first defines the CH and the second controls the orientation. The hierarchical routing protocol consists of several protocols: LEACH low-energy adaptive clustering hierarchy, LEACH-Centralised (C), threshold-sensitive energy efficient sensor network (TEEN), adaptive TEEN (APTEEN), power efficient gathering in sensor information systems (PEGASIS) and STAT CLUS, as is shown in Figure 4.

The HC oversees the gathering of information from the nodes and its transmission to the BS. The main aim of the hierarchical routing protocol is to create clusters, select HCs and conserve power to extend the network lifetime. The hierarchical orientation of this protocol is a solution for reducing energy consumption in WSNs. Hierarchical orientation assigns a different task to each node based on the power capacity of the sensor, and this process ensures an even distribution of energy. This orientation is also important to avoid data collisions within the network [accomplished using the medium-access control (MAC) protocol] as is shown in Figure 6 [Younis et al. (2006)].

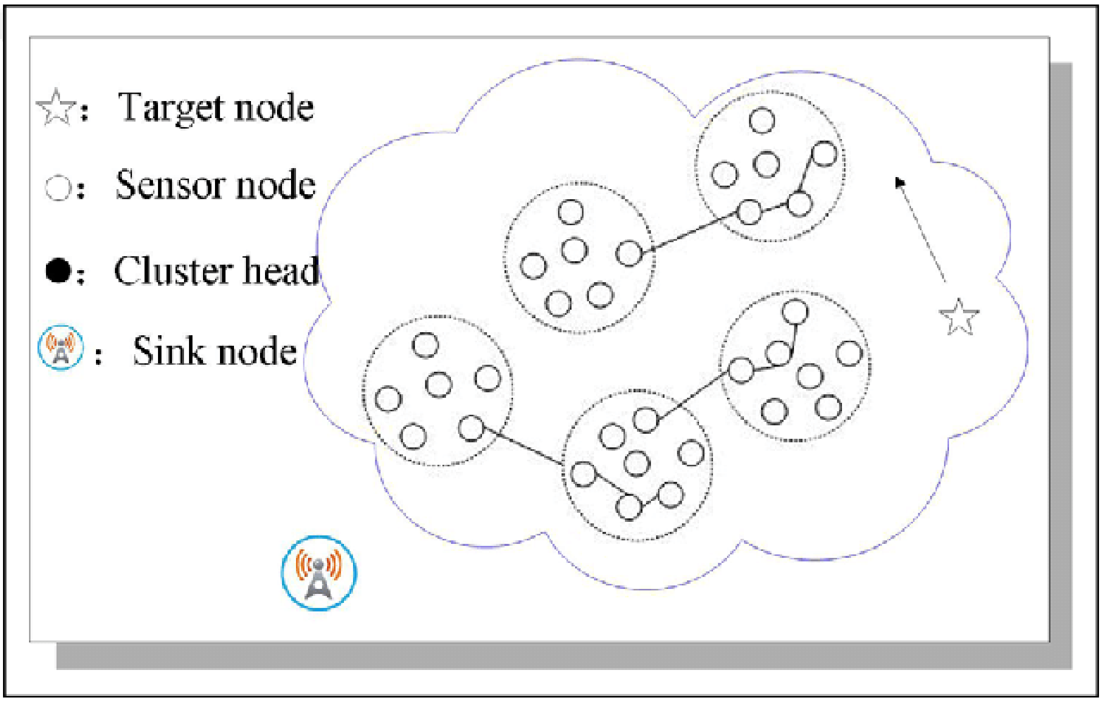

Figure 6. Hierarchical routing in sensor networks [Zhao et al. (2018)]

2.7.3. Location-Based Routing Protocol

If sensor nodes don't have an IP address, then IP-based protocols will not be utilised for sensor networking. The network nodes do not require complex calculations to find the next hop in this protocol; the directional decision is based on location information. This protocol consists of a set of facts of network nodes. First, the nodes must be defined by a GPS device. Second, each of the nodes should know the location of the neighbouring nodes. Third, the source node should know the location of the destination node [Ilyas et al. (2004)].

The location-based routing protocol consists of the following: geographic adaptive fidelity (GAF) and geographical and energy aware routing (GEAR), as is shown in Figure 4.

2.8. MEDIUM-ACCESS CONTROL PROTOCOLS USED IN THE WSN

One of the sub-layers of the data link layer is the MAC address. It has also been used to secure communications across a single channel for networks with multiple devices. The MAC protocol layers should conserve energy to extend the network's lifespan. There are multiple reasons for energy consumption in relation to the layers of this protocol; for example, collisions occur when multiple beams are received and transmitted at the same time. To achieve the best performance, the MAC protocol should avoid the problem of power loss. The MAC protocol has both advantages and disadvantages. As Demirkol (2006) and Ye et al. (2001) indicate, there are several types of MAC protocols:

1- Wireless sensor MAC (WiseMAC)

In this type of MAC protocol, the TDMA protocol can be utilized to access the data channel, and the sparse code multiple access protocol may be utilized to access the control channel. With a common media separator and an independent table, samples are taken from all network parts. When a node is awakened and the network is sampled, the nodes will arrive at a congested location and remain in a waiting state until an empty media or packet is received that completes the operation. A method for reducing power consumption is provided by the MAC protocol. At the transmitter node, this method is known as sleep tables for neighbours. The disadvantages of this type of MAC protocol are related to the difficulty of broadcast communication as a result of the decentralised duty cycle planning and presence of a station located on the sides of the network (as shown in Figure 7).

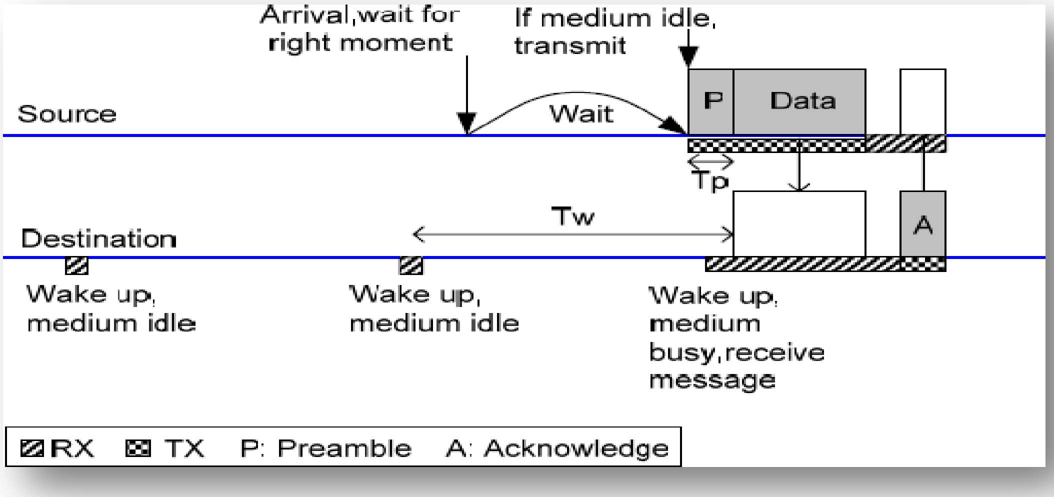

Figure 7. WiseMAC concept Ye et al. (2001)

1- Dynamic Media Access Control (DMAC)

The DMAC protocol reduces power consumption by reducing transmission time. This protocol takes advantage of converging communication within the sensor network, where one-way paths can be separated from paths that lead directly to the central station, and data is gathered in the form of a tree (as shown in Figure 8).

This protocol has the shortest transmission time when compared with sleep or listening statuses. However, because multiple nodes attempt to send information at the same level during this process, a collision cannot be avoided in this protocol [Ye et al. (2001)].

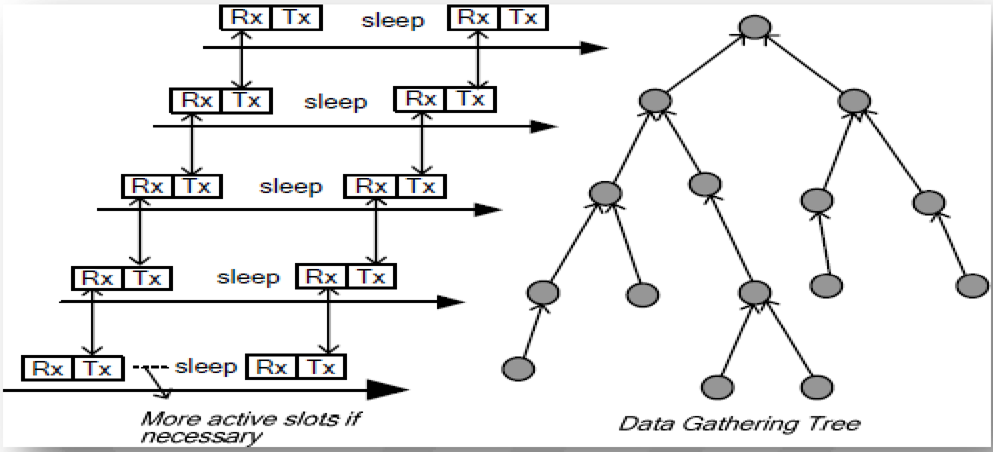

Figure 8. Data gathering tree of the DMAC protocol [Ye et al. (2001)]

3) Dynamic Sensor-MAC (DSMAC)

The DSMAC protocol aims to reduce the time required for sensitive applications to gain access. This protocol will shorten the time of inactivity when all nodes are in the same cycle and a high jump latency is detected. In the case of signal reception, this occurs during the synchronization period. The queue is subsequently checked, as is shown in Figure 9.

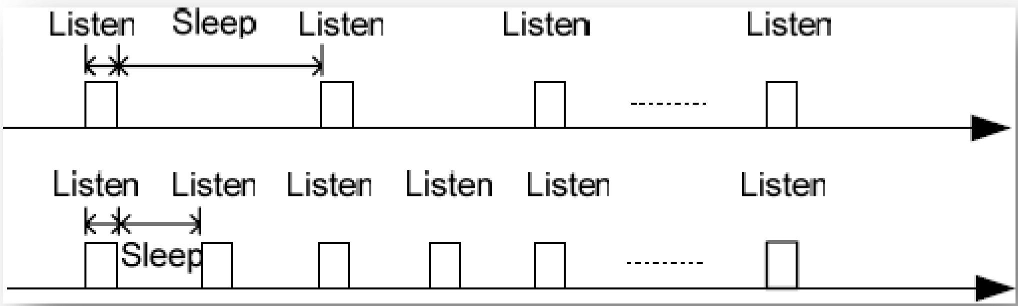

Figure 9. The DSMAC duty cycle [Ye et al. (2001)]

2.9. Proactive Network Protocol

In proactive networks, nodes can be periodically switching between sensors and transmitters. These nodes can also transfer data to the monitoring station. These networks are preferable for protocols like LEACH where continuous monitoring of information is important [Yulin and Xiangning (2007)].

2.10. Hybrid Network Protocol

The nodes in hybrid networks provide a general understanding of the energy efficiency within the network. Another feature of this network provides old, current and future information [Younis and Fehmy (2004)].

2.11. Leach Protocol

This protocol can be specified as a self-regulating assembly protocol in which the node depends on itself, and the basis of the currency is the random distribution of nodes for the equal distribution of power load between the sensors in a network. The LEACH protocol is operated by organizing the actual nodes in specific groups, and one of those nodes will represent the head cluster or BS (as can be seen from Figure10). The set-up phase is the first round of this protocol, where the nodes are organised, and the protocol is divided into iterations. The second round is steady-state phase where the information is transmitted to the BS. The phase of the steady state is long in comparison with the setup phase, so the sensors elect themselves to become HCs. The sensors do this in various time periods to distribute the energy among the HCs evenly. A sensor’s decision to form an HC is dependent upon the energy remaining in the node. When creating groups, each node decides whether to become an HC. This decision has been based upon the proposed percentage of HCs in addition to the number of times a node has become an HC by selecting a node at random between 0 and 1. In the case where the number is less than a certain threshold, the node will become an HC [Heinzelman *etal*. (2000)].

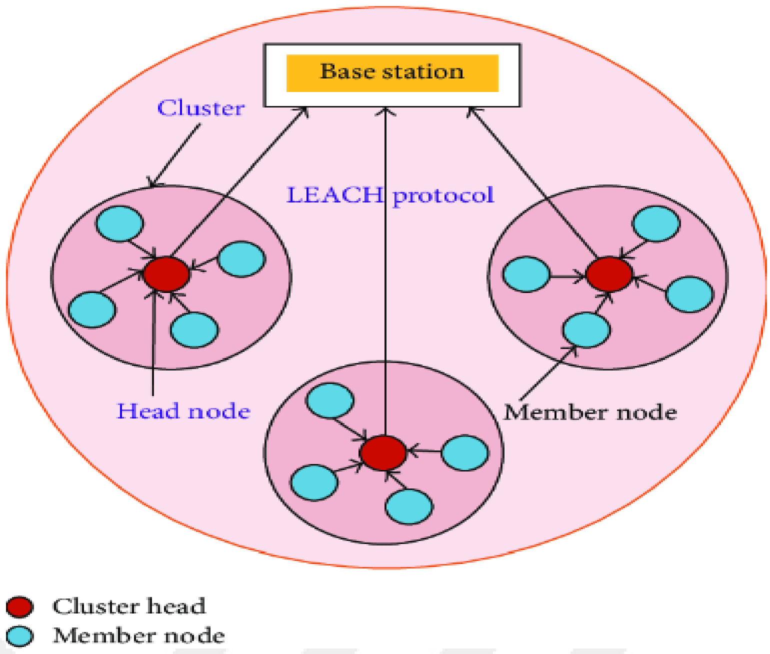

Figure 10. LEACH protocol structures [Heinzelman etal. (2000)]

The LEACH protocol exists in the second layer , near the data link layer, as is shown in Figure 11.

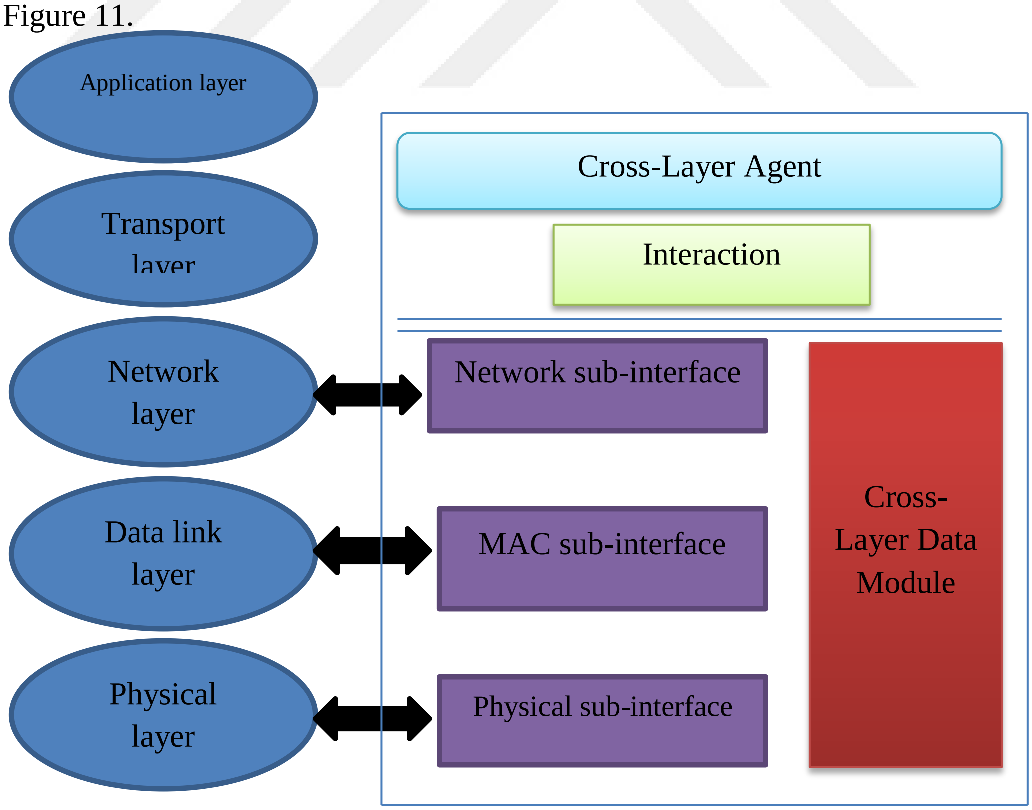

Figure 11. Layered Architecture of an WSN

2.11.1 LEACH Algorithm Details

The LEACH process is divided to rounds. Every one of the rounds starts with the setup phase where clusters are organized. This is followed by the steady-state phase where the data is transferred to BS. For the purpose of minimizing the overhead, the steady-state phase is long in comparison with the setup phase.

I. Set-up Phase

The four steps in the setup phase are CH selection, announcing the HCs, forming the HCs and cluster formation and schedule creation. The LEACH protocol chooses a subset of nodes in a network to become HCs. In the LEACH protocol, each node in the network generates an arbitrary number ranging from 0 to 1. The number is compared with the rest of the threshold numbers (Tn); if the result of the threshold is less than one, the node becomes cluster header. If the result of the threshold is smaller than one, the node becomes a regular node and not an HC.

$$\text{Tn} = \begin{cases} \frac{p}{1-p*(r mod * \frac{1}{p})} & if\ n\ \in\ G \\ 0 & otherwise \end{cases} \qquad (1)$$

The node will be the cluster head for current round if it meets the threshold (Tn), where P represents the required percentage of CHs. The threshold is set based on the following criteria. The cluster head percentage P (e.g. P = 0.050) is a parameter r for the current round. The group of the nodes that were not elected as cluster heads is represented by G in the final 1/P rounds.

After some nodes are defined as HCs, the entire network is announced by sending control message packets. All network nodes receive these messages that are then stored in their memory. These nodes then make the decision regarding which cluster to join, based on the strength of the received signal. The strength of the signal indicates the distance between the nodes and the cluster heads. The nodes will be nearest one of the clusters. This process helps to reduce energy consumption. After deciding which cluster to join, the normal nodes (not HCs) inform the cluster head that they have joined specific clusters by sending a control packet.

After formation of the clusters, all the cluster heads decide upon the communication time schedule for their own clusters. Within the cluster, the head and members utilise TDMA for communication. The cluster head distributes the data transmitting time slot every cluster member when it can send data to its HC. The TDMA schedule helps the nodes redsuce the number of unnecessary communications **[**Sarma et al. (2014)].

II. Steady-State Phase

In this phase (the data communication phase), every sensor node collects information from the environment and it to the cluster head. All sensor nodes follow the communication time schedule. The HCs receive data from the cluster members and process the data fusion. The data fusion process reduces the abundant data and makes data packets smaller. This helps the HCs use less energy when sending data to BS. In the last stage of the steady phase, the HCs send data packets to BS [Sarma et al. (2014)].

III. Reconstruction

The steady state phase lasts for a longer period in comparison with the setup phase. Following steady phase, the network repeats the cluster construction process again, including a new setup phase and a new steady state phase. This periodical process continues until the whole network dies. Figure 12 demonstrates a LEACH process based on a cluster's population. Each row in the round represents one time slot in TDMA and the columns represent different cluster members.

Round 1 {

Cluster1	**Cluster2**	**Cluster3**	**Cluster4**	**Cluster5**	**Cluster6**
Node	Node	Node	Node	Node	Node
Node	Node	Node	Node	Node	Node
Node	Node	Node	Node		Node
	Node	Node	Node		Node
	Node	Node	Node		Node
			Node		Node
			Node		Node
					Node

Figure 12. Distribution of nodes in a cluster

IV. Radio interference

Because radio waves are a broadcasting medium, transmissions in one cluster have an impact on communication in nearby clusters. Figure 13 illustrates an example of radio interference, in which the signal from nodes A to B is affected by signal from node C. various clusters utilize various CDMA codes to solve communication interference problem. Every CH selects a spread code and informs the rest of the cluster about it. As a result, each cluster has its own spread code that is used to encrypt data. Therefore, all signals received by the cluster head will be decoded correctly. The interference is reduced when CDMA codes are used. The radio signal from neighbouring clusters can be filtered out, and the node transmission in a cluster will not be interrupted [Heinzelman et al. (2000)].

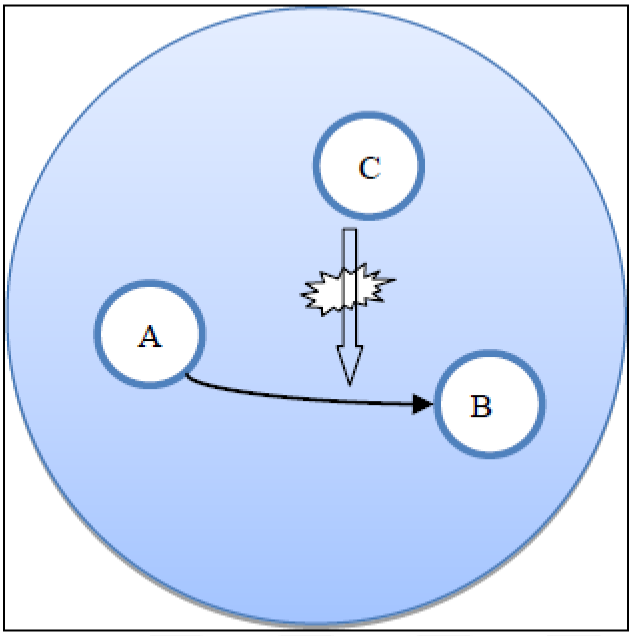

Figure 13. Illustration of radio interference: transmission of nodes A to B is corrupted by the signal from node C [Heinzelmanet al. (2000)]

V. **First-Order Radio Model**

As is shown in Figure 14, the first-order radio model consists of a transmitter circuit, a receiver circuit and a transmitter amplifier. The distance between the transmitter and the receiver is *d*. The transmitter circuit consumes energy for every one transmission bit and the receiver circuit requires energy for every one reception bit. The energy applied by the amplifier is related to the transmission distance.

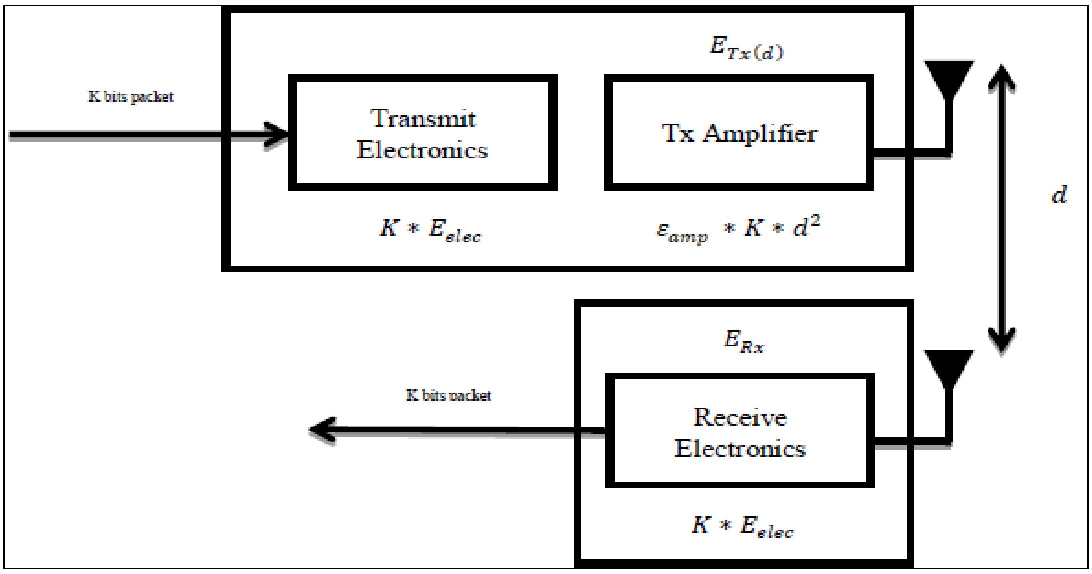

Figure 14. First-order radio model

There are 2 energy consumption models, which are: the open space model and the multipath model. The total energy consumed in a packet transmission of K bits in a distance d is given and consumed by the receiver. Here, E_{elec} represents the consumption of energy for running the circuitry of the transmitter or receiver. In addition, d_0 is the value of the threshold of distance that is obtained by

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \quad (2)$$

Here, ε_{fs} and ε_{mp} are the required energies for amplifying the transmitted signals in open space model and in multi-path model, respectively. In the open space model, energy dissipation per bit is calculated as follows:

$$\mathrm{E} = \varepsilon_{fs} d^2 \quad (3)$$

In the multipath model, energy dissipation per bit is

$$\mathrm{E} = \varepsilon_{mp} d^4 \quad (4)$$

Energy consumption for the transmitter is calculated as follows:

$$E_{Tx}(K, d) = \begin{cases} E_{elec} * K + K * \varepsilon_{fs} * d^2, d \leq d_0 \\ E_{elec} * K + K * \varepsilon_{mp} * d^4, d > d_0 \end{cases} \quad (5)$$

Energy consumption for the receiver is

$$E_{Rx} = E_{elec} * \mathrm{K} \quad (6)$$

CHAPTER THREE

PROPOSED APPROACH

3.1 Proposed protocol

This research developed a novel algorithm (IV-LEACH) that saves more energy than the original LEACH protocol with several the other benefits. The main improvements of this routing algorithm in comparison with the original LEACH protocol are listed as follows:

1. Increased energy saving and network lifetime.
2. Introduced a method for energy aware routing.
3. Provided decentralised protocol.
4. Improved cluster creation.
5. Located cluster heads in an appropriate position.
6. Reduced the required number of transmissions when selecting cluster heads.
7. Selected the optimum number of cluster heads to save more energy.

3.2 Network Model

In this network model, 150 nodes are randomly distributed over an area of 900m × 900m. The network is divided into groups. One of these groups contains the BS. All nodes transmit their information by selecting an HC from these nodes. The information is sent directly from HC to BS to reduce energy consumption. HCs continually communicate with the BS by transferring data until the last node in the network dies (as shown in Figure 15).

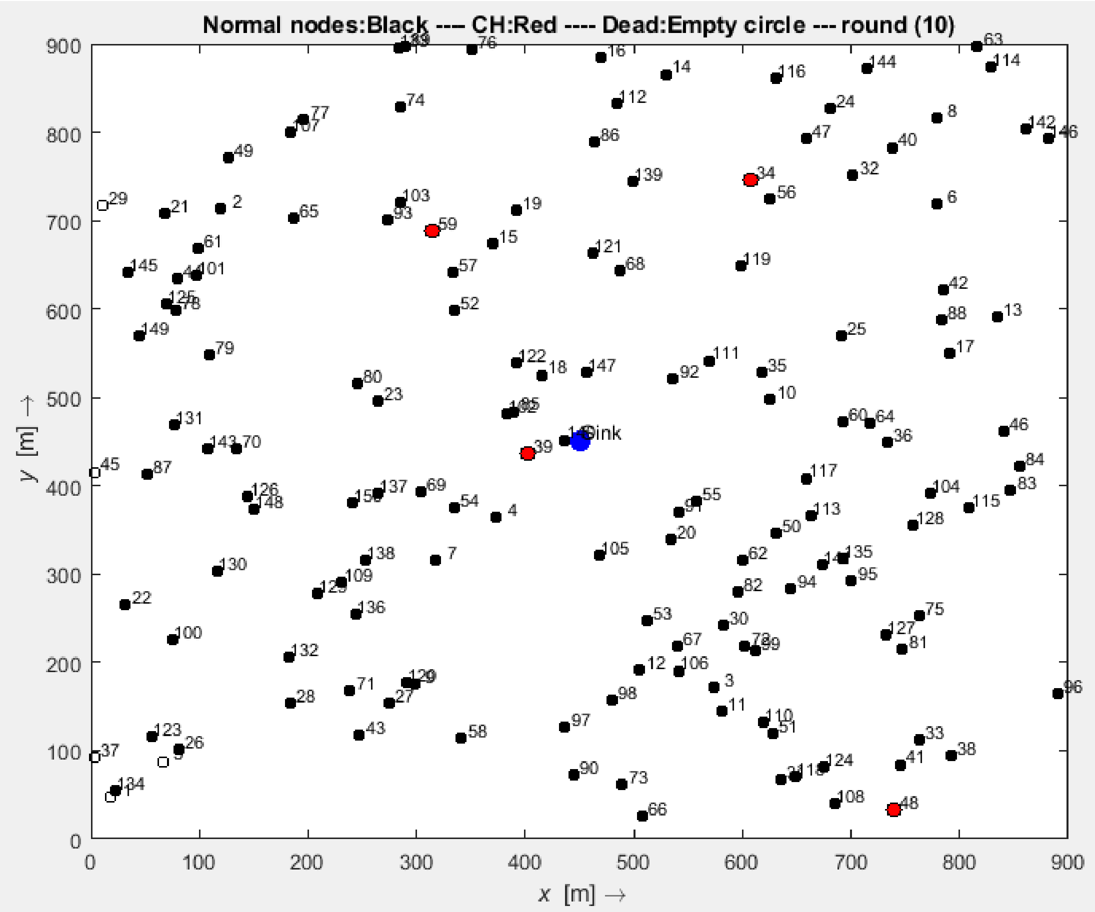

Figure 15. The x-axis and y-axis coordinates of sensor nodes

3.3. IV-LEACH protocols

3.3.1. TEEN protocol

This section presents the TEEN protocol. It's targeted at and is the first protocol that has been developed for the reactive networks where the nodes continuously sense their environment [Manjeshwar and Agrawal (2001).]

Functioning

As is demonstrated in Figure 16, the CH broadcasts to its members at each one of the cluster change times, besides the sensing attributes. There are 2 thresholds in this protocol.

Hard Threshold (HT)**:** which can be defined as threshold value for sensed attribute. It represents the attribute's absolute value beyond which a node that senses that value has to switch on its transmitter and report to the CH.

Soft Threshold (ST)**:** which is a small change in the sensed attribute triggering the node to switch on the transmitter and transmit.

The first time that a parameter from the set of the attributes reaches its HT value, the node switches on the transmitter and transmits the data that has been sensed. The sensed value has been stored in internal variable in a node, which has been referred to as sensed value (SV). The nodes will transmit the data afterwards in current cluster period, however only in the case where the following two conditions have been true:

- The current sensed attribute value is higher than HT.
- The current sensed attribute value is different from sensed value by an amount that is greater than or equal to ST. in the case where a node transmits the data, the sensed value equals current sensed attribute value. Which is why, HT attempts at the reduction of the number of the transmissions through allowing nodes to transmit only in the case where sensed attribute is in a range of interest. The ST additionally decreases the number of the transmissions through the elimination of all transmissions that could've otherwise happened in the case where there is little or no change in sensed attribute as soon as the HT has been reached.

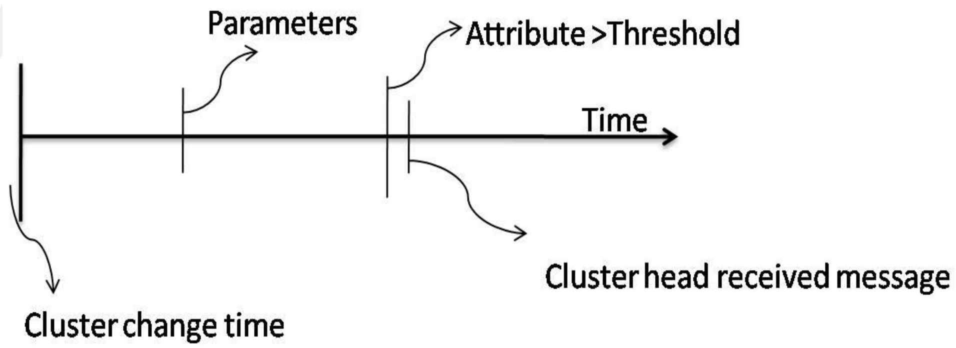

Figure 16. Timeline for the TEEN protocol

The main features of this scheme are as follows:

- This scheme is well suited for the time-critical applications of data sensing as it reaches the user almost instantaneously.
- Message transmission can consume more energy compared to the data sensing. Therefore, although this network's nodes sense in a continuous manner, the energy consumption in this method has been found to be much

less compared to it in proactive networks due to the fact that the data transmission is less redundant.

- The ST varies according to the sensed attribute's criticality and target application.
- A smaller value of the ST can give a more precise picture of a network, at the expense of the increased consumption of energy. Which is why, user can control trade-off between the accuracy and energy efficiency.
- At each time cluster change, attributes are newly broadcasted, thus, the user has the ability of changing them as desired [Manjeshwar and Agrawal (2001)].

3.3.2. HEED protocol

The algorithm of Hybrid Energy-Efficient Distributed (HEED) can periodically select the CHs based on a hybrid of node residual energy and some secondary parameter (e.g. node proximity to the neighbours or node degree). The HEED protocol terminates in iterations zero and one, incurs a low message overhead and can achieve a uniform distribution of the CH across network. HEED protocol can asymptomatically guarantee the connectivity of clustered networks with bounds on node density and intracluster and intercluster ranges of the transmission [Younis and Fahmy, (2004)].

3.3.3. E-LEACH

Energy-LEACH (E-LEACH) results in improving the cluster head selection process by making the residual energy of the node the primary metric in determining whether the node becomes a cluster head or not. In the 1st round, each node has a chance to become a cluster head, indicating that the choice is random (like the LEACH protocol). Following first-round communication, the residual energy of each node is determined and considered for cluster head selection. Nodes with more energy will become cluster heads. This process also incorporates distance and residual energy into the cluster head election question of the WSN lifespan. Harmonic distribution nodes produce both slight and dense clusters in the same network at same time, demonstrating that a few cluster heads may be loaded more than other sensors, as is shown in Figure 17 [El-Sayed and Hagag, (2012)].

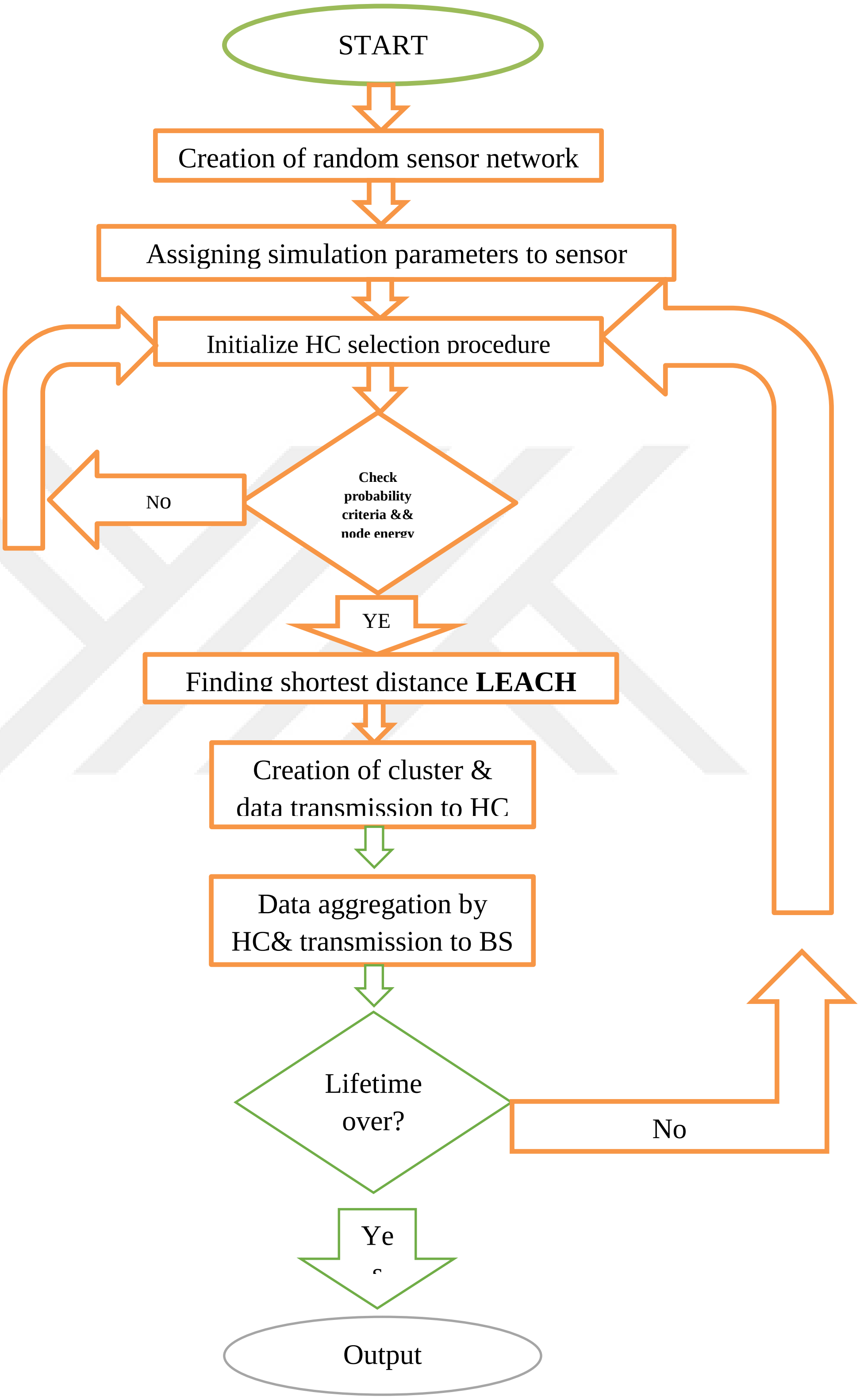

Figure 17. Flowchart of the E-LEACH protocol

3.3.4. TL-LEACH

As is shown in Figure 18, the protocol of cluster formation is a local process realising 2-level hierarchy where possible. Each node decides, in an autonomous way, for the purpose of resulting in a good cluster. Using 2-levels of the clusters for the transmission of the data to BS results in leveraging advantages of the small transmit distances in comparison to the original LEACH protocol. Therefore, less nodes are required to transmit data to the base station over large distances. Which is especially true in the networks where there is a high node density. This protocol contains primary cluster heads (CHi), 2nd level cluster heads (CHij) and simple nodes [SN Manzoor et al. (2019)].

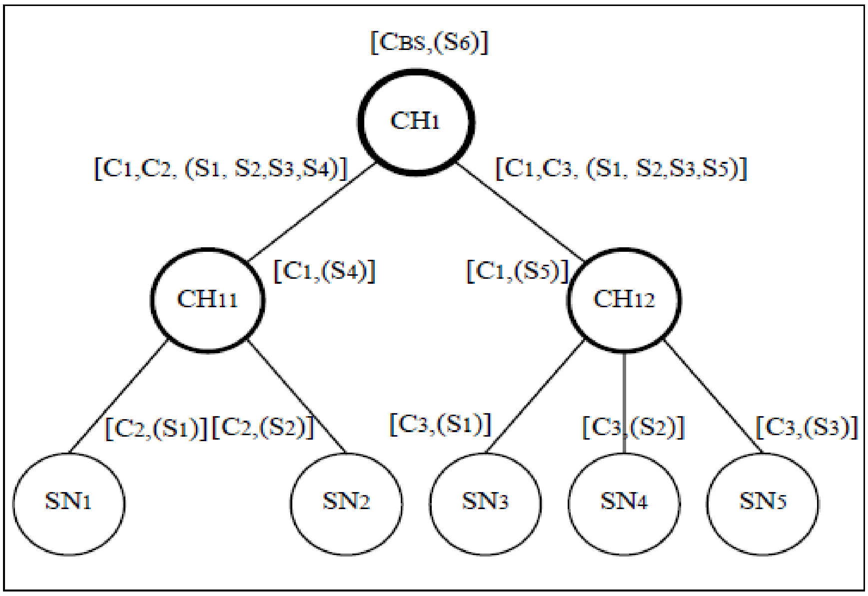

Figure 18. Construction of a typical cluster in the TL-LEACH protocol [Manzoor et al. (2019)]

3.3.5. POWER EFFICIENT GATHERINGS IN THE SYSTEMS OF SENSOR INFORMATION

The PEGASIS protocol is one of the protocols of the hierarchical routing, following a chain-based method and greedy algorithm, as has been illustrated in Figure 19. The sensor nodes organise themselves in a specific order to form a chain. In the case were a node dies in the chain, the chain is re-constructed and bypasses the dead node. A cluster head node or a leader is allocated and transmits data to the base station or sink node. The nodes alternate in the cluster head position and in transmitting data to the sink node. The main objective of PEGASIS is receiving and transmitting data to and from neighbours [Heinzelman, et al. (2000)]

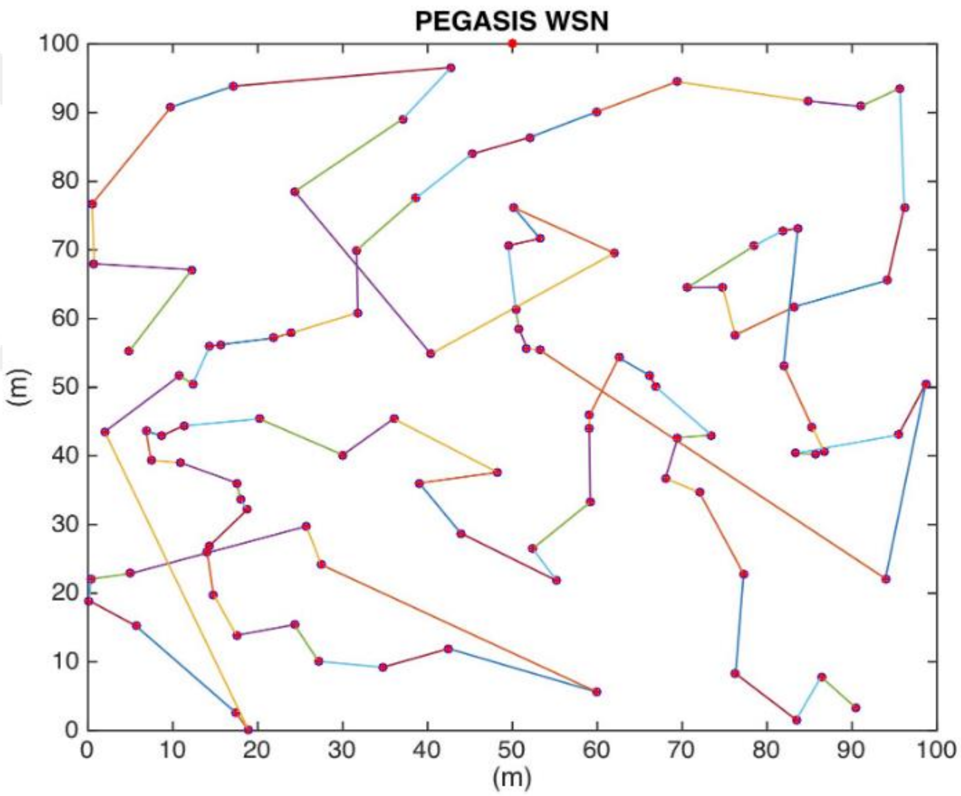

Figure 19. Node chain formation in the PEGASIS protocol [Heinzelman, et al. (2000)]

3.4. Proposed algorithm

The proposed IV-protocol makes sure that the chosen CHs have been distributed in an even manner over network. Which is why, it is not possible that CHs will be concentrated in a single part of network. The efficiency of the suggested IV-LEACH has been assessed according to the following criteria:

- Average consumption of the energy: which is measured at identical time intervals.
- Average throughput: which represents the average number of the packets that have been received at sink.
- Network lifetime: The total number of the alive nodes at the end of all of the algorithm cycles.

The mechanism of action added in the proposed protocol is a joint work and cooperation between a group of protocols, namely, the original protocol of LEACH, the secondary protocol of TL-LEACH, and the third of E-LEACH with the protocol on the equal distribution of energy, PEGASIS. All of these protocols take a role in each round, meaning when they depend on the remaining energy, the Enhance League protocol will be activated. As shown in figure 20.

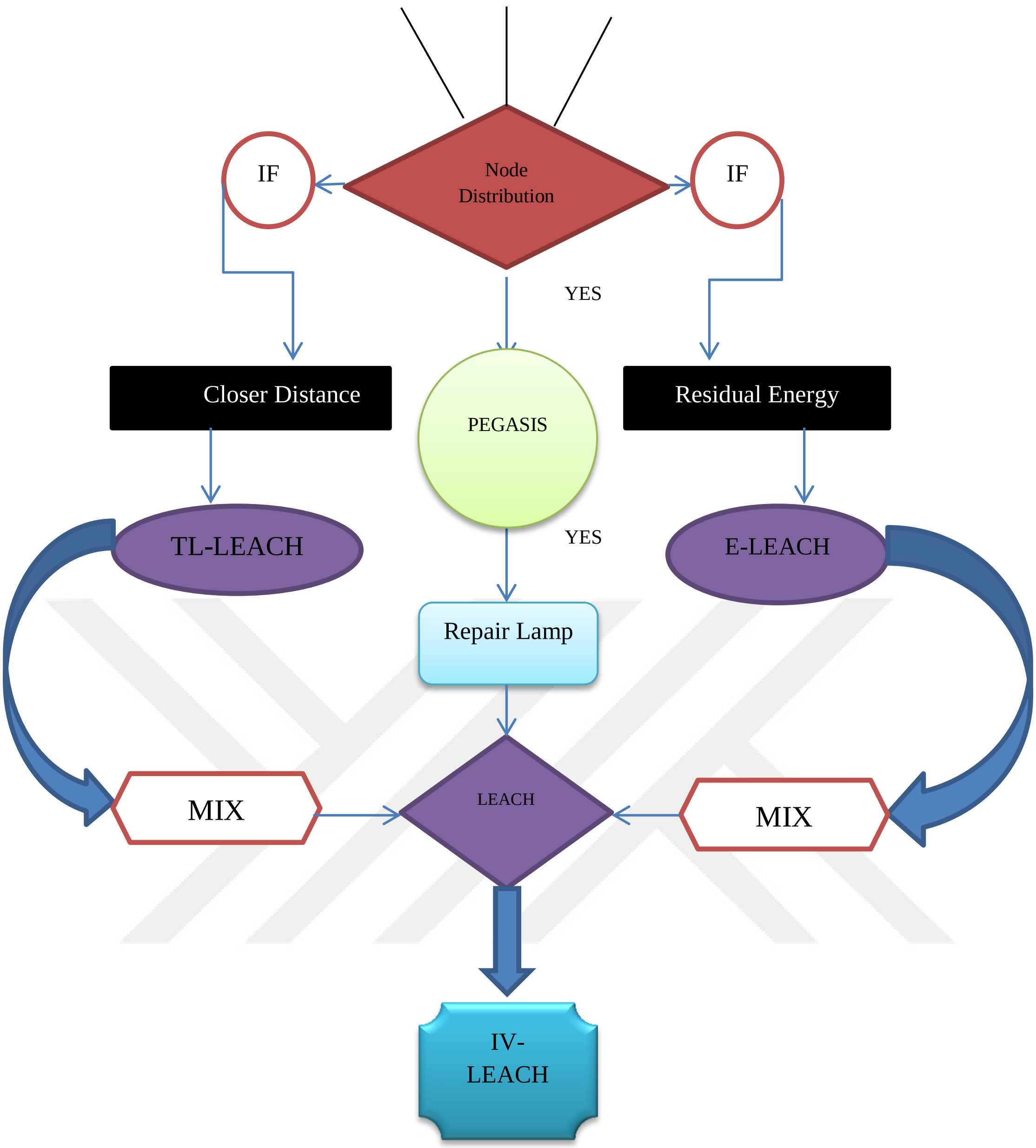

Figure 20. Flowchart of propose algorithm

How the proposed protocol works

The IV-LEACH protocol utilizes the method of the distributed clustering, in contrast to LEACH. Total sensor field has been divided to similar sub-regions. The choice of the cluster head from every one of the sub-regions has been determined by the threshold method, like the they are chosen in the LEACH protocol. Each regular node in this network can be turned off until the allocated time of the transmission, minimizing the dissipation of the energy in these nodes.

WSNs include hundreds to thousands of the sensor nodes that are supplied by the sensing, calculating and communication capabilities. Every one of the nodes can sense its environment elements, carry out simple calculations and communicating amongst its peers or directly to external base station. Sensor network utilization can be random or manual. Those networks promise a fault-tolerant, maintenance-free platform for the gathering of various data types. Due to the fact that a sensor node requires operating for a long time on a very small battery, innovative approaches for the elimination of the energy inefficiencies shortening the network life-time have to be utilized and developed. A higher number of the sensors allows to sense over larger geographical areas with a higher precision. Multiple challenging factors affect the routing protocol design in the WSNs [Mohammad and Imad (2005)]. These factors include increasing energy consumption without compromising the accuracy. This is difficult, however, due to a limited supply of energy performing computations and the challenge of reliably transmitting information in wireless environments.

The PEGASIS protocol allows every one of the nodes to receive from and transmit to close neighbours, and to take turns being the cluster head for transmission to base station [Lindsey and Raghavendra (2002)]. This method performs the distribution of the energy load evenly amongst network's sensor nodes. Because sensor nodes are deployed randomly in sensor field, they are randomly located. The nodes organise to form a chain. This can be conducted by the actual sensor nodes utilizing a greedy algorithm or a base station can calculate this chain and broadcast it to all the sensor nodes. It is assumed that all nodes have network and greedy algorithm knowledge for chain construction. The greedy approach for the construction of a chain is done prior to the first communication round. Chain construction begins with the node that is furthest from base station.

In the TEEN protocol, the network nodes periodically switch on their transmitters and sensors, sense environment, and transmit data of interest [Manjeshwar and Agrawal (2001)]. This method provides a snapshot of the relevant parameters at regular time intervals (a proactive network). This type of network is well suited for applications requiring periodic data monitoring. The HEED algorithm [Younis and Fahmy (2004)] is a multihop clustering algorithm that focuses on the efficient clustering through the proper selections of the CHs based upon physical distance amongst the nodes. The E-LEACH protocol improves the selection procedure of cluster heads. After the first round, the main metric in deciding what nodes become cluster heads is the residual energy of every one of the nodes [Fan & Song (2007)]. Like the LEACH protocol, the E-LEACH algorithm has been divided to rounds. In the 1^{st} one, each one of the nodes has the same probability of turning into a CH. Which is an indication of the fact that CH are chosen randomly. In subsequent rounds, the residual energy of every one of the nodes differs after 1 round communication, and it is considered for the selection of the cluster heads. Nodes that have more energy will become cluster heads. In the TL-LEACH protocol, cluster heads collect data from the other members of the cluster, however, instead of the direct transfer of the data to base station, it utilizes one of the CHs that lies between cluster and the BS as a relay point [Loscri et al. (1999)]. The IV-LEACH protocol has 2 phases, which are: the setup and the steady phases. A new protection mechanism is added into the LEACH algorithm to reduce the number of required re-clustering operations. According to the LEACH protocol, at each time slot within a cluster, only one node communicates with its own cluster head. The most populated cluster decides the fixed time of the round. As is depicted in Figure 20 (in bold), if a CH is notified of a node with low energy level, it will be substituted by another node. Cluster heads can also be replaced. Then, after the substitution, the new cluster head continues the job within the cluster until the round ends

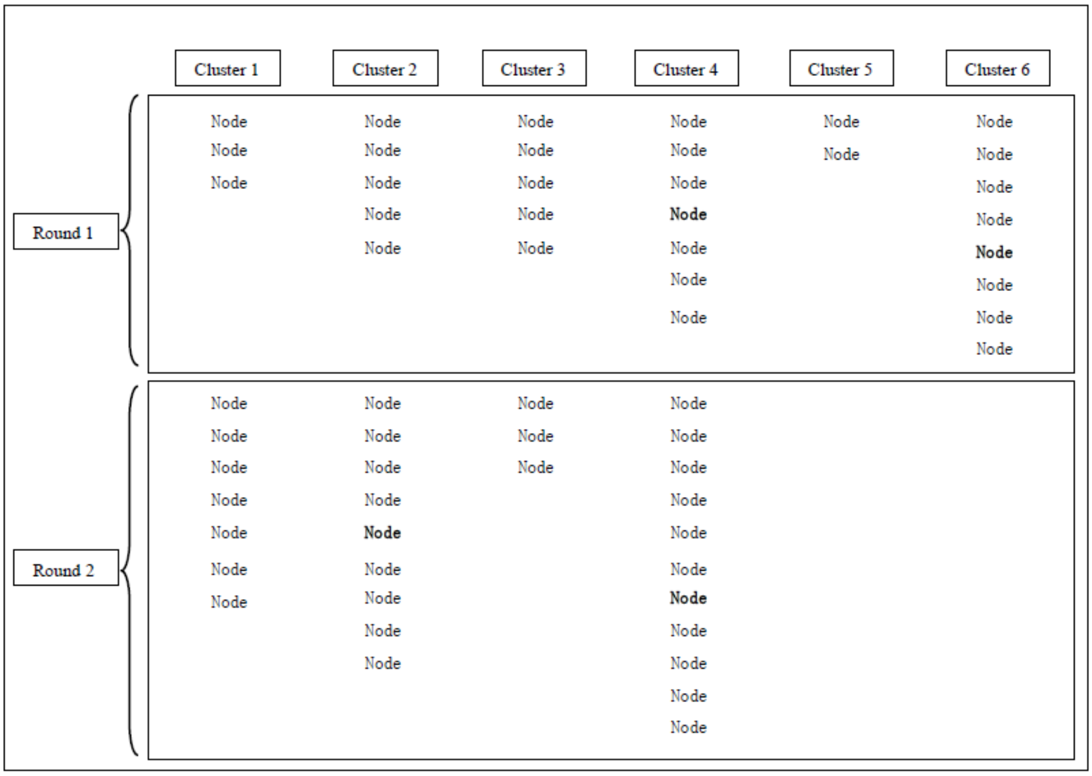

Figure 21. Fixed round time and cluster information.

In this figure, a bolded "**Node**" indicates that the cluster head switched to another node within the cluster, not another node in the whole network. The algorithm flowchart that applies the proposed protocol is shown in Figure 22. This figure has three loops that have the following functions: advertisement) the stage of information announcement that must be transferred to the BS), cluster set-up and cluster head transfer. These functions are described in the following sections.

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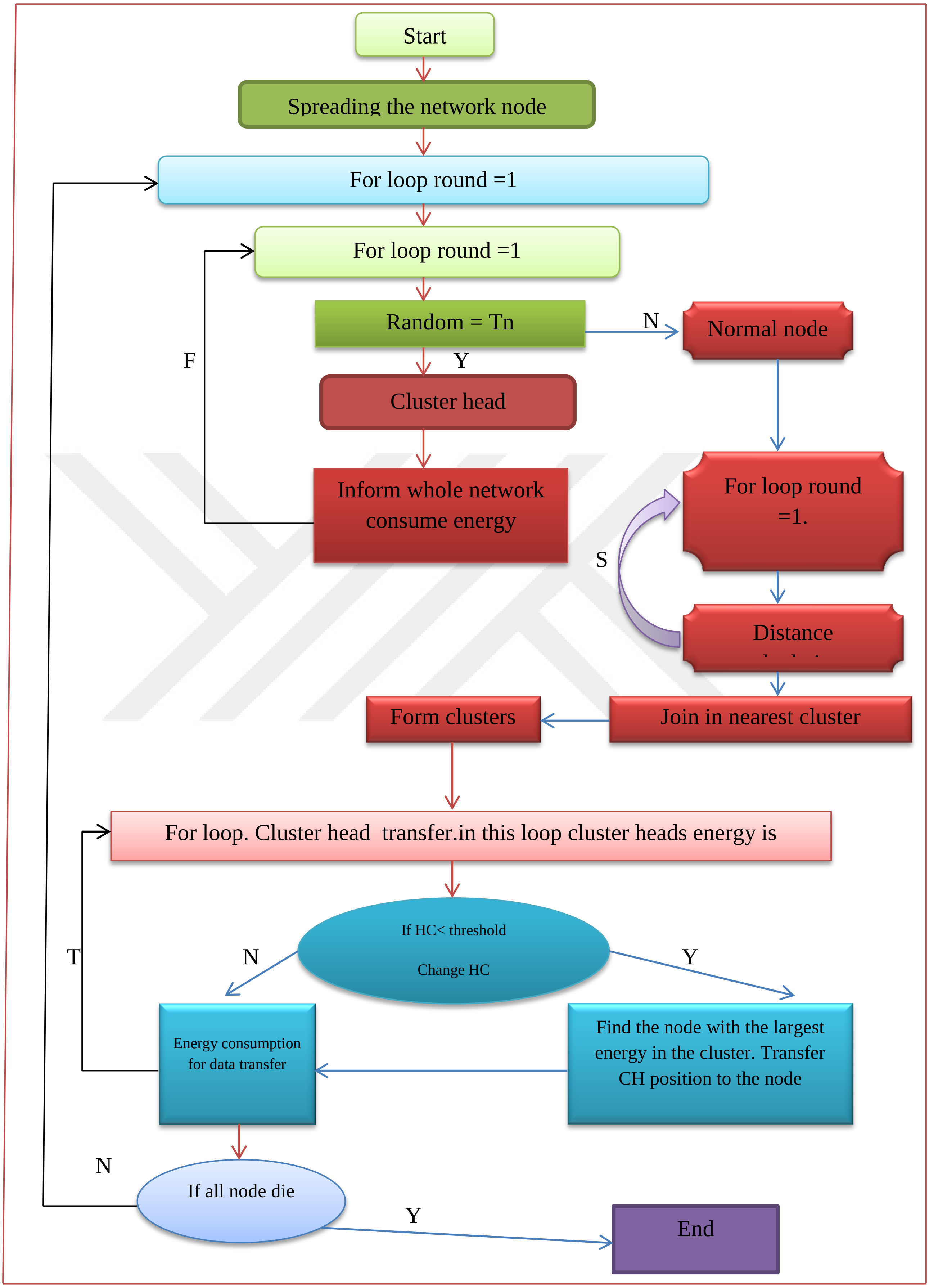


Figure 22. Working mechanism flowchart

In this figure, *n* represents the number of the nodes, *Tn* represents the threshold, *F* represents the first loop, *S* indicates the second loop and *T* indicates the third loop.

3.4.1 Advertisement

During the first loop (*F*), every node in the network is assigned an arbitrary number and compares it to the value of the threshold. This procedure is aimed at establishing cluster heads. Following this selection process, cluster heads advertise the messages to the whole network. This phase is the same as in the original LEACH protocol.

3.4.2. Cluster set-up

During the second loop (*S*), the clusters are formed. The algorithm is based on the estimation of the distance between cluster members and CHs. The cluster members decide to join certain clusters based on their distances to the cluster heads. The nodes join in the nearest cluster head to save energy for communication. This phase is also the same as in the original LEACH protocol.

3.4.3. Cluster head transfer

The third loop (*T*) is the additive stage. This stage is the new protection mechanism stage in the LEACH algorithm. During this loop, the suggested algorithm adopts a monitoring mechanism that is responsible for controlling the cluster head energy and a predefined threshold value. This monitoring approach aims to transfer the cluster heads according to the result of the comparison between cluster head energy and the value of the threshold. In the case where the energy of the cluster head is below a pre-defined threshold, the third loop is applied for the replacement of the cluster head with a different node. This keeps the cluster at maximum energy. This new cluster head continues cooperating with the other cluster members. This process protects CHs that have less energy from rapid death and increases network lifetime.

3.5.Network set-up for simulation

Two simulation networks were set up with different node distributions. The distribution of the first network was uniform, as is shown in Figure 23, where the nodes were spread uniformly. The other network was not uniformly distributed, as is shown in Figure 24, where the nodes were spread randomly. Some areas of this second network have more nodes while some areas have just a few nodes. Both networks deployed 150 wireless sensor devices within a 900 × 900 m square.

The purpose of the uniformly distributed network was to validate if the new algorithm could ensure a longer network lifetime in normal environments. The non-uniform network was set up because this kind of network gives a high probability of forming a cluster with a large population. Cluster heads can die quickly in large clusters; however, the proposed algorithm solves this problem. The algorithm must be evaluated on different kinds of network distributions to find all possible applications.

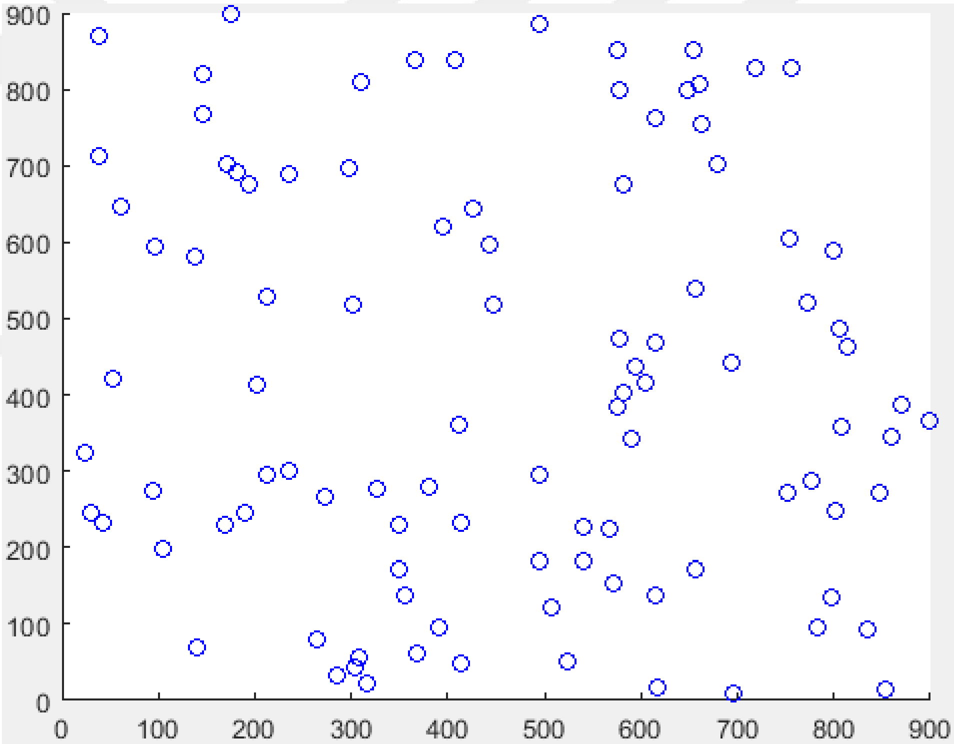


Figure 23. Uniform node distribution network

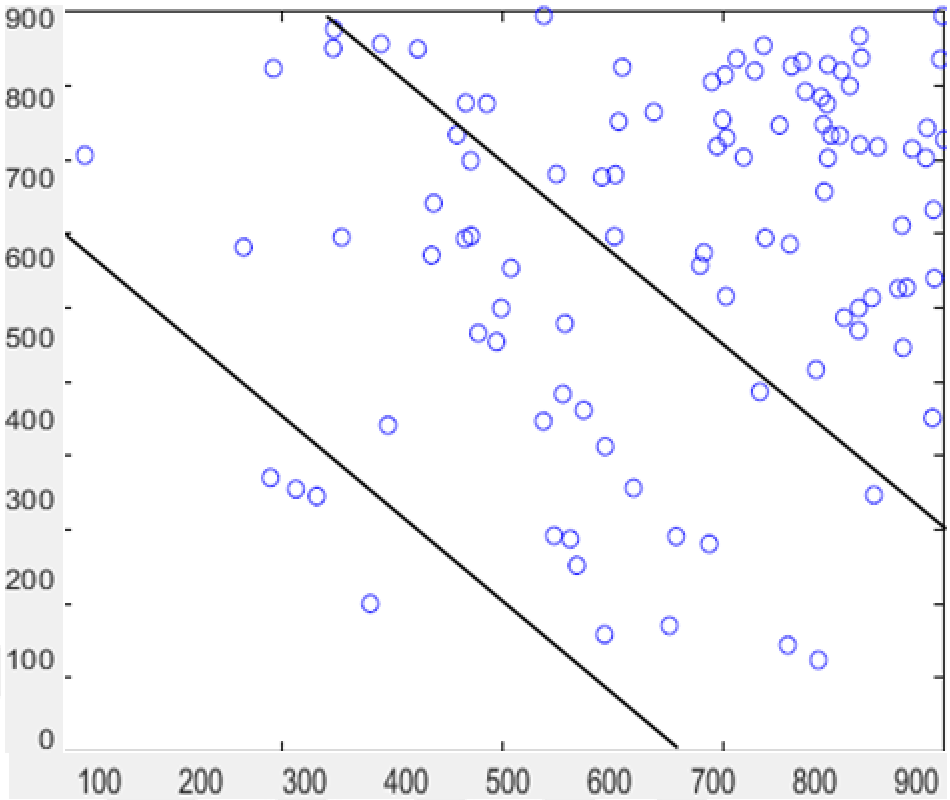


Figure 24. Non-uniform node distribution network

Nodes were distributed in the three parts with different populations using the Gaussian function.

3.6. Initial conditions

The initial network conditions for the simulation are laid out in Table 1 for proposed algorithm

Table 1: Simulation parameters for uniform node distribution

Symbol	Parameter	Unit	Quantity
S	Size of WSNs	m (meter)	900 × 900
N	Total number of nodes		150
P	Likelihood of being chosen to be a cluster head		0.1
Ini.E	Initial energy of each node	J (Joule)	0.5
TR.E	Transmit or receive energy for sensor devices	J (Joule)	5×10^{-2}
E_{fs}	free space transmit energy	J (Joule)	10^{-11}
E_{mp}	multi path transmit energy	J (Joule)	1.3×10^{-15}
PS	Data or control packets size	b (bit)	4,000

3.7. (IV-LEACH) MODIFICATION

WSNs include hundreds of thousands of low power multifunctional sensor nodes that operate in unattended environments with limited sensing and computational abilities. The sensor nodes are powered by small batteries that are usually irreplaceable and have limited power capacity. The use of WSNs is continually increasing, and their energy constrains due to limited battery lifetimes are an issue. A variety of methods have been investigated for the purpose of saving energy in WSNs.

As soon as the cluster heads have been selected, a WSN uses the CSMA MAC protocol for advertisement of its status. The remaining nodes make their CH decision in the current round according to the strength of the received signal of the advertisement message. An TDMA schedule is applied to all cluster group members for sending messages to the cluster head. The cluster head subsequently sends data to the BS. Once a CH has been chosen for a specific area, the steady-state phase begins. A flow-chart for this is shown in Figure 25.

As soon as clusters have been created and TDMA schedule has been fixed, the transmission of the data may start. This begins the steady-state phase. With the assumption that the nodes always include all data, the nodes will communicate throughout their allocated time of transmission to CH. This type of transmission utilises a minimum energy amount (the level of which was selected based on the received strength of CH advertisement). Then, the radios of the nodes are turned off until the allocated transmission time. As shown in Figure 25.

The proposed IV-LEACH protocol ensures that the chosen CHs are uniformly distributed throughout network. This protocol also ensures that the CHs will not be concentrated in a single area of a network. The efficiency of IV-LEACH has been fundamentally assessed according to the following metrics:

- Average throughput: which represents the average number of the packets that have been received at sink node.
- Average consumption of energy: sensor nodes are evaluated at identical intervals of time.
- Network life-time: The number of alive nodes at the end of all algorithm cycles.

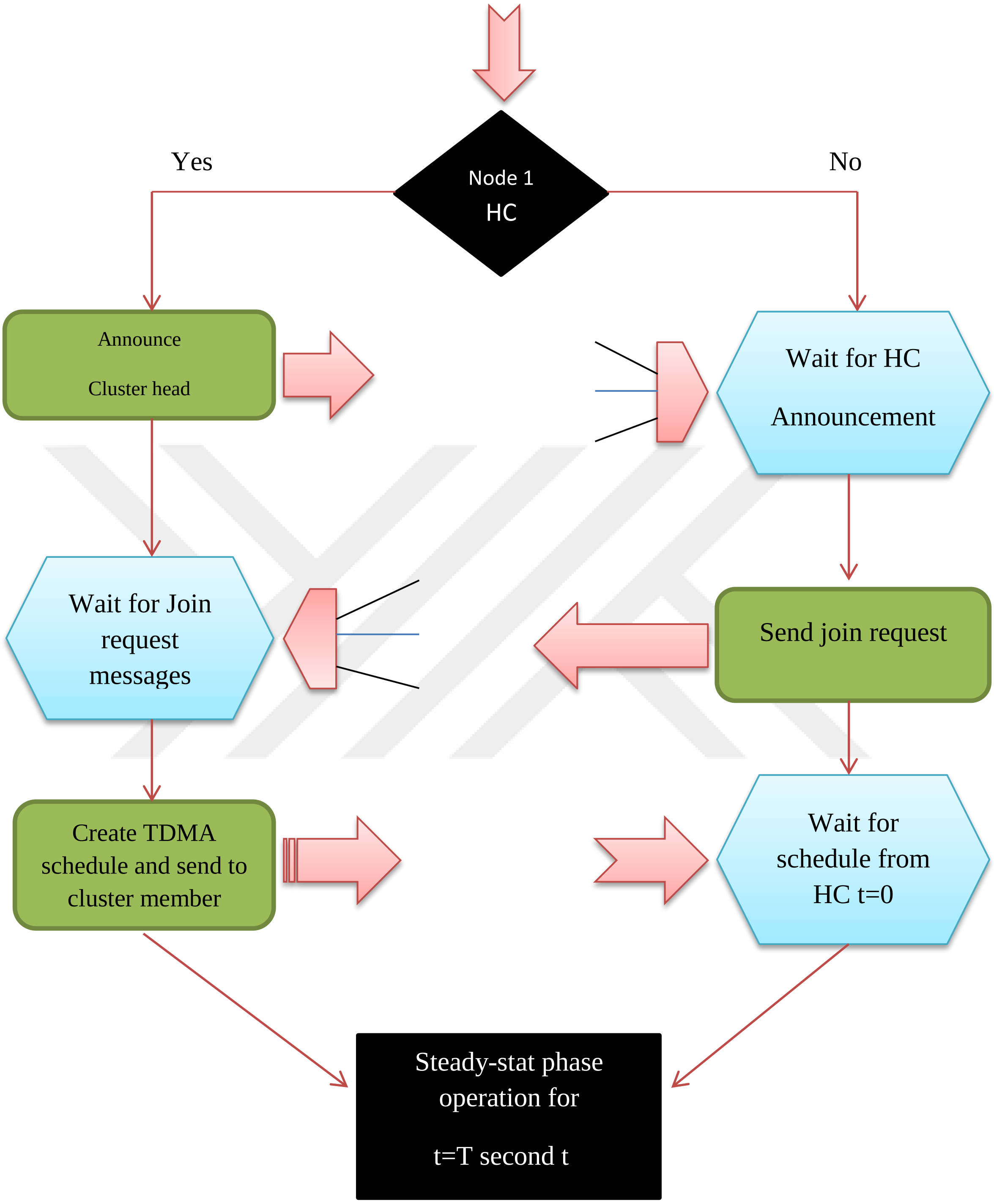


Figure 25. Diagram of setup phase in IV- LEACH protocol

CHAPTER FOUR
SIMULATION RESULTS

4.1. Overview

This chapter shows simulation results of the proposed IV-LEACH algorithm and compares it with the original LEACH algorithm.

4.2 Comparison between the LEACH and IV-LEACH Simulations

The efficiency of the IV-LEACH protocol is evaluated based on the period of network stability, network throughput, and network lifetime and energy dissipation. (The parameters are shown in Table2).

Table 2: Simulation parameters for the IV-LEACH protocol

Parameter	Value
Sensing area (W×L)	$900 \times 900\ m^2$
Number of nodes (N)	150
Initial energy of nodes (E_0)	0.5 j
Desired percentage of cluster heads	0.1 j
Position of BS	X = 450, Y = 450
Packet size for cluster head per round	6,400 bits
Max Number of simulated rounds	200
The energy of free space model amplifier	0.3400e−9j
Energy for transmitting and receiving one bit	50×10 ^ (−9) j
Amount of energy that is spent by the amplifier for transmitting bits	100x10 ^ (−12) j
Energy of data aggregation	5x10 ^ (−9) j

All nodes were simulated to be distributed randomly in a 900 × 900 m area, and the BS resides in the centre at the (450, 450) point, as is shown in Figure 26. This simulation was run for 1,300 rounds to observe the effectiveness of the IV-LEACH protocol.

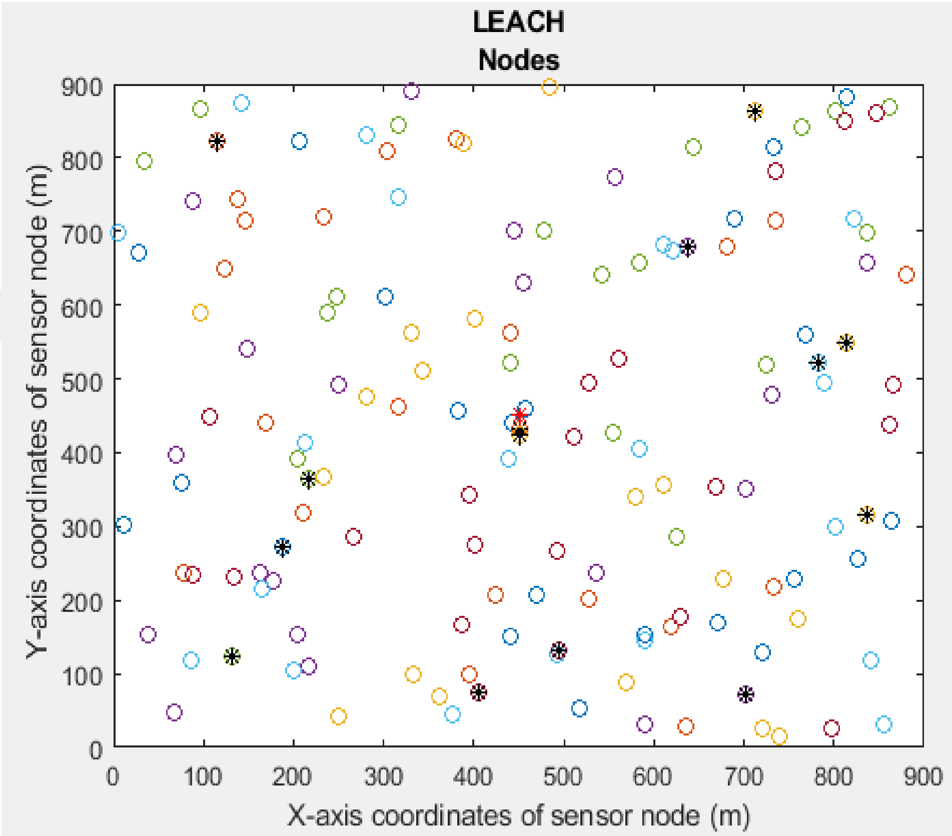


Figure 26. Node distribution in the WSN utilising the IV-LEACH protocol

4.2.1.Life-time of the Network

Network's lifetime represents the interval of time from the start of communication to the sensor node’s death. Following 1,300 rounds of the IV-LEACH protocol and 1,000 rounds of the LEACH protocol, 10 live nodes remained. This is demonstrated in Figure 27.

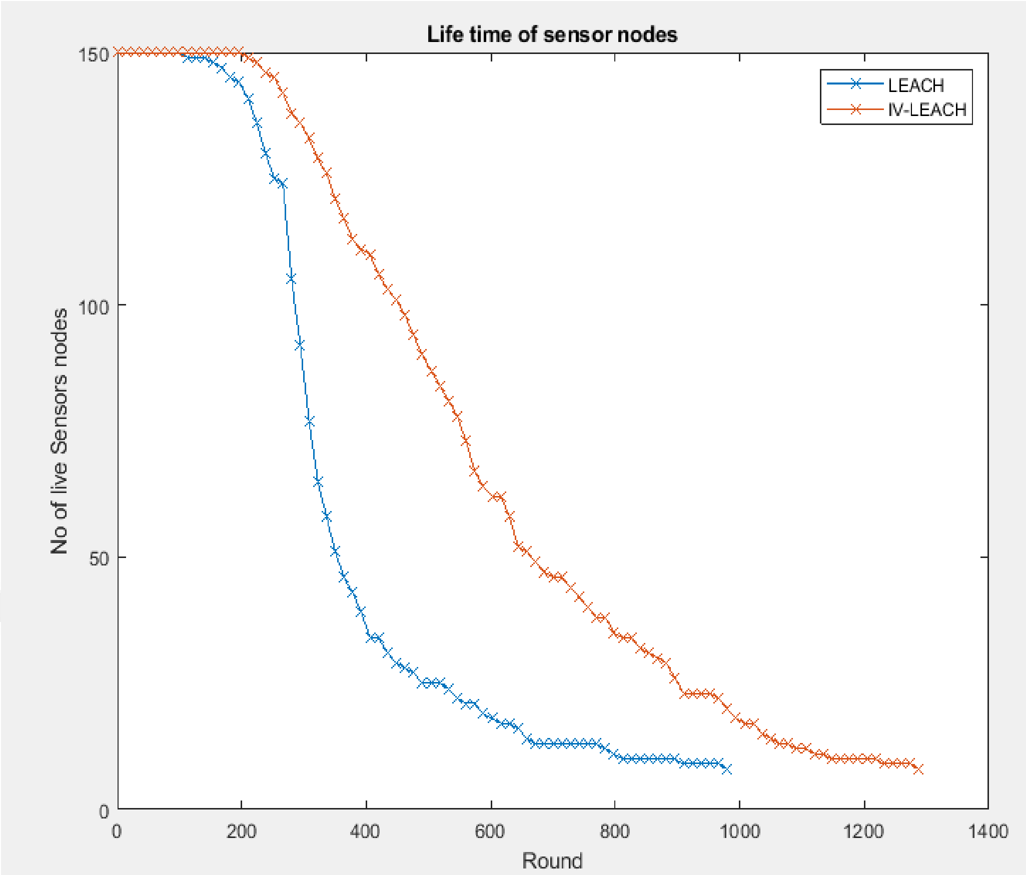


Figure 27. Lifetime of the sensor nodes

4.2.2. Energy

The performance of WSN improved drastically with the IV-LEACH protocol when compared with the traditional LEACH protocol. The average residual energy was 300 J after completing 950 rounds in the traditional protocol, while it was 300 J in round 1,400 for the IV-LEACH protocol. This is shown in Figure 28.

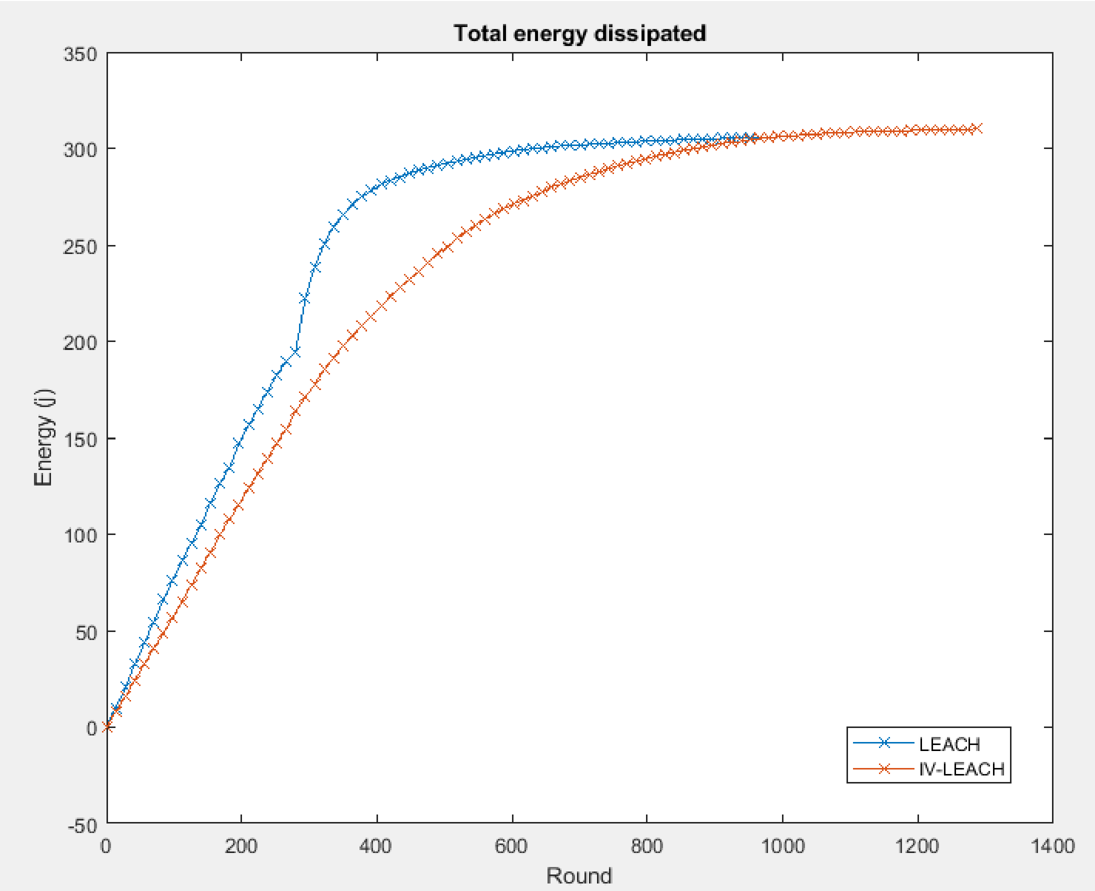


Figure 28. Total energy dissipation

4.2.3.Throughput of the Network

Simulation results have demonstrated the fact that the proposed IV-LEACH algorithm outperformed the original LEACH protocol concerning the throughput of the network, as is shown in Figure29. Under the LEACH protocol, the number of packets was 3.6×10^6 in round 1,000. Under the IV-LEACH protocol, however, the number of packets was 7×10^6 in round 1,300.

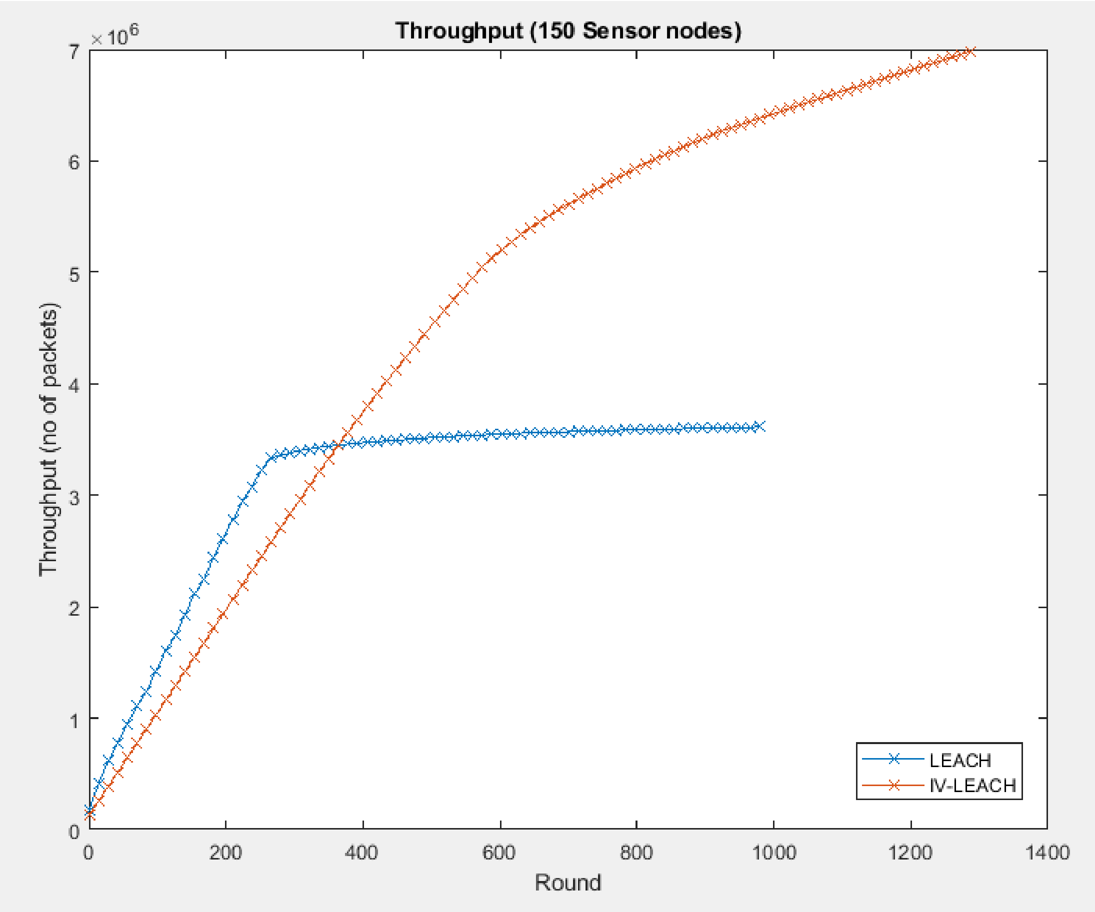


Figure 29. Throughput of the network

4.3.Correlation between the number of HCs and Network Lifetime

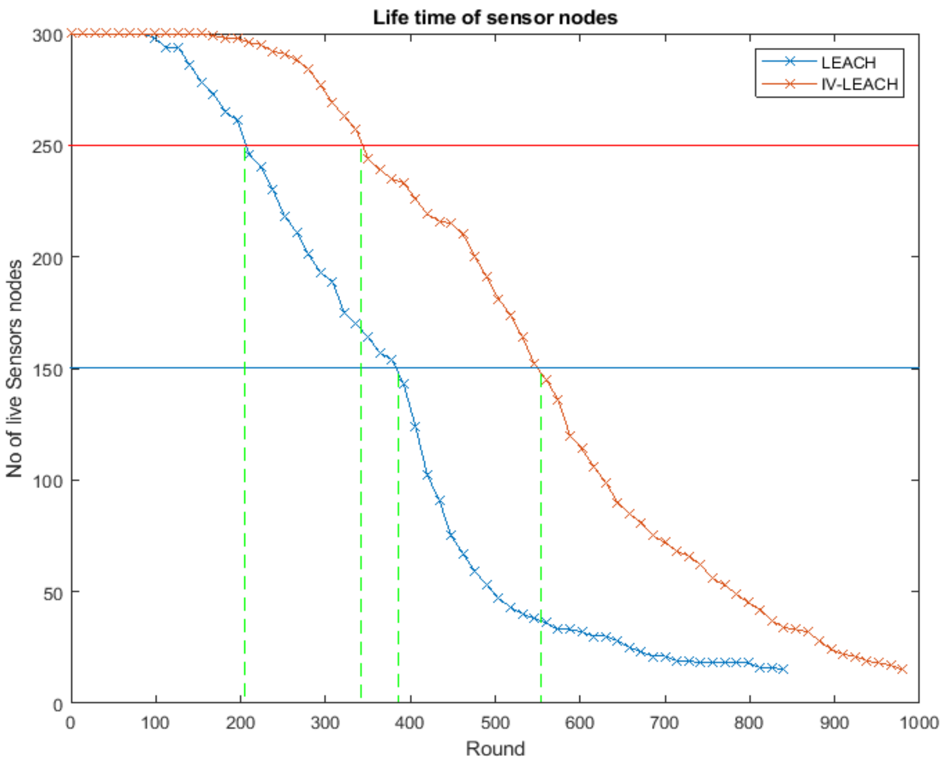
4.3.1 Scenarios

Five scenarios demonstrated the superiority of the IV-LEACH Protocol compared with the original LEACH protocol.

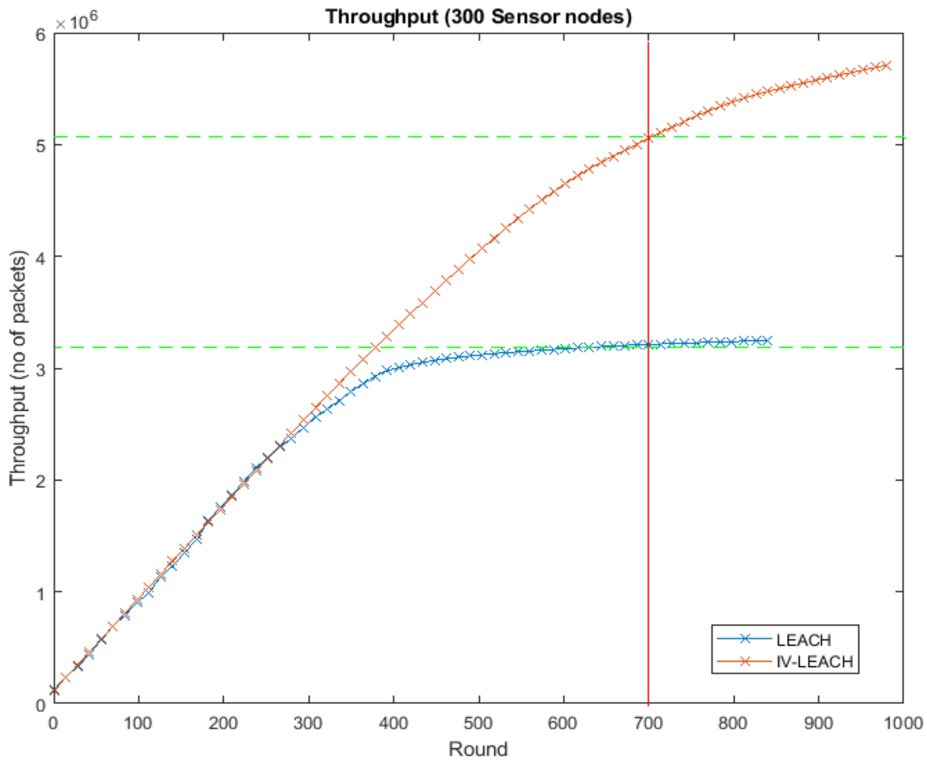
In total, 300 nodes were deployed in the network, under five different scenarios. The first scenario had ten HCs, the second had twenty HCs, the third had thirty HCs, the fourth had forty HCs and the fifth scenario had fifty HCs. These scenarios are shown in Table 3, along with the comparisons between both protocols based on network life-time and energy dissipation. When the network increases, number of head clusters will increase. However, it will be proven that if the network size increases, the quality of the improved protocol increases, and this means that it can be relied on in large networks

Table 3: The results of the comparison of the five scenarios

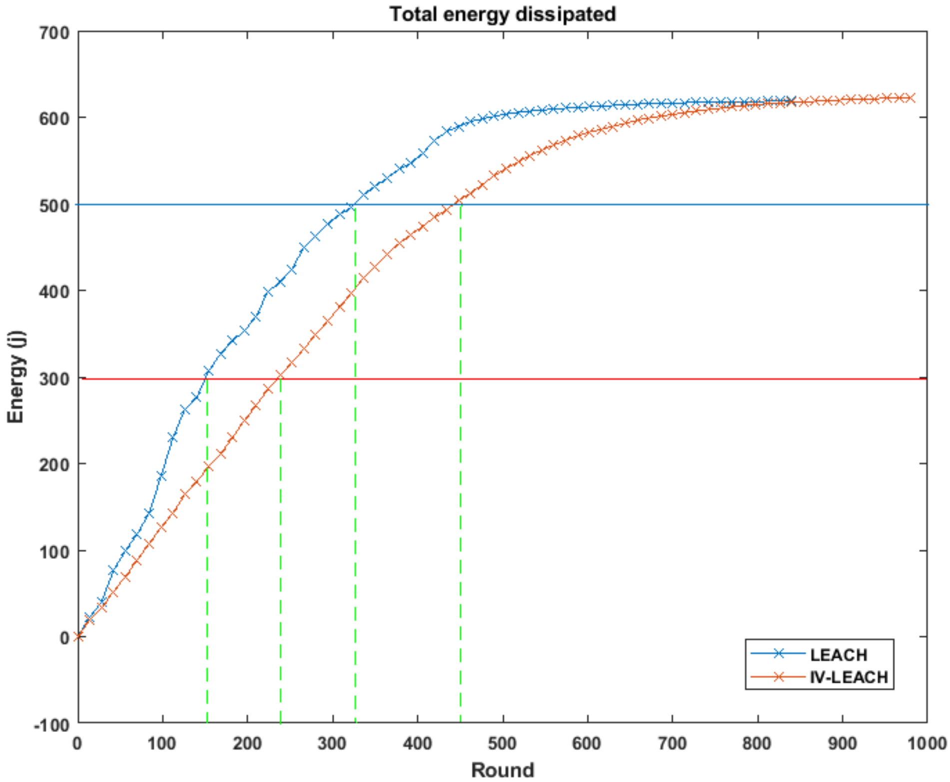
Scenario	Protocol	No of live node	Round	Energy (joule)	Round	No. of packet	Round	Figure
Scenario 1 For 10 HC	LEACH	250	250	500	330	3.2 x 10*6	700	Figure 29
	IV-LEACH		350		450	5.1 x 10*6		
	LEACH	150	480	300	150	3.4 x 10*6	800	
	IV-LEACH		550		240	5.45 x 10*6		
Scenario 2 For 20 HC	LEACH	200	400	550	440	5.8 x 10*6	1,000	Figure 30
	IV-LEACH		600		770	9.3 x 10*6		
	LEACH	100	490	450	410	5.9 x 10*6	1,090	
	IV-LEACH		890		560	9.7 x 10*6		
Scenario 3 For 30 HC	LEACH	175	450	550	530	7.8 x 10*6	1,500	Figure 31
	IV-LEACH		625		950	14.4 x 10*6		
	LEACH	125	480	450	410	7.89 x 10*6	1,700	
	IV-LEACH		900		600	15 x 10*6		
Scenario 4 For 40 HC	LEACH	200	350	550	410	0.74 x 10*7	1,000	Figure 32
	IV-LEACH		570		800	1.52 x 10*7		
	LEACH	100	410	450	350	0.75 x 10*7	1,100	
	IV-LEACH		770		520	1.59 x 10*7		
Scenario 5 For 50 HC	LEACH	200	255	550	400	0.7x10*7	1,000	Figure 33
	IV-LEACH		405		1000	1.68 x10*7		
	LEACH	100	350	450	300	0.72 x 10*7	1,200	
	IV-LEACH		910		500	1.89 x 10*7		


Life time of sensor nodes
LEACH
IV-LEACH
No of live Sensors nodes
Round
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
900
1000

(A)


Throughput (300 Sensor nodes)
×10^6
LEACH
IV-LEACH
Throughput (no of packets)
Round
6
5
4
3
2
1
0
0
100
200
300
400
500
600
700
800
900
1000

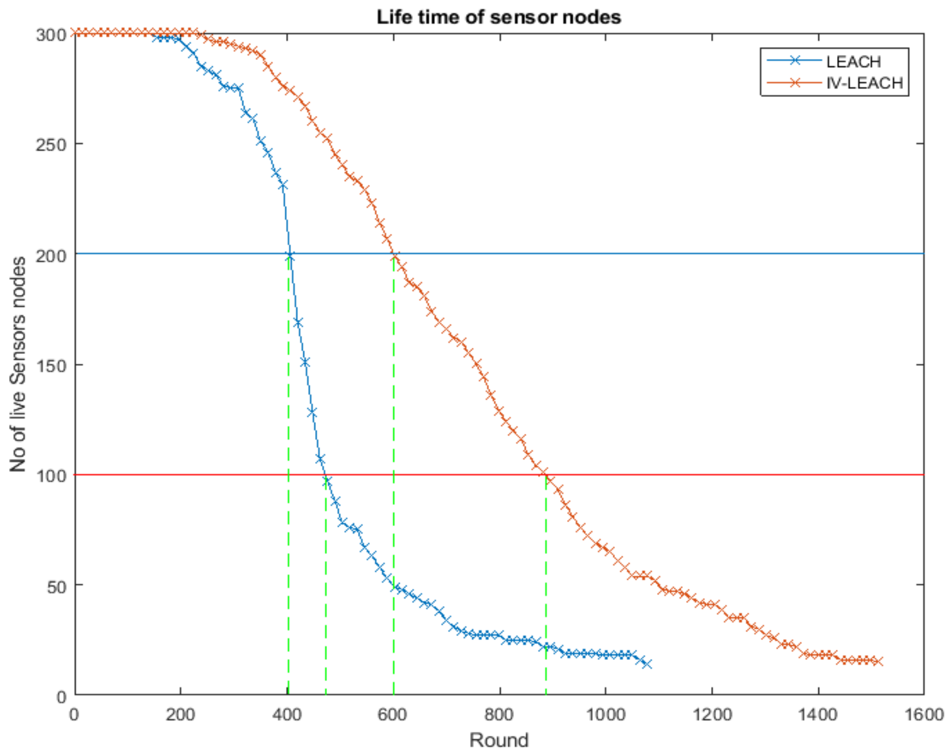
(B)



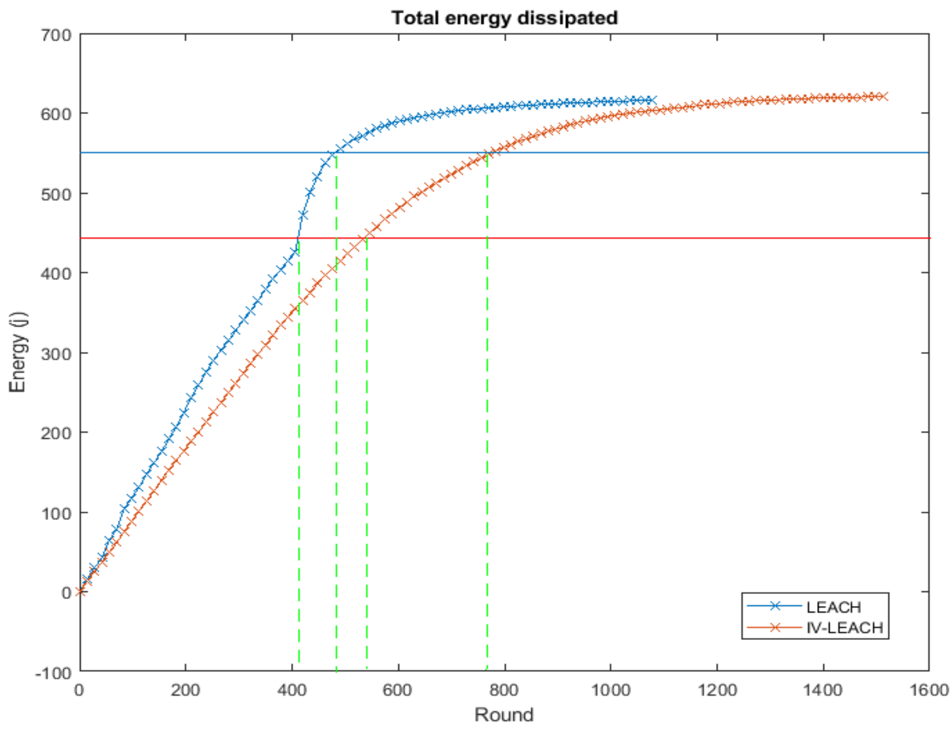
(C)

Figure30 .

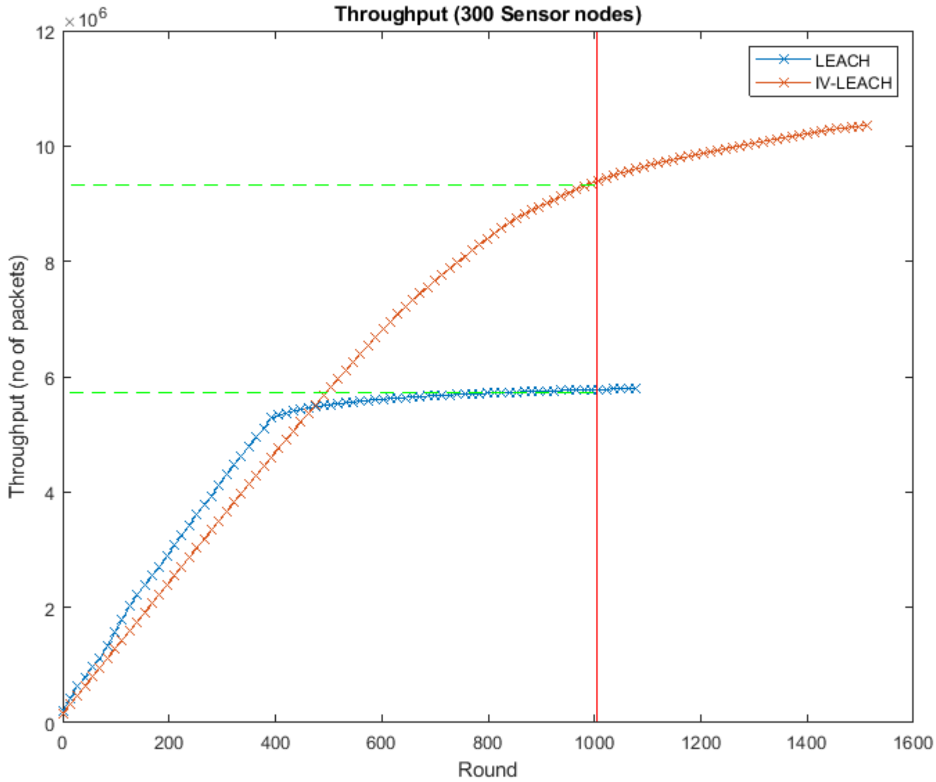
Scenario 1: (A) number of live nodes, (B) total energy that has been dissipated .and (C) throughput


Life time of sensor nodes
No of live Sensors nodes
Round
LEACH
IV-LEACH
0
50
100
150
200
250
300
0
200
400
600
800
1000
1200
1400
1600

(A)


Total energy dissipated
Energy (j)
Round
LEACH
IV-LEACH
-100
0
100
200
300
400
500
600
700
0
200
400
600
800
1000
1200
1400
1600

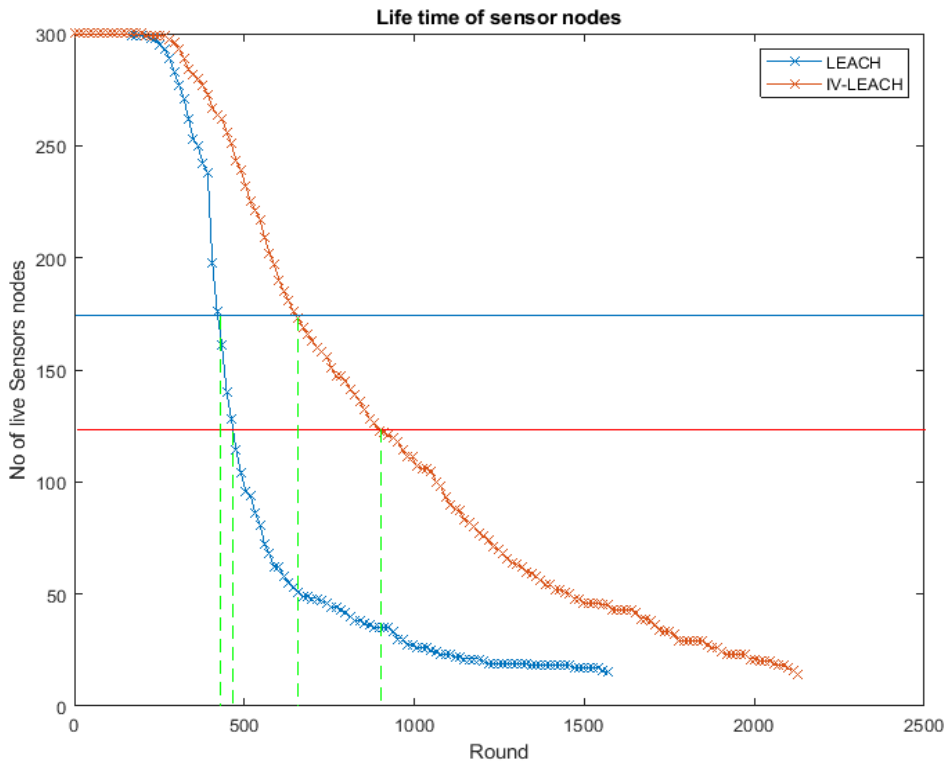
(B)



(C)

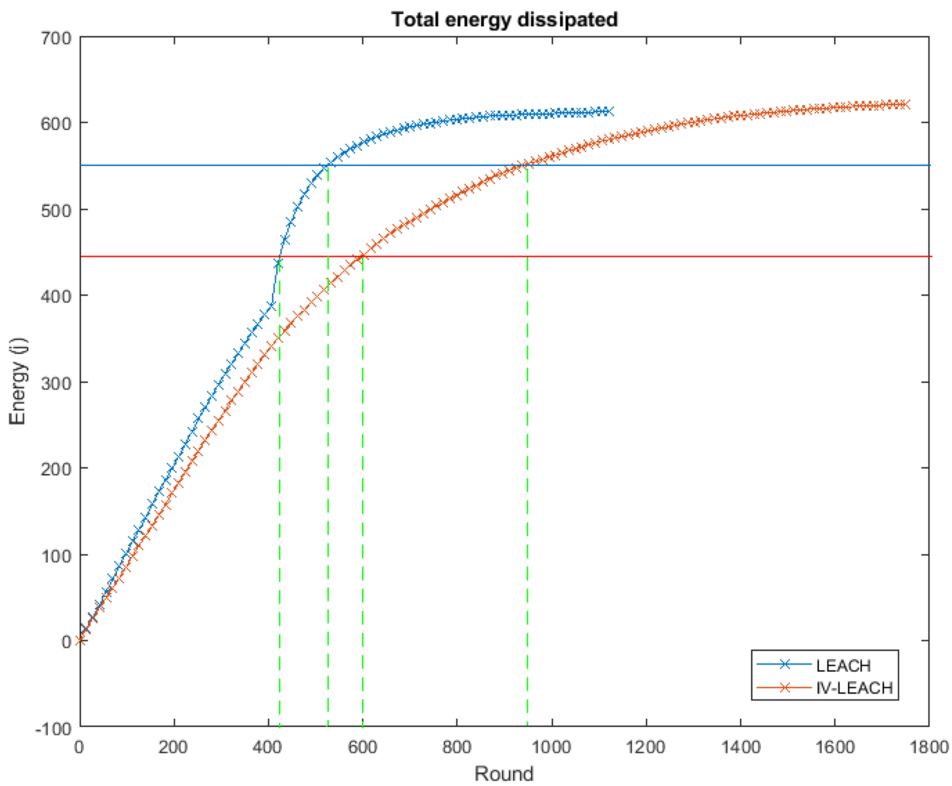
Figure 31 .

Scenario 2: (A) number of live nodes, (B) total energy that has been dissipated and .(C) throughput



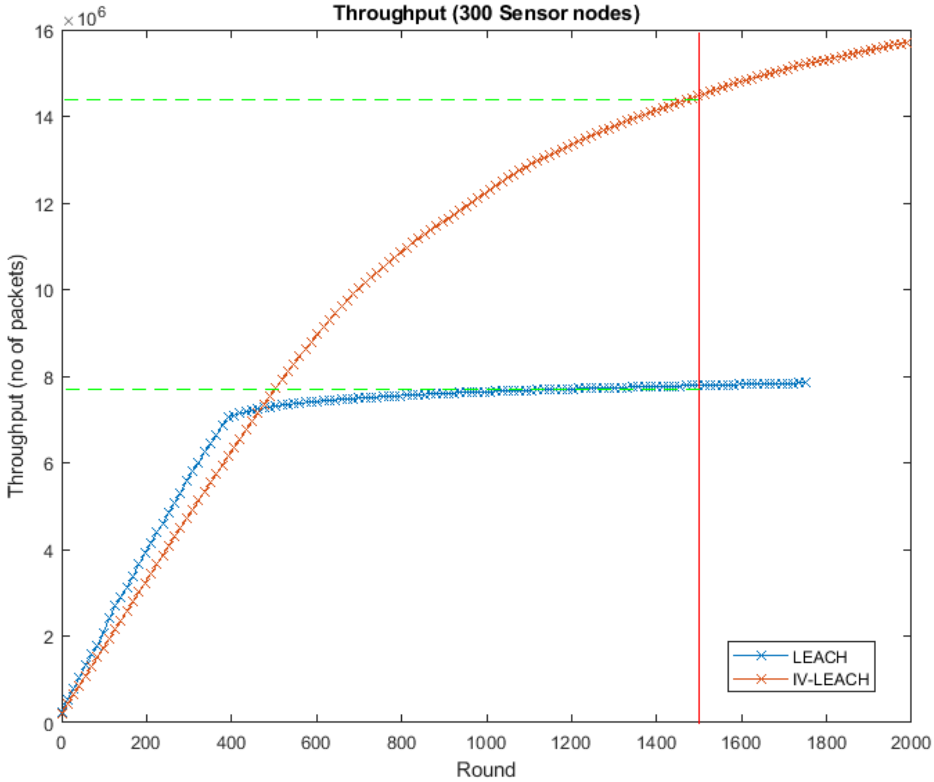
Life time of sensor nodes
LEACH
IV-LEACH
No of live Sensors nodes
Round
300
250
200
150
100
50
0
0
500
1000
1500
2000
2500

(A)



Total energy dissipated
LEACH
IV-LEACH
Energy (j)
Round
700
600
500
400
300
200
100
0
-100
0
200
400
600
800
1000
1200
1400
1600
1800

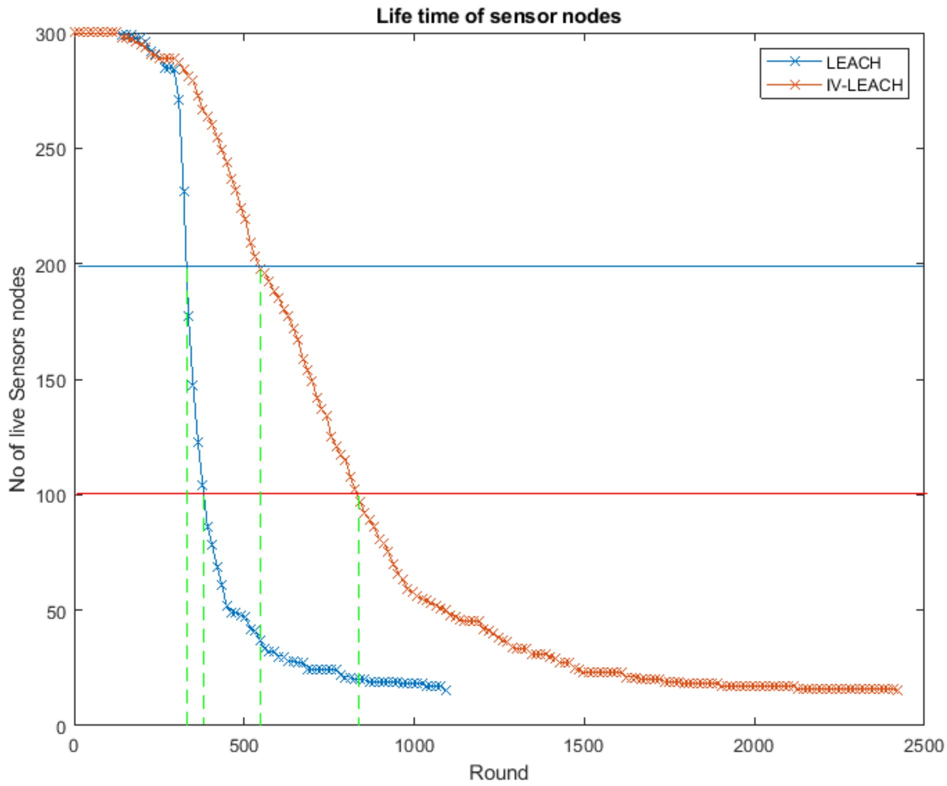
(B)



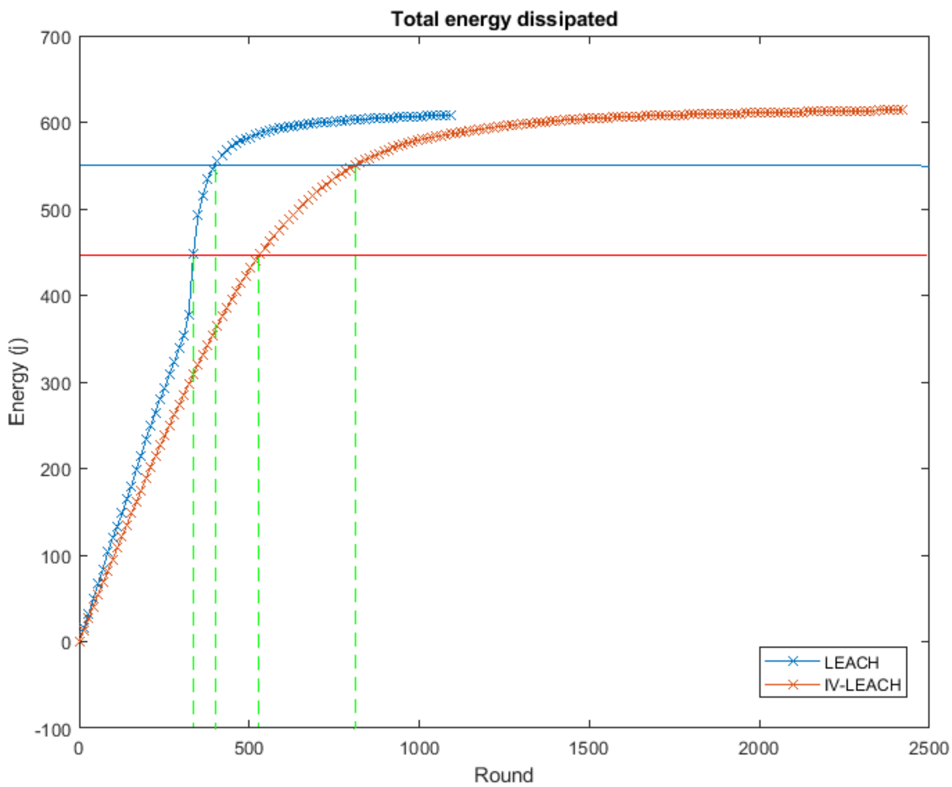
(C)

Figure 32 .

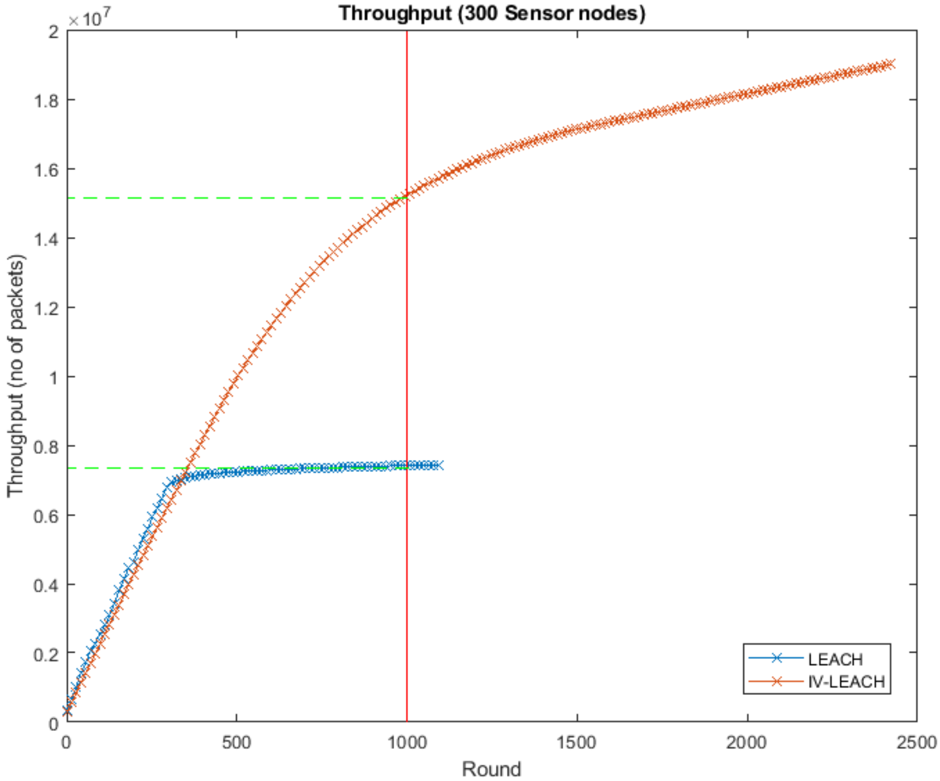
Scenario 3: (A) number of live nodes, (B) total energy that has been dissipated and .(C) throughput


Life time of sensor nodes
LEACH
IV-LEACH
No of live Sensors nodes
Round
300
250
200
150
100
50
0
0
500
1000
1500
2000
2500

(A)


Total energy dissipated
LEACH
IV-LEACH
Energy (j)
Round
700
600
500
400
300
200
100
0
-100
0
500
1000
1500
2000
2500

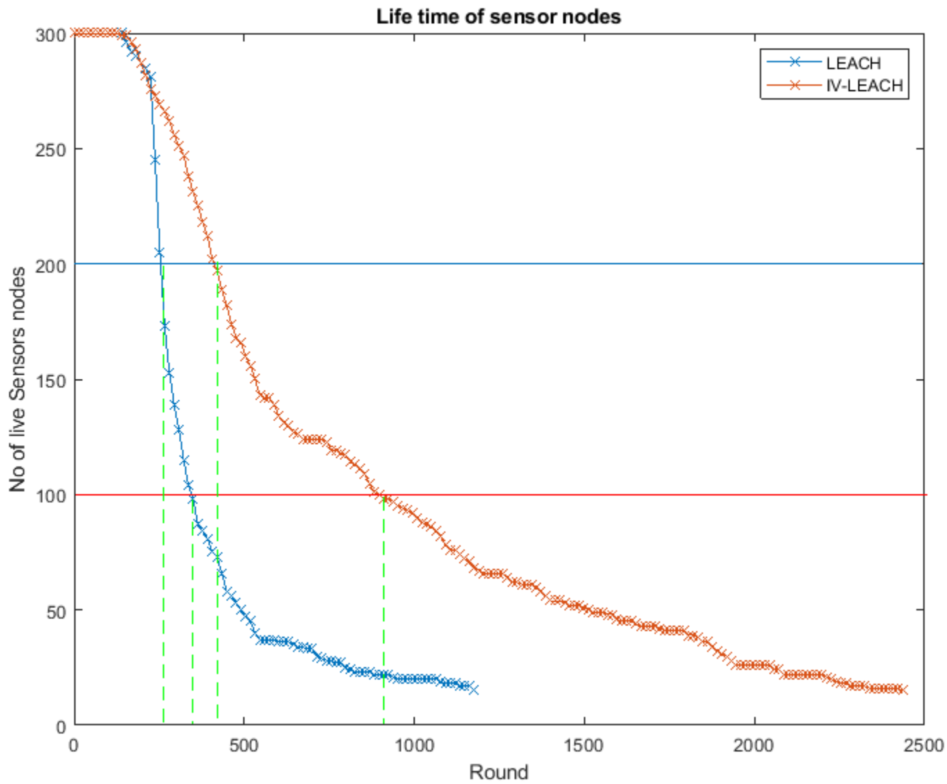
(B)



(C)

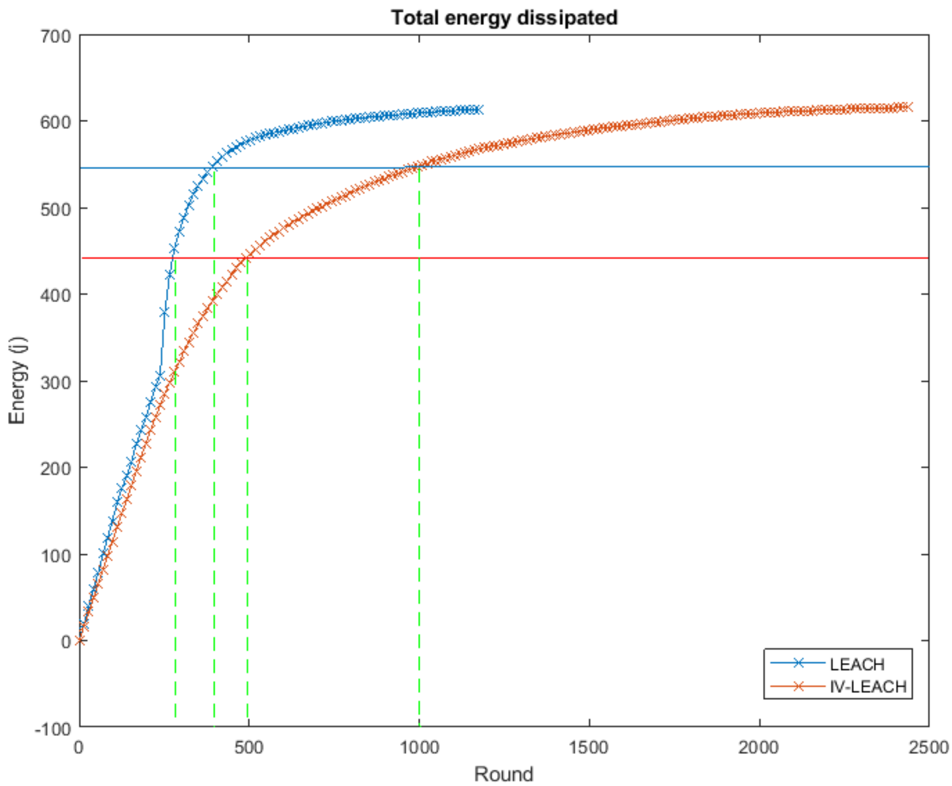
Figure 33.

Scenario 4: (A) number of live nodes (B) total energy that has been dissipated and .(C) throughput



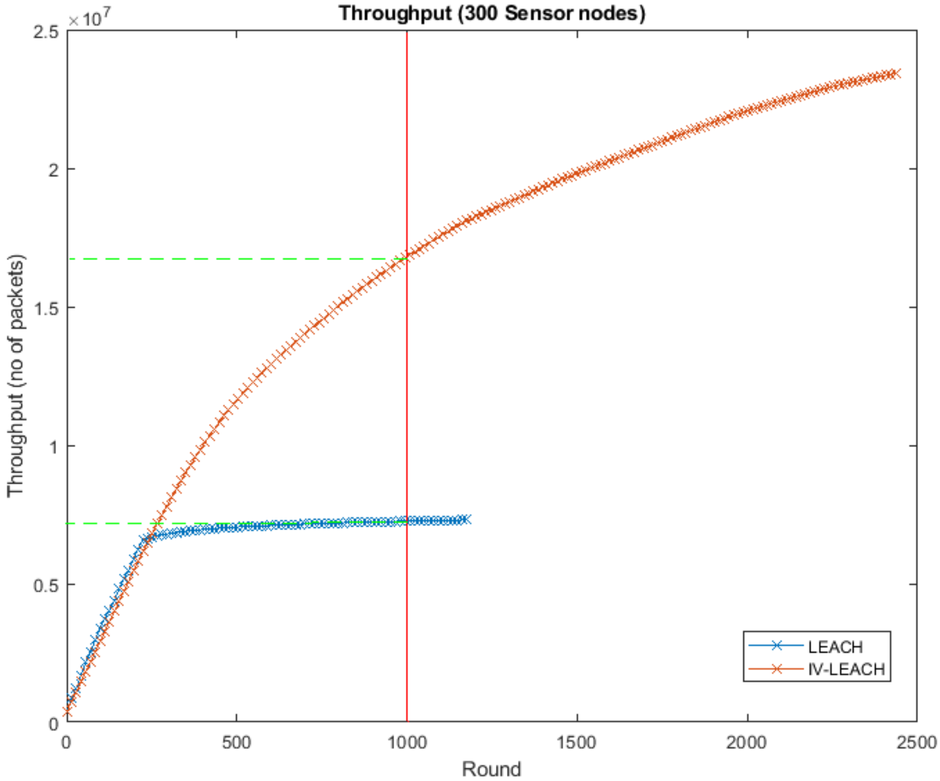
Life time of sensor nodes
LEACH
IV-LEACH
No of live Sensors nodes
Round
300
250
200
150
100
50
0
500
1000
1500
2000
2500

(A)



Total energy dissipated
LEACH
IV-LEACH
Energy (j)
Round
700
600
500
400
300
200
100
0
-100
500
1000
1500
2000
2500

(B)



(C)

Figure 34.

Scenario 5: (A) number of live nodes, (B) total energy that has been dissipated and .(C) throughput

4.4. Performance comparison of the algorithms in Dense Networks

This section discusses a comparison of the performances of the LEACH, TL-LEACH, E-LEACH and IV-LEACH algorithms in dense and sparse networks. In addition, the performances of protocols in terms of data that has been received at BS, the energy dissipated and the network lifetime are discussed.

All simulations were performed in a 900 × 900 m network with 150 nodes, and the nodes were both uniformly and randomly placed.

- Figure 35 demonstrates that the IV-LEACH protocol consumes lower energy when compared with the TL-LEACH, E-LEACH and original LEACH protocols.
- Figure 36 shows an improvement in network throughput with the IV-LEACH protocol when compared with TL-LEACH, E-LEACH and original LEACH protocols.
- In Figure 37, the performance of the IV-LEACH protocol in terms of network lifetime and average delay is compared with the TL-LEACH, E-LEACH and original LEACH protocols.

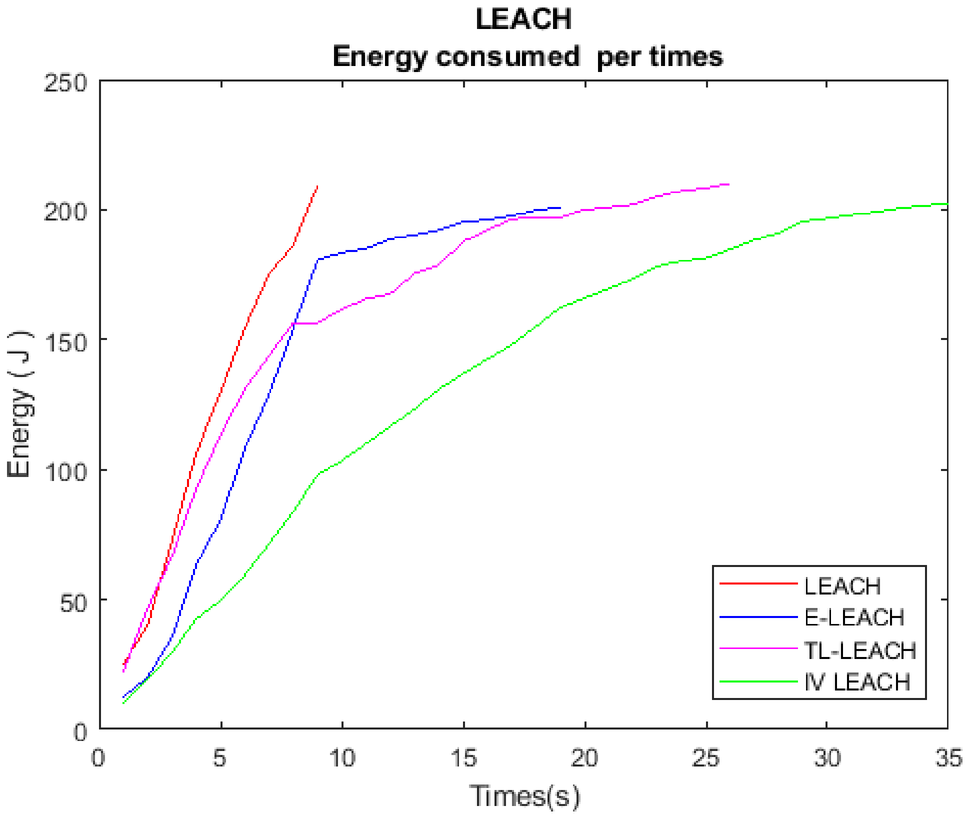


Figure 35. Energy consumption per time

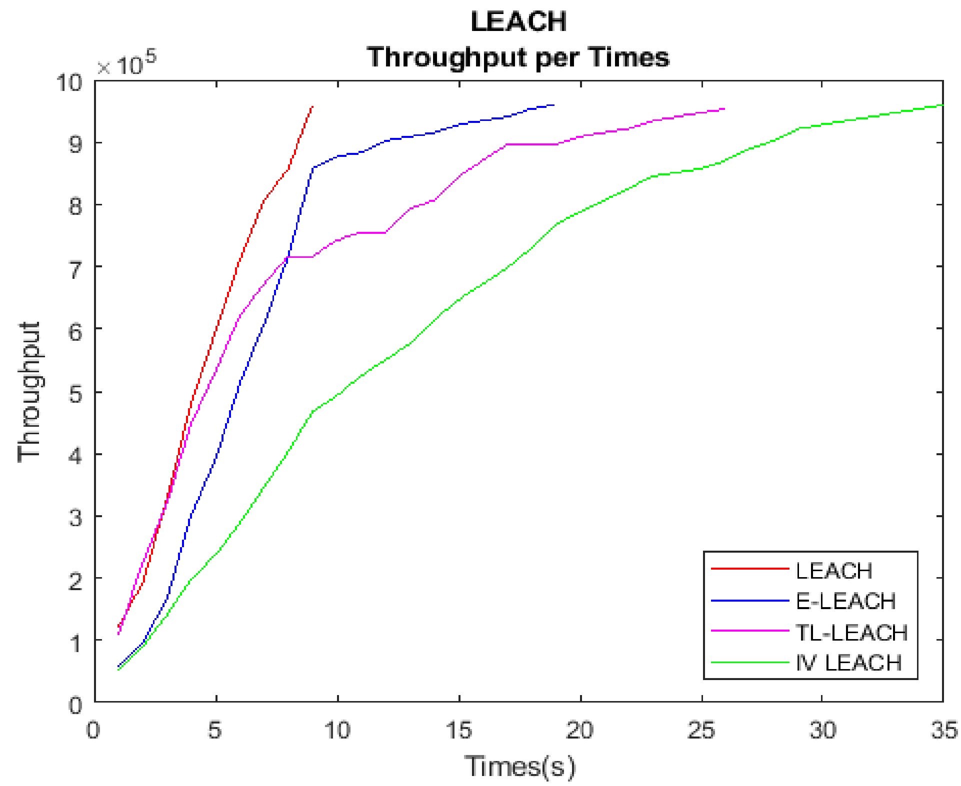


Figure 36 . Throughput per time

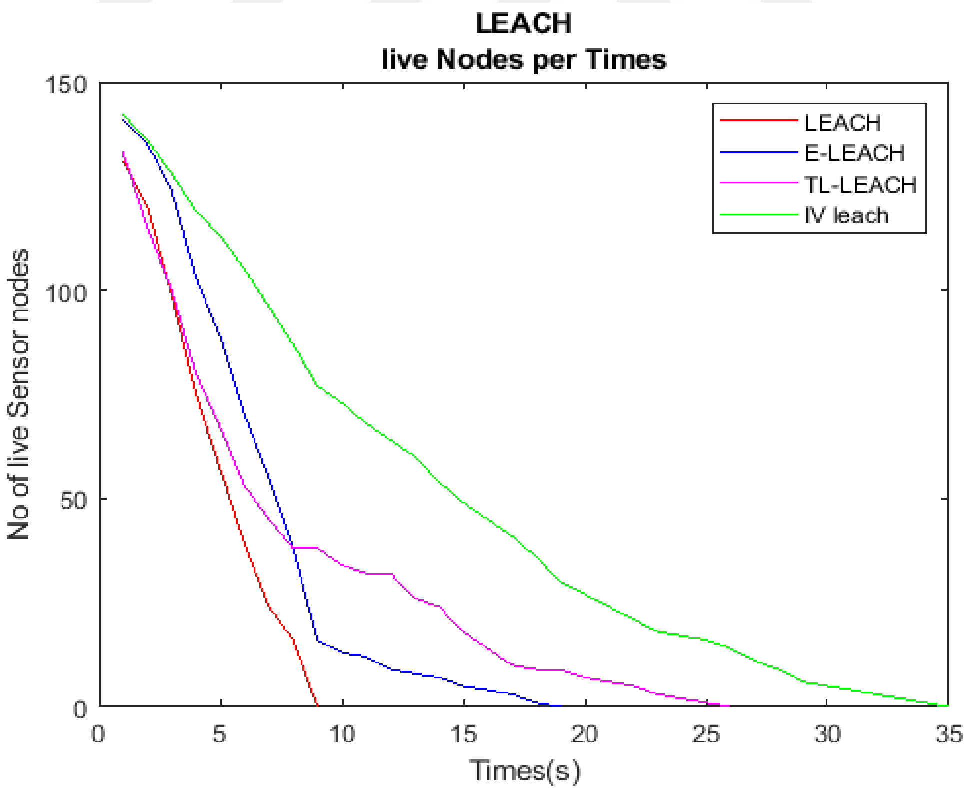


Figure 37. Number of live nodes per time

4.5. Period of Network Stability

The period of stability of the network has been represented by the 1st dead node (FDN): the number of rounds where the 1st sensor node's death occurs according to the time(s). The simulation results demonstrate that IV-LEACH protocol has higher stability compared with E-LEACH, TL-LEACH and original LEACH protocols.

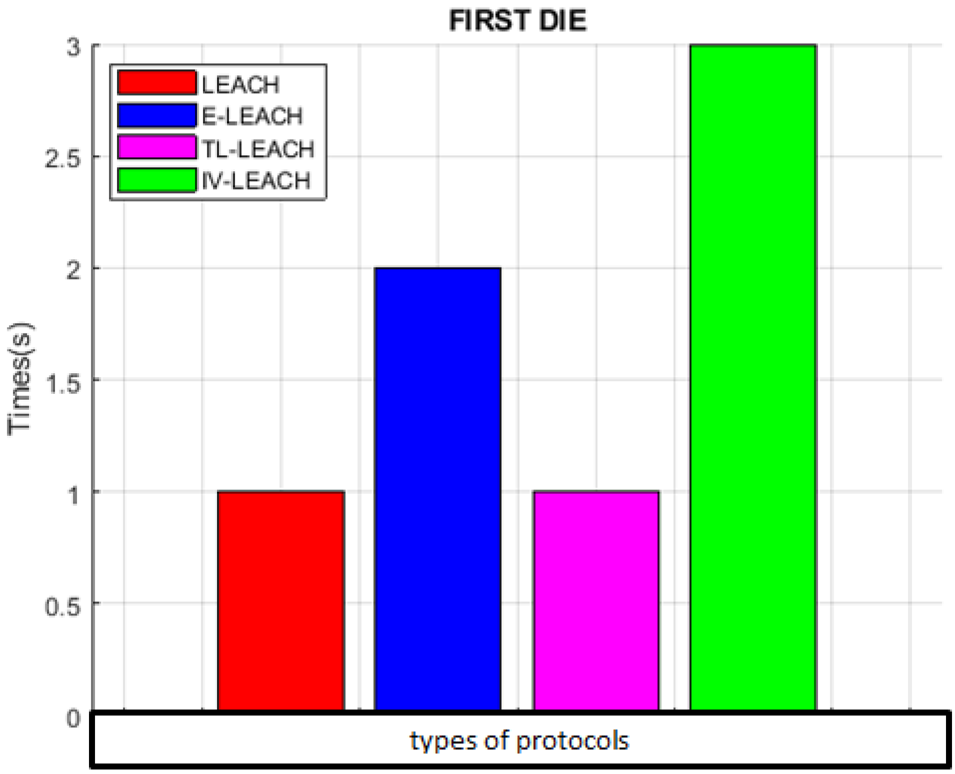


Figure 38. FDNs per time

As is shown in Figure 38, after several simulation runs, the FDN for the LEACH protocol and the TL-LEACH protocol occurs at one second. The FDN for the E-LEACH protocol occurs at two seconds, and the FDN for the IV-LEACH protocol occurs at three seconds.

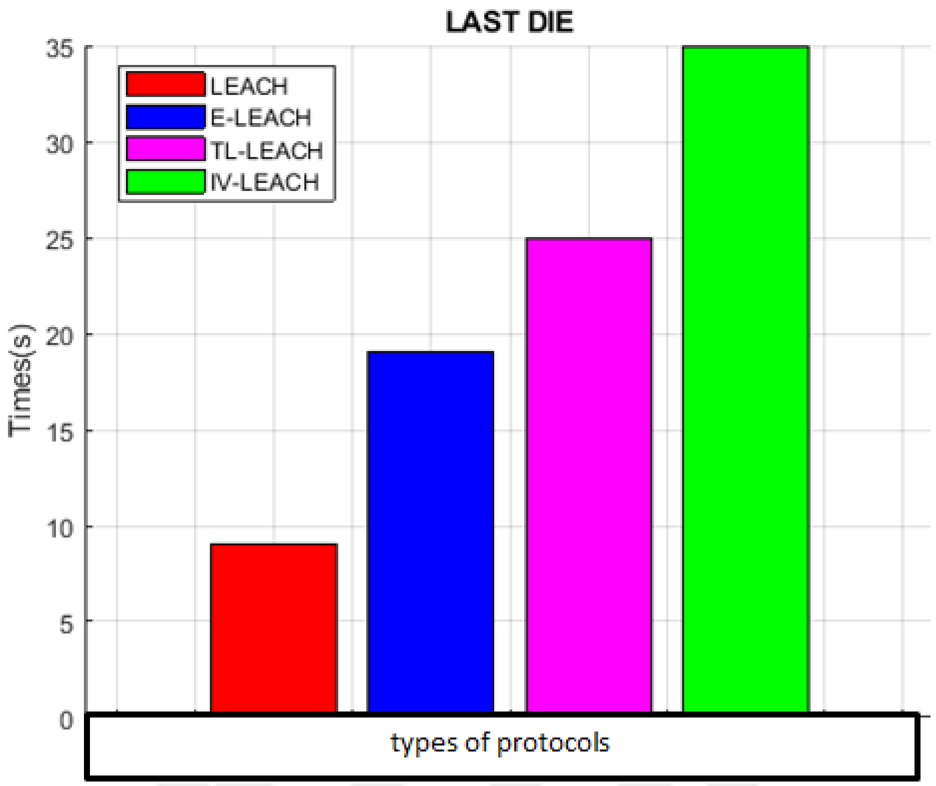


Figure 39. Last dead node per time

As is shown in Figure 39, the last dead node under the original LEACH protocol occurred at eight seconds. The last dead node under the E-LEACH protocol occurred at 18 seconds and under the TL-LEACH protocol 25 seconds. The last dead note under the IV- LEACH protocol did not occur until 35 seconds.

CONCLUSION AND FUTURE WORK

Conclusions

Saving energy in WSNs is an important issue. For the purpose of increasing the energy efficiency and extend the lifespan of sensor nodes, multiple energy-aware cluster-based techniques have been suggested. Cluster head selection is an essential subject in cluster formation that influences network lifetime and throughput. The IV-LEACH protocol suggested in this dissertation ensures evenly distributed cluster head selection across the network. The IV-LEACH protocol improves energy exhaustion by approximately 49% and productivity by approximately 50% in 150 nodes. Nodes permanently turn on sensors, sending data at a steady cyclic periods of time.

Improving the lifetime of WSNs was a recent research challenge. This is because The sensors are powered by a small, non-replaceable battery The IV-LEACH routing protocol has been suggested for extending the lifetime of sensor nodes by considering their residual energy and their distance from base station. This protocol has the potential to extend the network's lifespan. Nonetheless, the period of network stability is still considered short for many applications that require reliable network feedback. The IV-LEACH had been modified to improve the network's stability. This protocol gives nodes with higher residual energy and a shorter distance from the BS a larger chance of becoming cluster heads. The proposed study's simulation results have demonstrated that the proposed IV-LEACH protocol can overcome the limitations of the original LEACH protocol according to network energy, throughput and network life-time.

Future work

The increase in WSN stability and lifetime is still being investigated. When constraints such as battery power, computing power and storage are considered, adequate solutions are available. As an extension of this study, future work could include investigating how to make the IV-LEACH protocol more secure against attacks. This research has presented a concept that reflects the used data flow of WSNs as well as their application in the daily lives of robots. This includes their ability to make appropriate decisions and the ability to think and deal with events similarly to humans.

Future work could combine the Clustering Using Representatives (CURE) algorithm with an optimization algorithm to increase the quality of the clusters.

1. CURE could be used for centralised clustering in WSNs.

2. Utilising nature-roused calculations to create a virtual cluster made from high leftover vitality sensors and group heads.

3. Using computational frameworks and information lattices to share handling force, memory and information crosswise over multiple sensors with the goal of creating assets that can be used to run asset-expending assignments for high need reactions. Currently, itis difficult to keep running WSNs under the conventional assets of the remote sensor arranged bunch.

REFERENCES

A. Manjeshwar, D. P. Agrawal, "TEEN: a protocol for enhanced efficiency in wireless sensor networks", *in: Aerospace Conf. Proceding, vol. 3, 9-16, pp. 1125-30,* 2002.

Akkaya, K., & Younis, M. (2005). A survey on routing protocols for wireless sensor networks. *Ad hoc networks*, *3*(3), 325-349.

Al Rasyid, M. U. H., Mubtadai, N. R., & Abdulrokhim, J. (2019, September). Performance Analysis LEACH Based Genetic Algoritm In Wireless Sensor Network. In *2019 International Seminar on Application for Technology of Information and Communication (iSemantic)* (pp. 394-399). IEEE.

Al Sibahee, M. A., Lu, S., Masoud, M. Z., Hussien, Z. A., Hussain, M. A., & Abduljabbar, Z. A. (2016, April). LEACH-T: LEACH clustering protocol based on three layers. In *2016 International Conference on Network and Information Systems for Computers (ICNISC)* (pp. 36-40). IEEE.

Amiya Nayak , and Ivan Stojmenovic, *Wireless Sensor and Actuator Networks*, ch. 4,

Bari, A. (2005). *Relay nodes in wireless sensor networks: A survey*. A. Bari.

Bharti, A., Devi, C., & Bhatia, V. (2015, December). Enhanced energy efficient LEACH (EEE-LEACH) algorithm using MIMO for wireless sensor network. In *2015 IEEE International Conference on Computational Intelligence and Computing Research (ICCIC)* (pp. 1-4). IEEE.

Chen, C.; Yan, J.; Lu, N.; Wang, Y.; Yang, X.; Guan, X. Ubiquitous Monitoring for Industrial Cyber-Physical Systems over Relay Assisted Wireless Sensor Networks. IEEE Trans. Emerg. Top. Comput. 2015, 3, 352–362

Chen, Y., Shen, C., Zhang, K., Wang, H., & Gao, Q. (2018, January). Leach algorithm based on energy consumption equilibrium. In *2018 International Conference on Intelligent Transportation, Big Data & Smart City (ICITBS)* (pp. 677-680). IEEE.

Demirkol, I. S. (2008). Medium Access Layer Performance Issues in Wireless Sensor Networks. *ppt file from Bogazici University NetLab*.

Fan Xiangning, Song Yulin. “Improvement on LEACH Protocol of Wireless Sensor Network, *2007.*

G. Pottie and W. Kaiser, “Wireless integrated network sensors” ACM Communications, vol. 43, no. 5, pp. 51–58, May (2000).

Hagag, S., & El-Sayed, A. (2012). Enhanced TCP westwood congestion avoidance mechanism (TCP WestwoodNew). *International Journal of Computer Applications*, *45*(5), 21-29.

Heinzelman, W. R., Chandrakasan, A., & Balakrishnan, H. (2000, January). Energy-efficient communication protocol for wireless microsensor networks. In *Proceedings of the 33rd annual Hawaii international conference on system sciences* (pp. 10-pp). IEEE.

Hoang D.C., Kumar R., Panda S.K. Fuzzy C-means clustering protocol for wireless sensor networks; Proceedings of the 2010 IEEE International Symposium on Industrial Electronics (ISIE); Bari, Italy. 4–7 July 2010.

Hong, J., Kook, J., Lee, S., Kwon, D., & Yi, S. (2009). T-LEACH: The method of threshold-based cluster head replacement for wireless sensor networks. *Information Systems Frontiers*, *11*(5), 513.

K. Whitehouse, "The design of calamari: an ad-hoc localization system for sensor networks," Master Thesis, University of California, 2003.

Karl, H., & Willig, A. (2007). *Protocols and architectures for wireless sensor networks*. John Wiley & Sons.

Karn, P. (1990, September). MACA-a new channel access method for packet radio. In *ARRL/CRRL Amateur radio 9th computer networking conference* (Vol. 140, pp. 134-140).

Kulik, J., Heinzelman, W., & Balakrishnan, H. (2002). Negotiation-based protocols for disseminating information in wireless sensor networks. *Wireless networks*, *8*(2), 169-185.

Kumar, A., Shwe, H. Y., Wong, K. J., & Chong, P. H. J. (2017). Location-Based Routing Protocols for Wireless Sensor Networks: A Survey. Wireless Sensor Network, 9, 25-72.

Lee J.-S., Kao T.-Y. An improved three-layer low-energy adaptive clustering hierarchy for wireless sensor networks. *IEEE Internet Things J.* 2016;**3**:951–958.

Li, X., Xu, L., Wang, H., Song, J., & Yang, S. X. (2010). A differential evolution-based routing algorithm for environmental monitoring wireless sensor networks. *Sensors*, *10*(6), 5425-5442.

Loscri, V., Morabito, G., & Marano, S. (2005, September). A two-levels hierarchy for low-energy adaptive clustering hierarchy (TL-LEACH). In *IEEE vehicular technology conference* (Vol. 62, No. 3, p. 1809). IEEE; 1999.

Manjeshwar, A., & Agrawal, D. P. (2001, April). TEEN: ARouting Protocol for Enhanced Efficiency in Wireless Sensor Networks. In *ipdps* (Vol. 1, No. 2001, p. 189).

Messaoudi, A., Elkamel, R., Helali, A., & Bouallègue, R. (2017). Cross-layer based routing protocol for Wireless Sensor Networks using a fuzzy logic module. *2017 13th International Wireless Communications and Mobile Computing Conference (IWCMC)*, 764-769.

Manzoor, K., Jokhio, S. H., Khanzada, T. J., & Jokhio, I. A. (2019, May). Enhanced TL-LEACH routing protocol for large-scale WSN applications. In *2019 Cybersecurity and Cyberforensics Conference (CCC)* (pp. 35-39). IEEE.

Mittal, N., Singh, U., & Sohi, B. S. (2019). An energy-aware cluster-based stable protocol for wireless sensor networks. *Neural Computing and Applications*, *31*(11), 7269-7286.

Mohammad Ilyas and Imad Mahgoub.“Handbook of sensor networks: compact wireless and wired sensing systems”, *Book, Chapter 1 & 6 CRC Press*, 2005.

Patel, H. B., & Jinwala, D. C. (2014). *E-LEACH: Improving the LEACH protocol for privacy preservation in secure data aggregation in Wireless Sensor Networks. 2014 9th International Conference on Industrial and Information Systems (ICIIS).* doi:10.1109/iciinfs.2014.7036607

Qiang, T., Bingwen, W., & Zhicheng, D. (2009, May). MS-Leach: a routing protocol combining multi-hop transmissions and single-hop transmissions. In *2009 Pacific-Asia Conference on Circuits, Communications and Systems* (pp. 107-110). IEEE.

Rahmadhani, M. A., Yovita, L. V., & Mayasari, R. (2018, July). Energy consumption and packet loss analysis of LEACH routing protocol on WSN over DTN. In *2018 4th International Conference on Wireless and Telematics (ICWT)* (pp. 1-5). IEEE.

Regmi, R., Prasad, P. W. C., Alsadoon, A., Elchouemi, A., & Sreedharan, S. (2017, September). Modified LEACH algorithm for wireless sensor networks in agricultural field. In *2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI)* (pp. 3100-3104). IEEE.

S. Fengjun and L. Yang, "An Energy-Balanced Clustering Routing Algorithm for Wireless Sensor Network," Scientific Research Journal, vol. 2, no. 10, pp. 777-783, 2010.

S. Lindsey and C. Raghavendra, "PEGASIS: Power-Efficient Gathering in Sensor Information Systems," *IEEE*

Sarma, H. K. D., Rai, P., & Deka, B. (2014, May). Energy efficient communication protocol for wireless sensor networks with mobile node. In *International Conference on Recent Advances and Innovations in Engineering (ICRAIE-2014)* (pp. 1-6). IEEE.

Singh, S., & Raghavendra, C. S. (1998). PAMAS—power aware multi-access protocol with signalling for ad hoc networks. *ACM SIGCOMM Computer Communication Review*, *28*(3), 5-26.

Stallings, W. (2004). *Computer networking with Internet protocols and technology*. Upper Saddle River, NJ, USA: Pearson/Prentice Hall.

Sujee, R., & Kannammal, K. E. (2017, January). Energy efficient adaptive clustering protocol based on genetic algorithm and genetic algorithm inter cluster communication for wireless sensor networks. In *2017 International Conference on Computer Communication and Informatics (ICCCI)* (pp. 1-6). IEEE.

Loscri, V., Morabito, G., & Marano, S. (2005, September). A two-levels hierarchy for low-energy adaptive clustering hierarchy (TL-LEACH). In *IEEE vehicular technology conference* (Vol. 62, No. 3, p. 1809). IEEE; 1999.

Liu, X. (2015). Atypical hierarchical routing protocols for wireless sensor networks: A review. *IEEE Sensors Journal*, *15*(10), 5372-5383.

Wang, B. (2011). Coverage problems in sensor networks: A survey. *ACM Computing Surveys (CSUR)*, *43*(4), 1-53.

Xiangning, F., & Yulin, S. (2007, October). Improvement on LEACH protocol of wireless sensor network. In *2007 international conference on sensor technologies and applications (SENSORCOMM 2007)* (pp. 260-264). IEEE.

Yang, T., Guo, Y., Dong, J., & Xia, M. (2018, September). Wireless Routing Clustering Protocol Based on Improved LEACH Algorithm. In *2018 IEEE*

International Conference on RFID Technology & Application (RFID-TA) (pp. 1-6). IEEE.

Yassein, M. B., Khamayseh, Y., & Mardini, W. (2009, June). Improvement on LEACH protocol of wireless sensor network (VLEACH. In *Int. J. Digit. Content Technol. Appl. 2009*.

Younis, O., & Fahmy, S. (2004). HEED: a hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks. *IEEE Transactions on mobile computing*, *3*(4), 366-379.

Zhao, Z. N., Wang, J., & Guo, H. W. (2018). A hierarchical adaptive routing algorithm of wireless sensor network based on software-defined network. *International Journal of Distributed Sensor Networks*, *14*(8),