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INSTITUTE OF GRADUATE STUDIES

Department of Electrical-Electronic Engineering

OPTIMIZATION OF HEAD CLUSTER SELECTION IN WSN BY HUMAN-BASED OPTIMIZATION TECHNIQUES

Master Thesis

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Istanbul – 2021

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Kablosuz sensör ağları, fiziksel veya kimyasal olaylarla ilgili verileri toplama ve bunları kablosuz kanallar aracılığıyla özel işlem merkezlerine aktarma yetenekleriyle ayırt edilir. Veri aktarımındaki tüm yönlendirme protokolleri, veri alışverişi işlemleri yoluyla enerji harcamasının ana kaynağını temsil ettikleri için büyük enerji tüketicileridir. Küme tabanlı yönlendirme protokolleri, yavaş güç tüketimi için en iyi akımlar arasındadır. En yaygın küme tabanlı hiyerarşik protokoller, iyi performansları ile bilinen Düşük Enerjili Uyarlanabilir Küme Başlığı'dır (LEACH). LEACH, büyük güç kaybıyla sonuçlanan sözde rasgele küme kafası seçiminin ana probleminden muzdariptir. Bu kritik soruna bir çözüm bulmak için, yönlendirme sürecinde güç tüketimini azaltmak ve böylece ağın ömrünü uzatmak için kablosuz bir sensör ağında bir optimizasyon algoritması kullanılır. LEACH'teki iyileştirilmiş küme kafası seçimi, tüm sensörler arasındaki güç dağılımını dengeleyerek ve daha iyi bir kümeleme

haritası sağlayarak sensör yaşam döngüsü üzerinde doğrudan olumlu bir etkiye sahiptir.

Son zamanlarda ortaya çıkan insan tabanlı optimizasyon algoritmalarından biri Coronavirus Sürü Bağışıklığı İyileştiricisi (CHIO) olarak adlandırılıyor. Bu yeni algoritma, koronavirüsün mevcut yayılımıyla bağlantılı. Algoritma, sosyal uzaklık ve sürü bağışıklığı olmak üzere iki temel kavramı kapsayarak insanların büyük çoğunluğunu pandemiden korumayı amaçlamaktadır. LEACH'te grup başı seçimini iyileştirmek için önerilen protokol, 20 ila 100 arasında değişen değişken sayıda düğümden oluşan çeşitli kablosuz sensör ağı senaryolarının simüle edilmesiyle uygulanmış ve doğrulanmıştır. Değerlendirme göstergeleri olarak üç gösterge incelenmiştir, yani güç tüketimi, canlı düğüm sayısı ve alınan paket sayısı. Simülasyon sonuçları, önerilen algoritmanın yüksek performansını göstermiştir ve bu nedenle LEACH protokolünden daha iyi performans göstermiştir.

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DECLARATION

I hereby declare that in the preparation of this thesis, scientific ethical rules have been followed, the works of other persons have been referenced in accordance with the scientific norms if used, there is no falsification in the used data, any part of the thesis has not been submitted to this university or any other university as another thesis.

Hajer Faris FADHEL

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THE DIRECTORATE OF INSTITUTE OF GRADUATE STUDIES

The thesis study of Hajer Faris FADHEL titled as Optimization of Head Cluster Selection in WSN by Human-Based Optimization Techniques has been accepted as MASTER THESIS in the department of ELECTRICAL-ELECTRONIC ENGINEERING by out jury.

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SUMMARY

Wireless sensor networks are distinguished by their ability to collect data related to physical or chemical phenomena and transfer them to specialized processing centers through wireless channels. All routing protocols in data transmission are large consumers of energy, as they represent the main source of energy expenditure through data exchange operations. The cluster-based routing protocols are among the best current for slow power consumption. The most spreading cluster-based hierarchical protocols is the Low Energy Adaptive Cluster Head (LEACH) known for its good performances. LEACH suffers from the main problem of pseudo-random selection of cluster head resulting in large power dissipation. To find a solution to this critical problem, an optimization algorithm is used in a wireless sensor network to reduce the power consumption in the routing process and thus increase the life of the network. Improved cluster head selection in LEACH has a direct positive impact on the sensor life cycle by balancing the power dissipation between all sensors and by providing a better clustering map.

One of the recently emerging human-based optimization algorithms is called the Coronavirus Herd Immunity Optimizer (CHIO). This new algorithm is linked to the current spread of the coronavirus. The algorithm aims to immunize the vast majority of people from the pandemic by covering two basic concepts, namely social distancing, and herd immunity. The proposed protocol to improve group head selection in LEACH is implemented and verified by simulating various wireless sensor network scenarios, which consist of a variable number of nodes ranging from 20 to 100. Three indicators have been examined as evaluation indicators, namely, power consumption, number of live nodes, and number of packets received. The simulation results have shown the high performance of the proposed algorithm, and thus outperformed the LEACH protocol.

Keywords : Wireless Sensor Networks, Coronavirus Herd Immunity Optimizer (CHIO), LEACH, Cluster Head Selection.

ÖZET

Kablosuz sensör ağları, fiziksel veya kimyasal olaylarla ilgili verileri toplama ve bunları kablosuz kanallar aracılığıyla özel işlem merkezlerine aktarma yetenekleriyle ayırt edilir. Veri aktarımındaki tüm yönlendirme protokolleri, veri alışverişi işlemleri yoluyla enerji harcamasının ana kaynağını temsil ettikleri için büyük enerji tüketicileridir. Küme tabanlı yönlendirme protokolleri, yavaş güç tüketimi için en iyi akımlar arasındadır. En yaygın küme tabanlı hiyerarşik protokoller, iyi performansları ile bilinen Düşük Enerjili Uyarlanabilir Küme Başlığı'dır (LEACH). LEACH, büyük güç kaybıyla sonuçlanan sözde rasgele küme kafası seçiminin ana probleminden muzdariptir. Bu kritik soruna bir çözüm bulmak için, yönlendirme sürecinde güç tüketimini azaltmak ve böylece ağın ömrünü uzatmak için kablosuz bir sensör ağında bir optimizasyon algoritması kullanılır. LEACH'teki iyileştirilmiş küme kafası seçimi, tüm sensörler arasındaki güç dağılımını dengeleyerek ve daha iyi bir kümeleme haritası sağlayarak sensör yaşam döngüsü üzerinde doğrudan olumlu bir etkiye sahiptir.

Son zamanlarda ortaya çıkan insan tabanlı optimizasyon algoritmalarından biri Coronavirus Sürü Bağışıklığı İyileştiricisi (CHIO) olarak adlandırılıyor. Bu yeni algoritma, koronavirüsün mevcut yayılımıyla bağlantılı. Algoritma, sosyal uzaklık ve sürü bağışıklığı olmak üzere iki temel kavramı kapsayarak insanların büyük çoğunluğunu pandemiden korumayı amaçlamaktadır. LEACH'te grup başı seçimini iyileştirmek için önerilen protokol, 20 ila 100 arasında değişen değişken sayıda düğümden oluşan çeşitli kablosuz sensör ağı senaryolarının simüle edilmesiyle uygulanmış ve doğrulanmıştır. Değerlendirme göstergeleri olarak üç gösterge incelenmiştir, yani güç tüketimi, canlı düğüm sayısı ve alınan paket sayısı. Simülasyon sonuçları, önerilen algoritmanın yüksek performansını göstermiştir ve bu nedenle LEACH protokolünden daha iyi performans göstermiştir.

Anahtar Kelimeler : Kablosuz Sensör Ağları (WSN), Coronavirus Sürü Bağışıklığı İyileştiricisi (CHIO), LEACH, Küme Başkanı.

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ABBREVIATIONS

ADV	**:**	Advertisement
BSN	**:**	Base Station
CH	**:**	Cluster Head
CHIO	**:**	Coronavirus Herd Immunity Optimizer
CSMA	**:**	Carrier Sense Multiple Access
GPS	**:**	Global Positioning System
HEED	**:**	Hybrid Energy Efficient Distributed
LEACH	**:**	Low Energy Adaptive Cluster Head
MAC	**:**	Multiple Access Control
PEGASIS	**:**	Power-Efficient Gathering in Sensor Information System
QoS	**:**	Quality of Service
REQ	**:**	Request
SPIN	**:**	Sensor Protocols for Information via Negotiation
TDMA	**:**	Time Division Multiple Access
WSN	**:**	Wireless Sensor Networks

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PREFACE

I dedicate this humble work to my family who was always there to encourage me to complete my way of being here, to father, mother, and my lovely sister.

I am heartily grateful to my supervisor Dr. Musaria Karim Mahmood for his suggestions and guidance that enabled me to have a deep understanding of the subject of this project.

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I would also like to thanks the thesis's jury members, the staff of Istanbul Gelişim University Electrical and Electronics Engineering Department and the Institute of Science.

INTRODUCTION

Wireless sensor networks (WSNs) became very popular in the last few years because of their numerous applications in civil and military equipment such as crisis management, health care, targeting, transportation, forest fire detection, and other commercial and industrial applications (TLK, 2016). For example, WSN can be designed to monitor many physical parameters, such as vibration, temperature, strain, pressure, etc. (Gao et al., 2018). It also can be used in smart cities for traffic and parking management, atmospheric pollution detecting, monitoring structural health, and preventing noise pollutions. Tracking military vehicles is another example, with sensing the speed and path of these vehicles and by communicating with other sensors this information’s will be sent to the sink node, the Base Station Node (BSN), to track the enemy vehicles (Ahmad, Shah, and Ullah, 2016). WSN consist of a large number of sensor nodes of up to thousands of heterogeneous or homogeneous nodes with different size among large or small, and maybe remote or hostile area, depending on the events to be monitored. It is used to monitor the surrounding environment like temperature, vibration, humidity, etc. Data is collected by sensors from the field, processed, and sent to the BSN according to various routing algorithm strategies (Mishra, Kumar, Sharma, and Upadhyay, 2020). These nodes consist of radio transceivers that are used to communicate with each other with an antenna, microcontroller, electronics circuit to connect with the sensors, and a battery as an energy source (Agrawal, 2011). They are considered somehow cheap components, but their costs can vary depending on their complexity in the design. The energy source (a battery inside each sensor) is the main source of WSN lifetime limitation. For a given sensor-node type, the challenge is to keep these sensors alive for a maximum time by reducing the energy consuming during the sensor active operating time.

Sensor nodes play a critical role in sensing, monitoring, data processing, and collaborative decision making, by integrating detection systems, signal processing, and data communication tasks. this will leave the network with complex systems that have many obstacles, such as energy, bandwidth, speed, storage, and node localization (TLK, 2016). These problems become more challenging over time. It cannot be solved by deterministic algorithms. Optimization techniques were presented with the use of algorithms and protocols from the literature (Padmaja and Marutheswar, 2016).

The physical or chemical phenomena sense, process, and sent wirelessly by the WSN nodes, without the need for infrastructure. For example, the movement of an object is transformed into an electrical signal that can be analyzed and measured. These data are collected by sensors from the field, processed, and sent to the Base Station Node (BSN) according to various routing algorithm strategies (Mishra, Kumar, Sharma, and Upadhyay, 2020). BSN has improved memory and computing ability compared to normal sensor-node, enables it to perform complex processing and classification procedures before sending data to the supervisory party via a communication network (Kaur and Mir, 2016). Transmitting data from the field to the BSN using a routing algorithm presents the most critical operation in terms of communication and energy-consuming affecting WSN performances and lifetime (Padmaja and Marutheswar, 2016). Figure 1. shows the architecture of WSN.

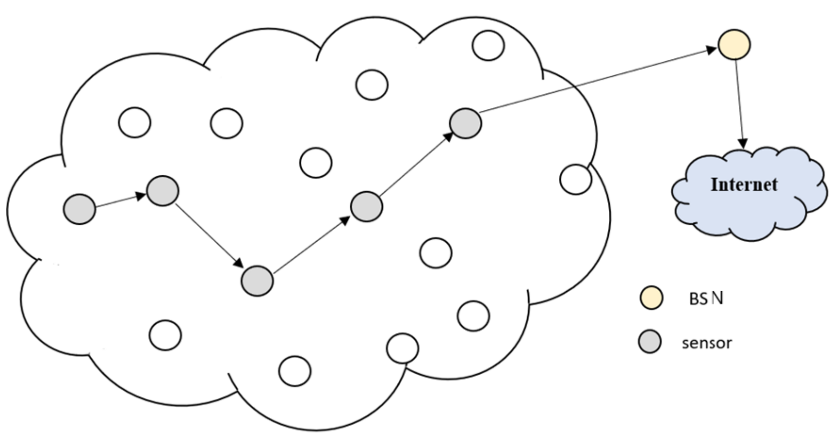


Figure 1. WSN architecture.

CHAPTER ONE

STATE OF THE ART

1.1 Literature Survey

Several hierarchical routing protocols for WSN have been developed, drawing on LEACH as their basis. This aims to improve the performance of the LEACH protocol in terms of strength, optimal CH selection, and cluster formation. LEACH variants have been mentioned in several surveys to compare their performance. In the SINGH et al. (2017) survey paper, the authors presented LEACH and its variants with single-hop and multiple-hop connectivity and their comparison based on several parameters. Among them, the main ones are energy efficiency, overload, delay, and scalability. Through this work, it has been found that many LEACH variants deal with GPS for node location information, which is a major energy drain and leads to a rapid end of network life. The network coverage and security issues have been also raised as it has been considered in depth in the LEACH variants. The same is true for the navigation feature, as this field hasn't properly exploited in LEACH variants. Therefore, many improvements are required for most LEACH variants in order to achieve an efficient WSN that maintaining operation as long as possible and consumes a small amount of energy in the communication processes. Heinzelman W. R., Chandrakasan A., and Balakrishnan H. (2002) have introduced an improved version of LEACH protocol called LEACH-centralized (LEACH-C). LEACH-C includes the steady-state phase of the basic LEACH, while the set-up phase is using centralized procedure. Sensor nodes are responsible for determining their positions, by using a Global positioning system (GPS), and sending their location to the BSN for analysis and determination of the CH IDs. The simulation has shown an evident outperform of LEACH-C compared to LEACH in extending the network lifetime of about 30%. MORGANATHAN et al. (2005) has suggested a centralized routing protocol called Base-Station Controlled Dynamic Clustering Protocol (BCDCP). In the BCDCP protocol, BSN has performed CH selection operations instead of sensor nodes since it has so high energy that it can carry out clustering formation in an almost balanced manner. The simulation showed an extension in the network lifecycle and efficiently distributes the power consumption across the network. Tong and Tang. (2010) has introduced the LEACH-Balanced (LEACH-B) which includes two selection processes for each round. The first is based on the LEACH protocol while the second relies roughly on the remaining power to hold the sensor to maintain the optimum number of CHs per round. A successful constant and near-optimal number of CHs has been presented in the simulation results of the LEACH-B protocol in comparison to LEACH. Another protocol that balances power consumption across the network has introduced by Suharjono, Wirawan, and Hendrantoro. (2011), called Overlapping LEACH (O-LEACH). The main mission of O-LEACH is to make the overlapping of sensor nodes between groups possible since there are some applications that require sensor nodes to join more than one group. Simulation has shown a great control on the overlapping degree while in terms of the energy consumption balancing, it has not been able to perform well in comparison to the LEACH protocol. The cluster distribution problem has been evidently shown in the simulation. The reason is due to the LEACH protocol and has nothing to do with the overlapping tasks. Another protocol that pretty good conserves the inner communication energy of the network has been proposed known as the Improved LEACH (I-LEACH). It is an efficient routing algorithm to improve the performance by reducing the WSN energy consumption. This is what Beiranvand, Patooghy, and Fazeli. (2013) have suggested, taking into account the number of CH neighbors, shorter BSN distance, and residual energy. In the cluster formation of I-LEACH, three factors have been used to select the CH. Higher residual energy in the node, shorter distance between the node and BSN, in addition, having a relatively little distance with the neighbor nodes (having more neighbors) for selecting as a CH. The simulation has shown that the I-LEACH has a resilience of changing the position of BSN and a superior in the performance in comparison to LEACH, Distance-Based Segmentation (DBS), and LEACH-C. ZHAO and YANG. (2014), have proposed LEACH-A, in order to select a cluster leader who would collect data from other CHs. The cluster leader is the node that has higher residual energy than the primary energy percentage. Therefore, this protocol improves the number of hops for data sent between CHs and BSN. The improved protocol performance has compared with LEACH and LEACH-C. the simulation result has showed an effective balance in the energy consumption of the network as well as prolong its lifetime. Mehmood, Lloret, Noman and Song. (2016) have proposed LEACH-VH, a new protocol that not only select CHs but also includes the Vice Heads (VHs). The VH node acts as a backup for CH and goes into the sleep state as long as CH does not drop its residual energy level below the threshold. VH is chosen by the CH node and it's the second-highest energy-owner candidate node. When the CH drains its energy and reaches the threshold value, the VH node wakes up and acts as CH. It then chooses a VH for it. The simulation results showed a prolonging in the lifetime of WSN by more than 47% compared to the LEACH protocol. Bendjeddou, Laoufi, and Boudjit. (2018) have introduced an enhanced version of LEACH for Low Energy Adaptive Clustering Hierarchy for Sensor Network (LEACH-S). The aim is to reduce the overheads generated in each sensor node due to messaging between the sensors, in a way to reduce the choice of CHs for each round, and in turn minimizing the exchanged control packets between them. An evident result of energy consumption minimization and overheads reduction in the network has been shown in the simulation results compared to LEACH. Ouldzira et al. (2019) have designed a CH selection process based on the lowest distance to the BSN. The task of selecting a CH is the responsibility of the sensor node by calculating the distances of the sensor to CHs, CHs-to-BSN, and choosing the minimum distance accordingly. The main idea of MG-LEACH improved version of LEACH protocol is to enhance the performance of WSN by utilizing the correlated nature of data inside clusters. It’s based on the framework of LEACH. A critical evaluation has been done for MG-LEACH in order to validate its efficiency in improving the network lifetime. The simulation results for the comparative performance of LEACH and MG-LEACH have showed a superior in the performance of the proposed algorithm in increasing network lifetime and number of data transferred.

To extend the lifetime of WSNs, some researches based on optimization algorithms have been suggested to improve the LEACH protocol and other existing routing protocols by reducing its energy consumption. Karaboga, Okdem and Ozturk. (2010) have designed an energy-saving clustering protocol based on an Artificial Bee Colony (ABC) optimization algorithm with a sensor node that does not contain GPS and aims to identify the best CHs to reduce energy cost. They have used a centralized control algorithm with a proposed objective; the fitness function takes the node's energy level, energy consumption, and Quality-of-Service (QoS) as constraints. The results of the simulation have been compared to LEACH and PSO-based optimized routing protocols. It has shown that the newly proposed protocol is more efficient in extending the network lifecycle as well as reducing the delay that comes from the signals transmitted between clusters. Liu and Ravishankar. (2011) have introduced a Genetic Algorithm based on LEACH protocol (LEACH-GA). The proposed algorithm works like the LEACH protocol in terms of setup and steady-state phases. The difference is that BSN is responsible for selecting the optimal CH by applying a genetic algorithm to reduce the total power consumption of one round in the network. The simulation has shown that the optimum distribution of probability in LEACH-GA yields an optimal energy consumption in the network as well as prolonging the WSN lifecycle. Moreover, the simulation of LEACH-GA has exceeded the performance of Minimum Transmission Energy (MTE), Direct Transmission (DT), and LEACH. Sharawi et al. (2014a) have developed a Flower Pollination Optimization (FPO) algorithm to enhance the problem of selecting optimal CHs and forming clusters efficiently for extending the network lifetime. The goal is to minimize the fitness function depending on intra-cluster distances, in a way that ensures distributing the CHs efficiently for minimizing the communication energy losses between cluster members. Simulation results have shown that applying the FPO algorithm to WSN gives efficient results in terms of energy balance in sensor nodes, resulting in a longer network lifetime compared to the LEACH protocol. In order to reduce the energy consumption level of each node resulting an extending of WSN lifetime, Sharawi et al. (2014b) have proposed a population-based metaheuristic algorithm known as the Bat Swarm Optimization (BSO) algorithm. The proposed algorithm has been implemented for optimal selection of CHs. The simulation has been performed for four network deployments with a fitness function intended to inter-cluster compactness. Simulation results have been compared with the classic LEACH approach that shows WSN life extension. Al-Aboody and Al-Raweshidy. (2016) have proposed Three-level Hybrid Cluster Routing Protocol (MLHP) algorithm. The protocol has based on Gray Wolf Optimizer (GWO) and consists of three levels for selecting the optimal CH. For the first level, a centralized selection has presented in such a way that the BSN is responsible for selecting CH. In the second level, routing based on GWO for the transmission of data has introduced. The aim is to assist the node in choosing the optimal path to the BSN that provides more energy. For the third level, the system of the distributed clustering has presented based on the cost function. The simulation results have shown improved performance compared to the most popular routing protocols in terms of network life, power efficiency, and stability period. Sun, Dong, and Chen. (2016) have designed a routing protocol based on the Ant Colony Optimizer (ACO) to find the optimum routing for data transmission. With the use of improved function, the distance of nodes communication transmission, direction, and residual energy the optimal path for nodes has been determined to extend network life and reduce power consumption. simulation of the proposed protocol has detected an improvement in the energy consumption, lifespan of the network, and the number of dead nodes in comparison to Energy Efficient Ant Based Routing (EEABR), LEACH-based Ant Colony Optimization Algorithm (LEACH-Ant), and Optimized Ant Routing Algorithm (OARA) protocols. Jadhav and Shankar. (2017) have presented a CH selection energy-aware protocol based on Whale Optimization Algorithm (WOA). A suitable fitness function has been implemented that takes the residual energy of the node with the total energy of the adjacent nodes for the optimal selection of CHs. The simulation of WOA-C has outperformed in the performance LEACH, LEACH-C, and PSO-C routing protocols, in terms of energy efficiency, network lifetime, throughput, and stability period. Sarkar and Murugan. (2017) have developed an approach to select the optimal CHs in WSN. The work has covered the major problems in WSN, namely energy, distance, and delay by selecting the CH closest to BSN as well as to the rest of the nodes, which aims to reduce the delay. It has done by applying the Firefly algorithm with cyclic randomization to increase power efficiency and node life which in turn increased the network efficiency compared to other algorithms. Sharawi and Emary. (2017) have introduced a model for optimal CH selection in WSN. Gray Wolf Optimizer (GWO) has adapted with a suitable fitness function to find the optimal CH which in turn positively affected the lifespan of the network. The simulations were performed on four deployments and the results have shown a clear effect of Gray Wolf Optimizer on residual energy, lifespan, and network throughput performance compared to LEACH. Ahmed et al. (2019) have proposed an energy-efficient protocol for LEACH along with a Particle Swarm Optimization (PSO) algorithm to improve network performance. The result of the LEACH-based PSO simulation has compared to that of the LEACH on its own. It has shown a large difference in the number of dead nodes at the end of the simulation proving how good they are at conserving energy that positively affects network lifespan. Dattatraya and Rao. (2019) have developed a hybrid algorithm of Glowworm Swarm and Fruit Fly algorithms aimed at identifying the best CHs over the network life. The simulation results have shown the superiority of the proposed algorithm over nine of the well-known algorithms that have compared with in this paper. The aim was to reduce the fitness function that includes energy, distance, delay, and QoS as factors to prolong the life of the network and thus the energy efficiency of WSN. Mechta and Harous. (2019) have proposed a new hierarchical clustering protocol inspired by the behaviors of the Artificial Fish Swarm Algorithm (AFSA) based on optimal CHs selection. The optimal selection of CH in the proposed protocol has depended on the three behaviors of AFSA which are: Prey CH, Swarm CH, and Follow CH. It aims to establish a balanced hierarchical structure to ensure a good distribution of CH and its members with minimizing the distance between them as well as between the CH and BSN. The simulations have shown evident results in terms of increasing the network lifetime as well as decreasing the energy consumption compared to the LEACH-C protocol. Alghamdi. (2020) has presented a new clustering model for choosing the optimal nodes to present as CHs using a hybrid algorithm. The proposed algorithm (FPU-DA) is a combination of Firefly and Dragonfly Optimization Algorithms concepts. The simulation results have shown an amazing difference in performance compared to the results of some of the best-known optimization algorithms in terms of delay, safety, distance, and power as constraints. Zivkovic et al. (2020) have introduced an improved routing protocol based on the Firefly optimization algorithm (FOA) for optimal CH selection and cluster formation. The proposed protocol has compared with Firefly's basic algorithm, LEACH, and particle swarm optimization. Simulation results for the proposed protocol have shown a better and more consistent performance than the other comparative protocols.

1.2 Research Problem

Limited power issues in WSN are difficult and challenge many researchers in the field to try to extend the network lifetime, and then to obtain a largest amount of data packets. The routing protocol used for data transmitting in WSN is the basic LEACH. LEACH protocol is one of the most popular hierarchical routing protocols that have been used in the last two decades. The main problem with this protocol is the random selection of the CHs without taking fully into account their residual energy. CH is the node that consumes the most power by handling data reception-aggregation-transmission from all cluster nodes and sends it as a single signal to BSN. For optimal CH selection, an optimization algorithm was used to enhance the LEACH protocol. One of the latest human-based optimization algorithms is the Coronavirus Herd Immunity Enhancer (CHIO). An appropriate fitness function was implemented that taking into consideration, the total energy consumed and the power level of the node, in addition, to delay which is one of the QoS parameters.

1.3 Research Question

- Can the CHIO algorithm improve the lifetime and energy consuming of WSN?
- What is the effect of using CHIO CHs selection in LEACH protocol?
- Can CHIO bypass the issue of delay in receiving the data packets?

1.4 Research Objective and Scope

The objectives of the research are to prolong the network lifetime and minimizing energy consumption in WSN. LEACH-CHIO protocol is proposed as an energy-efficient cluster-based protocol. This LEACH-based protocol is compared to the basic LEACH algorithm in terms of energy, network lifetime, and the number of delivered data packets. The selection of CHs relies on a fitness-function, concentrating on the highest energy level, minimum distance between sensor nodes, CH and BSN as well as one of the QoS parameters that is packet delay. The scope of the research is represented in the following points:

a. Applying CHIO algorithm to one of the most popular protocols in WSN, which is LEACH in order to reduce the network energy consumption and extend its life.

b. Obtaining the best algorithm parameters to solve the LEACH protocol energy consumption problem.

c. Optimizing energy distribution to all network nodes in a balanced way.

d. One of the Quality-of-Service QoS parameter was employed to reduce the delay between data packets transferred to the base station by improving the objective function.

1.5 Importance of Research

This research focusing on improving the lifecycle of a wireless sensors network. It aims to minimize the energy consumption of the network, since the sensor nodes energy is limited and unchangeable. The power dissipation has a direct effect on the operation life of the WSN. Dissipation occurs during transmission activity which is higher for CHs as compared to other nodes. The optimal selection of CHs helps distribute the energy over the network to balance node energy consumption during its communication process, as well as increase the number of data packets transferred.

1.6 Structure of The Thesis

Five chapters presented in this thesis are as follows:

- **Chapter One** presents the related works, research problem, objectives, and importance in addition to the structure of the thesis.
- **Chapter Two** provides a theoretical background of routing protocols and their types with the methodology of the CHIO algorithm.
- **Chapter Three** presents the adopted methodology for improving LEACH protocol with details.
- **Chapter Four** presents the analysis of simulation results of different scenarios for LEACH, and LEACH-CHIO using MATLAB program.
- **Chapter Five** presents the Conclusion and Future Work.

CHAPTER TWO

THEORETICAL BACKGROUND

2.1 Routing protocols in WSN

Sensor nodes gather information from the deployment field and sent it to BSN through a predetermined route by using the routers (sensor nodes). The communications between routers to find the suitable routes for transferring information have known as the routing protocols. The Routing Protocols have been classified into four schemes based on the structure, the network topology, routing reliability, and communication model (Shafiq, Ashraf, Ullah, and Tahira, 2020). The communication model scheme is classified into Query-based, Negotiation-based, Coherent, and Non-Coherent-based Protocols, while, network topology scheme is categorized into Location-based and Mobile agent-based Protocols. Reliable routing scheme is categorized as follows: Multipath-based and QoS-based Protocols. In turn, the protocols under the structure or deployment of the network scheme are Flat and Hierarchical routing protocols (Liu, 2012). Some factors have been adopted for the designed routing protocol to be effective, such as mobility, connectivity, energy efficiency, location information, network coverage, and transmission media (Shabbir and Hassan, 2017). This section is focused on discussing a well-known three samples for each one of the network structures schemes; Flat and Hierarchical.

2.1.1 Flat Routing Protocol

Routing in WSNs is a challenging task because of their characteristics that differentiate them from other wireless networks. Usually, the number of nodes in the network is so high that it is not possible to have a global addressing scheme as the overhead would be very high to maintain. In WSNs, sometimes getting the data is more important than knowing the node identifiers (IDs) of the nodes that sent the data. Also, each node has the same information about the state of the network, so they play an equal role in data gathering (Liu, 2012). That approach is known as Data-Centric Routing Protocol (Yang, Deng, and Liu, 2015). Another feature of the sensor node has found in this approach that is all the nodes have the same function in transmitting data and consuming energy. An example of the widespread routing protocols in the Flat Routing Scheme is Flooding, Gossiping, and SPI.

a. Flooding Protocol:

In this protocol, the data received by the sensor node is sent to all neighboring nodes till reaching the maximum number of hops or receiving the data packet successfully at the destination. For that, each node gets more redundant copies of data, resulting in wasting of energy and bandwidth. Figure 2 shows the process of flooding protocol.

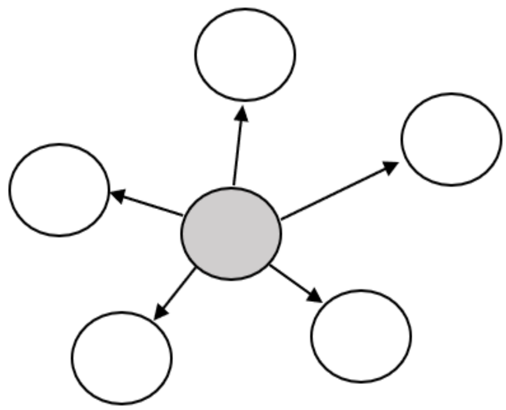


Figure 2. Flooding protocol.

One of the advantages is the ease of implementation, while it has implosions and overlapping problems as shortcomings due to the multiple copies of received data at each sensor node. Another feature is the high reliability of this protocol (Sohraby, Minoli, and Znati, 2007).

b. Gossiping Protocol:

It is an alternative approach to Flooding Protocol, using randomness for better energy conservation. In this protocol, every node sends the data to another randomly selected node. When this node receives the data in turn is going to send it to another randomly picked node and so on until it reaches the destination (Singh et al., 2010).

This protocol has avoided the implosion problem that appeared in the flooding protocol. But it has caused a delay in receiving the data messages and has no guarantee that the message will be received by the whole nodes. Figure 3 shows the process of the Gossiping Protocol.

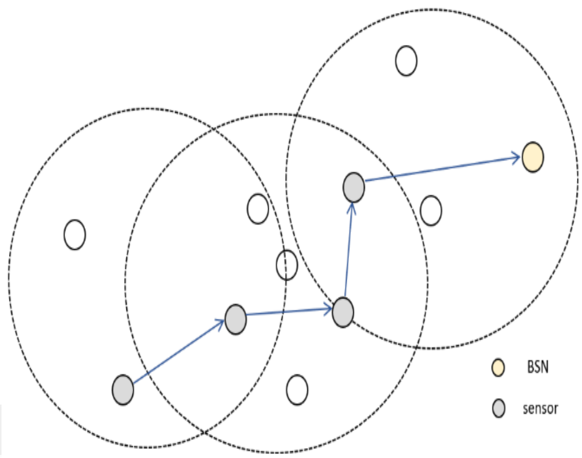


Figure 3. Gossiping protocol.

c. *SPIN Protocol:*

Sensor Protocols for Information via Negotiation (SPIN), is a data-centric routing protocol (Pandey, Nagwani, and Kumar, 2015). SPIN has been worked by assuming that all the sensor nodes work as a BSN. The nodes exchange the gathered information's between each other. These nodes use a meta-data approach so as it transfers the information of the sensor node data, to conserve energy. Advertisement data (ADV), Request for data (REQ), and DATA are the three types of messages has used in the SPIN protocol. by limiting the sources received, this protocol has solved the problem of implosion and overlapping that founds in the previously discussed protocols (Flooding and Gossiping). The major shortcoming of the SPIN that has been detected in the long time taking for the boundary nodes of the network to receive the data packet. Figure 4 is illustrating the SPIN protocol operational method. The sensed node (node 1) transmits ADV message to another node and wait for (node 2) to send back a REQ message for transmitting the DATA. (node 2) will, in turn, send an ADV message to its neighbor nodes and wait until it receives the REQ messages to disseminate the DATA (Mishra, Kumar, Sharma, and Upadhyay, 2020)

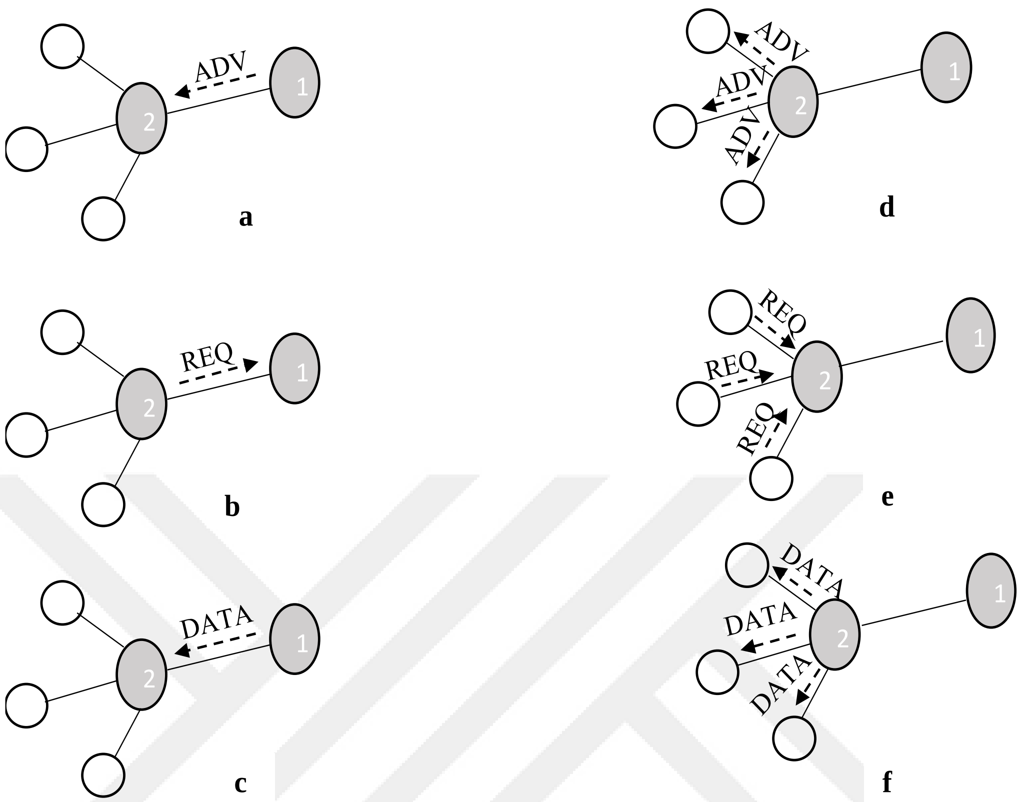


Figure 4. SPIN protocol.

2.1.2 Hierarchical Routing Protocol

A Hierarchical Routing is one of the network structure classifications, aiming to reduce the consumed energy. It performs a multi-hop communication between the sensor nodes and the BSN inside a pre-specified cluster for transmitting-fusion the gathered information messages (Ercan and Asim, 2018). This routing protocol type starts by dividing the network into many clusters. The node with the highest energy in a specific cluster is elected as a CH by the rest of the cluster nodes (Chan et al., 2020). Some of the most widely spreading examples of hierarchical routing protocols are the PEGASIS, HEED, and LEACH.

a. PEGASIS Protocol:

Power-Efficient Gathering in Sensor Information System (PEGASIS) is a Hierarchical Routing protocol, operating depending on Chain Formation and Greedy

Approach (Kumar and Khunteta, 2018). Once one of the nodes has sensed an event it transmits it to the nearest neighbor node connected to it. And so, on until it reaches the leader node, which will transfer the fused data to the BSN, as depicted in Figure 5. If one of the sensor nodes has drained its energy, then the chain is reconstructed utilizing the Greedy Algorithm. Unlike LEACH no cluster formation has needed nor several leaders for sending the gathered data to the BSN. Which has been considered as an effective way to extend the network lifetimes.

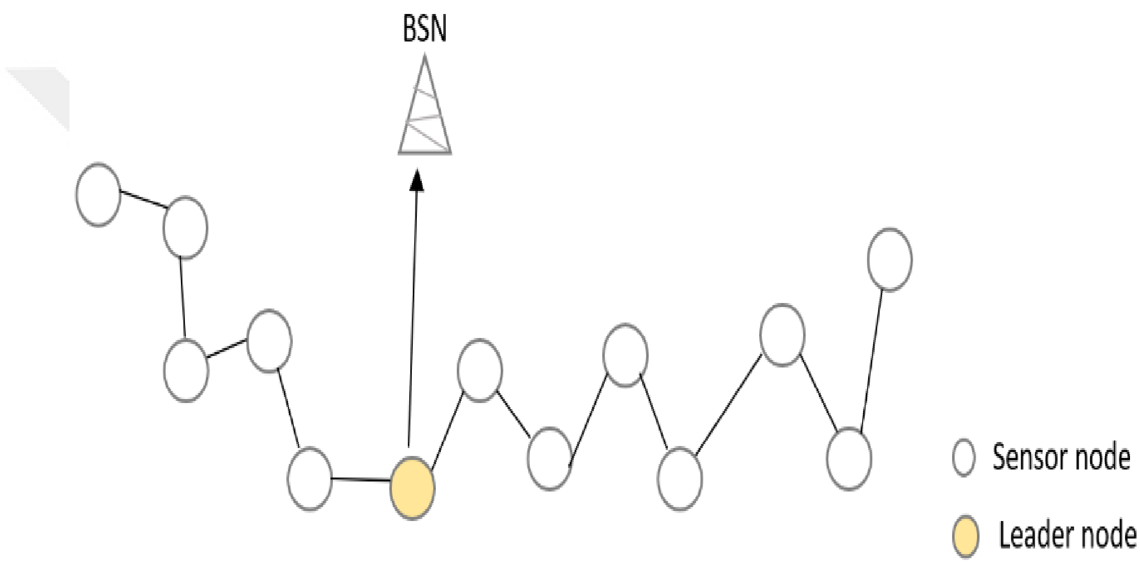


Figure 5. PEGASIS protocol.

b. HEED Protocol:

Hybrid Energy-Efficient Distributed (HEED) protocol aims to divide the network into clusters in such a way to terminate after a specific number of iterations. In each iteration, the nodes that are not elected as CHs have seen their chance of being CH in the next iterations doubled. There is no assumption in this protocol on the location and position of nodes. The selection of CHs is only depending on the residual energy as in LEACH but also, the node degree or the proximity of the node to its neighbors has considered which aimed to balance the load between the CHs (Younis and Fahmy, 2004). The random selection of CHs depends on two parameters for the clustering process. The first is the balanced energy in each sensor node for the selection purpose, and the second one is the intra-cluster communication cost that has been used to break the ties between the first set of CHs (Priyadarshi, Singh, Randheer and Singh, 2018). HEED has considered one of the most energy-efficient Hierarchical Routing Protocols for its ability to extend network lifetime and minimize communication costs. Figure 6 shows the HEED Protocol operation.

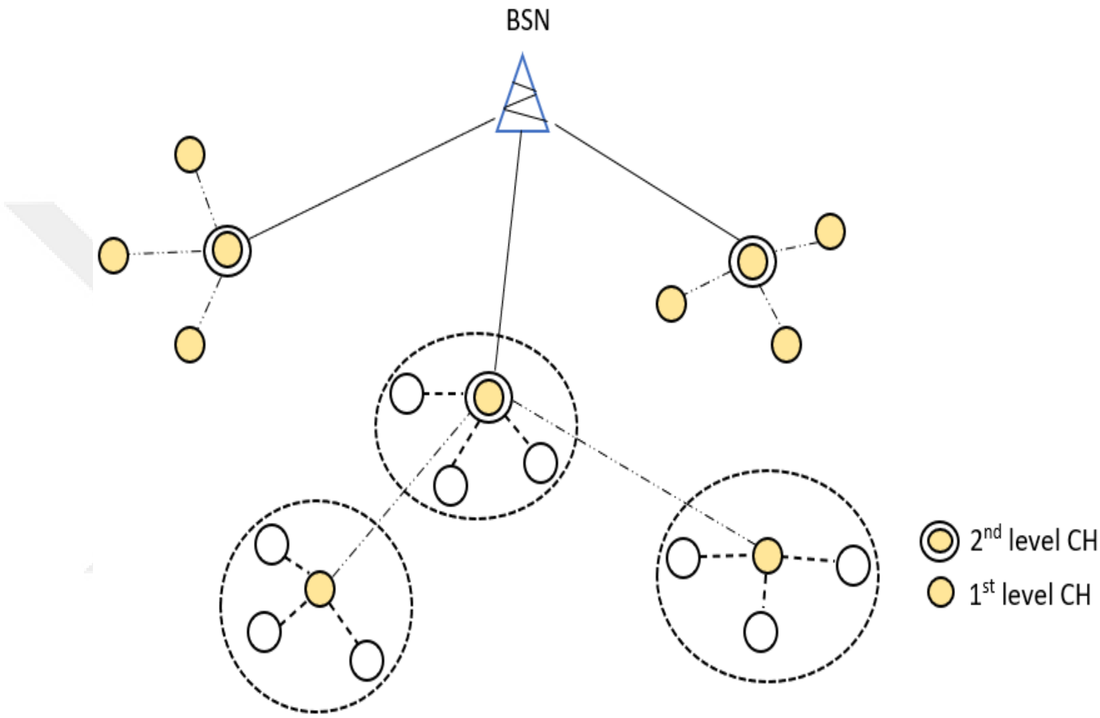


Figure 6. HEED protocol.

c. LEACH Protocol:

The Low Energy Adaptive Clustering Hierarchy (LEACH) protocol is a self-organizing cluster-based routing protocol that has first introduced by Heinzelman (Heinzelman, Chandrakasan, and Balakrishnan, 2000). The researchers have proposed a protocol that distributes the consumed energy over the whole network to enhance the energy efficiency, which in turn prolongs the network lifetime. LEACH protocol has been done through rounds consist of two phases: the set-up phase and steady-state phase. At each round, the election of CH has done by pseudo-random rotation depending on the residual energy. After selecting the CH, the formation of the clusters has been done by requesting messages between the nodes and the CH, this stage is known as the set-up phase.

In the steady-state phase, the nodes have transmitted the collected data to the CH, which in turn transmit it to the BSN. These nodes have organized in clustering form. Each cluster has chosen a CH after finishing the election period. In this way, the energy has been distributed among the whole network that led to reduces the energy consumption of the network due to the transmission of data between the CH's and the BSN, which in turn has extended the network lifetime. The operation of LEACH Protocol has depicted in Figure 7.

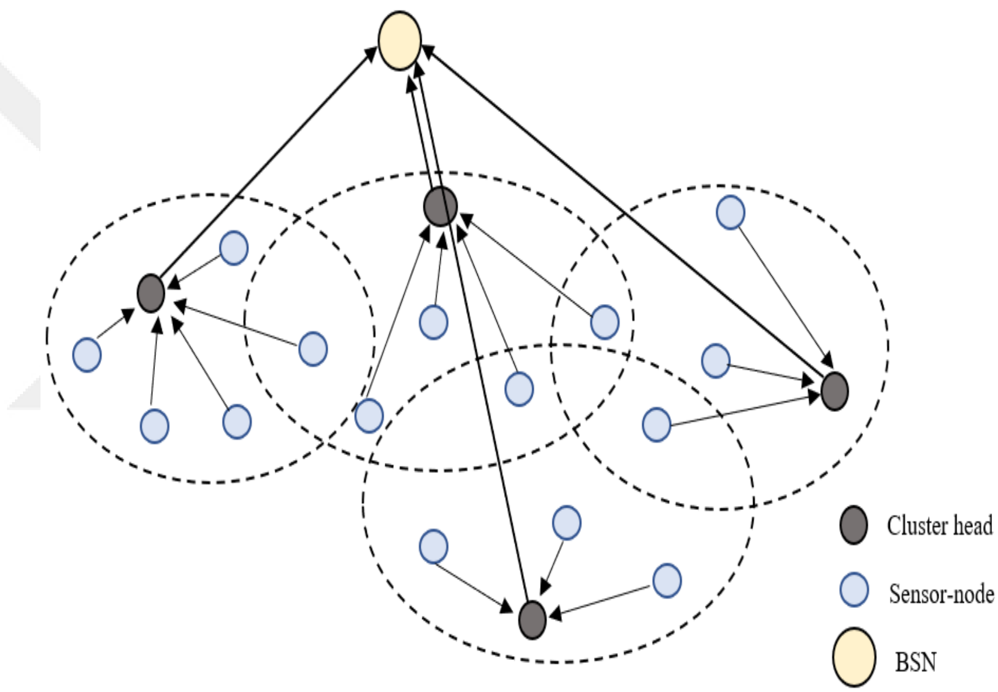


Figure 7. LEACH protocol.

2.2 Wireless Sensor Network Optimization

2.2.1 Optimization, an Overview

Optimization algorithms have gained wide popularity since their concept has first recognized by the founder of algebra M. Al-Khwarizmi. Optimization is the process of finding the minimum or maximum optimal solution for a specific problem or a specific arithmetic operation within a range of constraints. Five conditions have to be met in the problem that uses optimization algorithms namely: input, output, finiteness, definiteness, and effectiveness (Parwekar, Rodda, and Kalla, 2018). The goal of using optimization algorithms is to reduce costs and errors, increase efficiency, and save time. Optimization algorithms have to contain three main components: objective function, variables, and constraints. So, the definition of optimization is finding values of variables that minimize or maximize objective function by staying within the imposed constraints. Two methods have been suggested for solving optimization problems: Deterministic and Approximation-Based algorithms. A Deterministic algorithm is an algorithm that works on a series of states. Where when given input, it will pass through a series of states based on the initial one. Meaning that its current state determines its next state, and this value is produced as an output. These algorithms have not been able to solve NP-hard problems (Gogu et al., 2011).

Approximation-Based algorithms have been introduced to bypass this problem where the use of random components is the golden feature them. Whereby they can solve problems that cannot be solved in polynomial time such as NP-hard. Approximation-Based algorithms can be classified into Heuristic and Meta-Heuristic algorithms. In Heuristic algorithms, an optimal approximation of slow methods can be found more quickly when the optimal solution is impossible to find. That is, the solution is not the best, but it may be the closest to it, and it remains valuable because the algorithm hasn't taken a long time to find it (Parwekar, Rodda, and Kalla, 2018). Where Meta-Heuristic algorithms have inspired from nature, rely on intelligent knowledge based on random characteristics of problems with large spaces. In addition, it has also been based on multi-dimensional combinatorial problems, which makes comprehensive research not possible. Meta-Heuristic algorithms aim to search efficiently for finding the closest solution to the best, that achieve the two main components of the algorithm, namely exploration and exploitation (Pritee, Sireesha, and Neeharika). Meta-Heuristic algorithms have classified into: Human-Based, Physical and Chemistry Based, Swarm-Based and Evolutionary-Based algorithms (Naik and Satapathy, 2020). It should be known that not all optimization algorithms deal with the same problems and give one result. Each problem has its optimization algorithm. Therefore, the problem must be carefully analyzed to identify the most appropriate algorithm for it to obtain the optimal result.

2.2.2 *optimization algorithms for WSN*

Wireless sensor networks have been considered as one of the most famous modern technologies because of their great importance in facilitating the execution of several tasks in line with the contemporary lifestyle enhanced by cognitive technologies. WSN has been involved in many fields, which makes the consuming process of energy an important challenge for innovators. Communication process between sensors, analyzing, and transferring data to the controller is the basis for the work of these networks. These processes are considered a great draining process of WSN energy, which opens the way for many researchers to find solutions for reducing energy consumption. One of these solutions has been done by enhancing the algorithms of routing protocols by one of the optimization algorithms. Thus, the follow-up of developments on algorithms has been concluded, after several attempts and research, that meta-heuristic algorithms are one of the preferred algorithms to be used in improving the performance of WSN. Thereby many types of research work have played main roles in solving this issue. Taking into consideration different criteria such as security, the distance between nodes, packet delay, and residual energy. These constraints have been used in minimizing the objective function which is the target function for the optimization algorithm.

In the year 2020, a natural inspired human-based metaheuristic optimization protocol have been introduced, inspirited by the epidemic that invaded the world since the past year, which is the Coronavirus (Covid-19) (Al-Betar, Alyasseri, Awadallah and Doush, 2020). The proposed algorithm simulates how to achieve herd immunity as well as the social distancing recommended by the World Health Organization to overcome this pandemic. The algorithm has demonstrated its effectiveness by comparing it to 7 swarm-based algorithms and 9 other comparative methods, by testing 23 benchmark functions. For examining CHIO effectiveness, the authors have used three bound-constrained problems from the real-world. CHIO's experiment gave outstanding results, that make it possible to be used in several types of real-world optimization problems. In this study, CHIO has implemented to achieve an optimal selection of CH in the LEACH protocol is achieved. The improved network lifetime and reduce energy consumption in the network in addition to increasing the data packets received by the BSN are the expected results of this application.

3.1 Coronavirus Herd Immunity Optimizer (CHIO)

Coronavirus Herd Immunity Optimizer (CHIO) (Al-Betar, Alyasseri, Awadallah and Doush, 2020), is a natural-inspired human-based algorithm. The inspiration for the name for this algorithm came from the new virus that has recently spread in the world (Corona Virus or Covid-19). Herd immunity and social distancing terms have been proposed by health experts and World Health Organization as a way to combat and prevent the spread of this epidemic among individuals. Herd immunity is reached when the vast majority of people (60% of the population, depending on the herd immunity threshold) are immune from disease, and this can be achieved either by vaccination or direct infection. The speed of virus infection spreading depends on direct contact with the infected person in the community. Therefore, a proposal has been made to use the principle of social distancing to maintain the safety of community members. The CHIO algorithm deals with two concepts: social distancing and herd immunity. The transition from the susceptible state to the infected and from there to the immunized state against infection depends on the herd immunity threshold that has been taken from the Darwinian method (survival of the fittest). The population of herd immunity in case of an epidemic has been divided into three cases due to the reproduction rate BR_r and based on the principle of social distancing (susceptible, infected, and immune). The principle of herd immunity can be achieved by vaccination to immunize the majority of individuals from the disease, or when exposing a category of infected population to another category of susceptible population with weaker immunity. The speed of disease spread is called the basic reproduction rate. After a while, most of the infected people who have a strong immune system that can cope with the disease can be recovered. As for the few who have suffered from chronic diseases, and other elderly people, it will lead them to death. This later will lead the majority of the population to be immune from infection again. The immune system of individuals will create an immune memory of the disease. The proposal of herd immunity has adopted after it became clear that the government's proposal for the country lock-down has not been very effective in facing the disease.

The principle of social distancing, which was also proposed by the World Health Organization and has been applied by governments; is based on reducing the number of infected cases to control the outbreak of the disease. This can provide the necessary care for the infected people by the concerned health authorities. By applying the social distancing principle, the peak of the epidemic has reached a smaller number than expected of infected people. This principle has represented in the algorithm by taking the difference between a person's current state and that of a randomly selected person of the three possibilities: susceptible, infected, immune.

2.3.1 CHIO algorithm steps

The CHIO algorithm contains four algorithmic factors $(\mathrm{C_o}$, n, HIS,$Max_{itr})$ and two control factors ($\mathrm{BR_r}$ and $\mathrm{Max_{Age}}$), that affect the performance of the algorithm and are important for its implementation during the first step of the search phase.

1. CHIO parameters initialization; control and algorithmic parameters where:
    - C_o : the number of initial infected cases (equal to one in the experiment).
    - Max_{itr}: maximum iteration number.
    - HIS: the extent of in-population.
    - n : Dimensions of the problem.
    - BR_r, Reproduction rate that is used to control CHIO factors of virus-spreading among population.
    - Max_{Age}, is the maximum case-infection age, referring to the status of infected cases which is either recovered or died when it reaches Max_{Age}.

2. A randomized population generation of herd immunity (HIP) is stored in a Matrix for two dimensions of size $n \times HIS$, where, HIS is the herd immunity status.

$$HIP = \begin{bmatrix} x_1^1 & x_2^1 \ldots\ldots & x_n^1 \\ x_1^2 & x_2^2 \ldots\ldots & x_n^2 \\ \vdots & \vdots & \vdots \\ x_1^{HIS} & x_2^{HIS} \ldots\ldots & x_n^{HIS} \end{bmatrix} \qquad (1)$$

$x = (x_1, x_2, \dots, x_n)$, where x_i is the gene or the decision variable with a range of value for each gene $x_i \epsilon [lb_i, ub_i]$. Where lb_i and ub_i are the minimum and maximum limits of the gene (x_i). n, is the total number of genes in the individual.

Each row (j) introduce the individual case (x^j), whether is susceptible, infected, or immuned), and it's generated as follow:

$x_i^j = lb_i + (ub_i - lb_i) \times U(0,1), \forall i = 1,2, \dots, n$. Where $U(0,1)$ is a random number between 0 and 1.

The objective function indicating the optimization problem has been calculated in this step through equation number 2:

$$min_x^{f(x)} = x \in [lb, ub] \qquad (2)$$

The status vector (S) for each case within the HIP has been generating and represented as zero or one whether the individual is susceptible or infected, respectively. Taking into consideration 1-number in (S) is equal to that in C_o .

3. The third step is the important step in the algorithm through which it determines whether the gene x_i^j has preserved in its current state or affected by social distancing, depending on the basic reproduction rate $\mathrm{BR_r}$, which is done through three rules:

$$x_i^j(t+1) \leftarrow \begin{cases} x_i^j(t) & r \geq BR_r \\ Cx_i^j(t) \quad r \geq \frac{1}{3}BR_r & infected \\ Nx_i^j(t) \quad r \geq \frac{2}{3}BR_r & susceptible \\ Rx_i^j(t) \quad r < BR_r & immuned \end{cases} \qquad (3)$$

Where r is a random number between 0 and 1.

- $$x^j(t+1) = Cx_i^j(t) = x_i^j(t) + r \times (x_i^j(t) - x_i^c(t)) \qquad (4)$$

  In this equation, the infected state due to the effect of social distancing has represented by taking the difference of currently selected status of a gene (x_i^j) and the randomly selected status of the gene of an infected case (x^c) depending on the status vector (S), where $c = \{i | s_i = 1\}$.

- The second case is for the susceptible case, whose r value ranges between ($r \in [\frac{1}{3}BR_r, \frac{2}{3}BR_r]$) and it is represented as follows:

$$x^j(t+1) = Nx_i^j(t) = x_i^j(t) + r \times (x_i^j(t) - x_i^m(t)) \quad (5)$$

$x^j(t+1)$ has taken from the difference of currently selected status of a gene and a randomly selected gene status of a susceptible one x^m depending on the status vector (S), where $m = \{i|s_i = 0\}$.

- The third case is the immune case, in which the value of r is between ($r \in [\frac{2}{3}BR_r, BR_r]$) and represented by:

$$x^j(t+1) = Rx_i^j(t) = x_i^j(t) + r \times (x_i^j(t) - x_i^m(t)) \quad (6)$$

Depending on the principle of social distancing, the difference has taken between the current state of the gene x_i^j with a randomly selected gene of an immune case x^v depending on the status vector (S), where $f(x^v) = \underset{j\{k|S_k = 2\}}{\arg\min} f(x^j)$.

4. In the fourth step, the population of herd immunity has updated based on the previous equations, and the objective function or the immunity rate $f(x^j(t+1))$ has also been calculated for each new case $x^j(t+1)$ by replacing it with the previous case x_i^j if it's better. In addition, the age factor A_j is also has updated by increasing it by one in case its status vector (S) is equal to one, which in turn (S) has updated based on the herd immunity threshold as shown here:

$$S_j \leftarrow \begin{cases} 1 & f\left(x^j(t+1)\right) < \frac{f(x)^j(t+1)}{\Delta f(x)} \wedge S_j = 0 \wedge is\_corona\ (x^j(t+1)) \\ 2 & f\left(x^j(t+1)\right) > \frac{f(x)^j(t+1)}{\Delta f(x)} \wedge S_j = 1 \end{cases} \quad (7)$$

$is\_corona\ (x^j(t+1))$ which is a value equal to (one), achieved when the newly generated case $x^j(t+1)$ gain a new case infection. And $\Delta f(x)$ is the average of the immune rates population such as $\frac{\sum_{i=1}^{HIS} f(x_i)}{HIS}$.

That means reaching the herd immunity threshold where most of the population has become immune to the epidemic and has achieved by replacing the rate of individual immunity with the average immunity rate if it is better, and by relying on the principle of social distancing.

5. Detecting the fatality case has been done in this step by monitoring the immunity rate $f(x^j(t+1))$ of the currently infected case ($S_j = 1$). Where if the case has not developed from infected to immune after a some iteration number as shown in Max_{Age} $i.e.,$ $A_j \geq Max_{Age}$, the current case will be considered dead. So, the current case has rebuilt from scratch by using this formula$x_i^j(t+1) = lb_i + (ub_i - lb_i) \times U(0,1)$, $\forall i = 1,2, \dots, n$. In addition, the age A_j parameter and status S_j parameter has been updated by setting them to zero. The advantage of this step can be shown in terms of diversifying the current population and bypassing the best local solution.
6. The last step has achieved when the maximum number of iterations is reached, by repeating steps from three to six in proportion to the value of the maximum iterations. so, herd immunity, which contains two types of cases, namely susceptible and immune, has achieved with the disappearance of the infected cases.

It has been found through the experiments carried out by researchers in taking a small value of the BR_r parameter, gives the best performance of the algorithm in addition to its ability to balance exploration and exploitation in the search space (Al-Betar, Alyasseri, Awadallah, and Doush, 2020). A small value has also been taken for the Max_{Age} coefficient due to the ability of this value to diversify in the research. This parameter determines the percentage of deaths in this epidemic for infected people. taking into account canceling the solution of the current case and building a new solution from scratch has depended on this value. The principle of social distancing is an important factor in the algorithm as it is based on giving better performance for the algorithm and improve the strength of convergence if a Random-Random-Random strategy has been adopted. Random-Random-Random strategy based on the difference of a current state and a state from the random selection of herd immunity population. Other strategies tested for the herd immunity-social distancing are Random-Random-Best, Random-Best-Random, and Random-Best-Best.

2.3.2 Analysis of CHIO

In Figure 8, the step-by-step phases of CHIO are depicted. The CHIO algorithm starts by initializing the parameters (HIS, S_r, and Max_{Age}) as the first step. For the next step, the herd immunity population (HIP) is generated randomly as a set of cases stored in a Matrix for two dimensions of size $n \times HIS$. The fitness of every search agent is calculated. The status and age vectors are updating in the second step. In the third step, the coronavirus herd immunity is evaluated depending on the percentage of the basic reproduction rate BR_r. This step can decide whether the gene x_i^j preserved in its current state or affected by social distancing. By examining the three rules described in Figure 8, the gene x_i^j can be Considered either infected, susceptible, or immune case. The updating on the herd immunity population can be shown in the fourth step based on the equations mentioned in the third step. For each newly generated case, its objective function (immunity rate) must be updated. In addition, the age factor (A_j) is also updated depending on its status vector (S). That means the herd immunity threshold will be reached, where most of the population has become immune to the epidemic. The fatality condition is checked in the fifth step, by monitoring the immunity rate of the currently infected case. Where if the case has not developed from infected to immune after a certain number of iterations, the current case will be considered dead. So, the current case will be rebuilt from scratch. In addition, the age (A_j) parameter and status (S_j) parameter will be updated by setting them to zero. When the maximum number of iterations is reached the last step will be achieved. so, herd immunity, which contains two types of cases, namely susceptible and immune, can be achieved with the disappearance of the infected cases.

Compared to seven swarm-based algorithms and nine other comparative methods, known for their good performance by using the 23 known benchmark functions, CHIO algorithm has been able to give superior performance in many aspects of comparison made (Al-Betar, Alyasseri, Awadallah, and Doush, 2020).

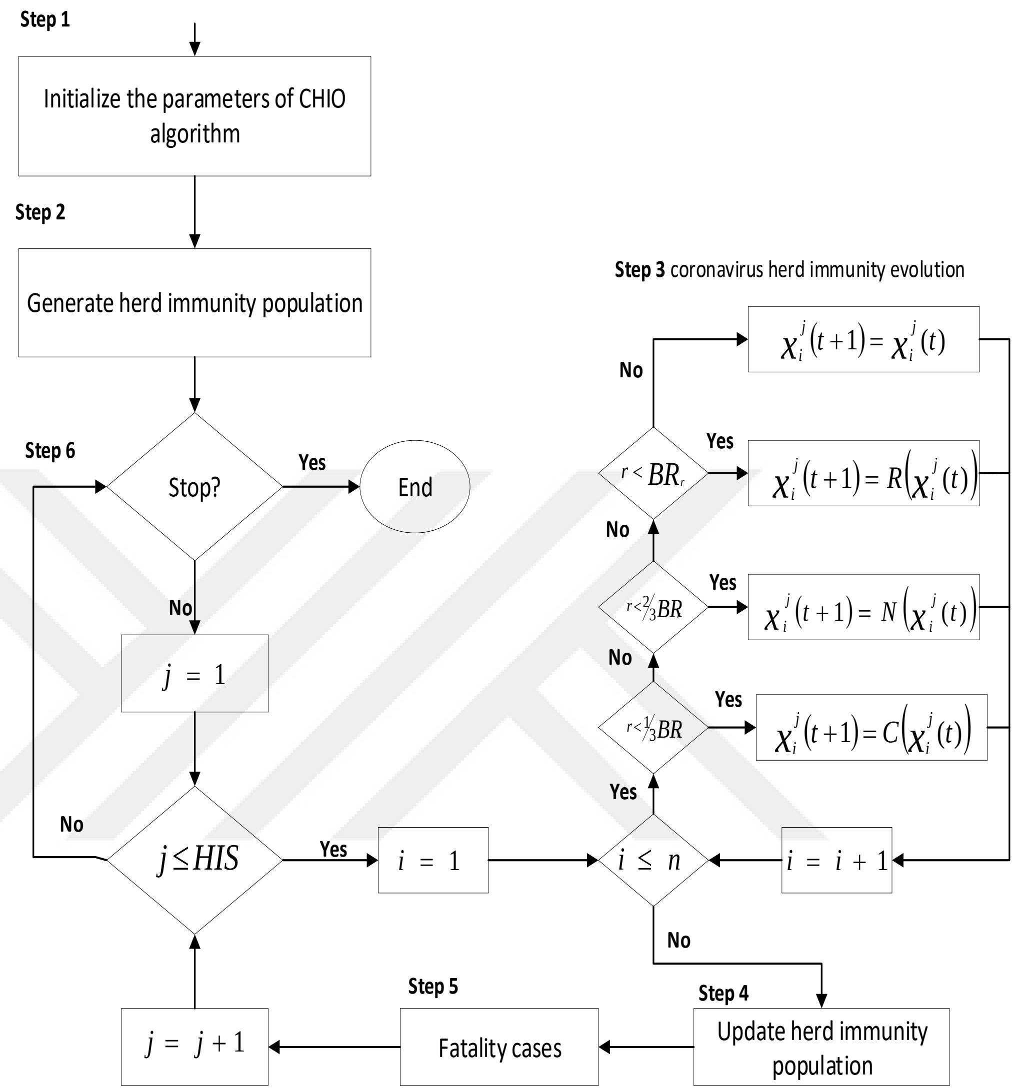


Figure 8. CHIO Flowchart.

CHAPTER THREE

METHODOLOGY

3.2 System model

A centralized cluster-based energy-aware protocol based on the CHIO algorithm is proposed in this thesis, LEACH-CHIO. LEACH is implemented with CHIO for increasing WSN lifetime. LEACH-CHIO select higher-level energy nodes as CHs, that means; selecting optimal CHs depending on their energy levels. The optimal selection of CHs results in a net saving in energy because the process of data aggregation and transmission to the BSN, which is performed by CHs, consumes more energy than other activities. The newly proposed protocol aims to select the most efficient cluster head in terms of energy to be able to extend the life of the network and deliver a greater number of data packets compared to other cluster-based routing protocols, including LEACH. In the following sections, an explanation of the LEACH protocol's mechanism will be discussed in detail, with the proposed protocol for the selection process of the most efficient CHs.

3.2.1 LEACH protocol

The main objective of LEACH is to increase the network life by balancing the energy dissipation through a pseudo-random selection of the CH in every round. The number of clusters, and then the number of CHs, is determined by the percentage of the node to become a CH. The algorithm is composed of two phases namely; the set-up and the steady-state, where each one is made up of many overlapping sub-stages. The set-up phase known also as the advertisement phase is composed of two sub-stages which are the CH-selection and the formation of the clusters. The CH-selection sub-stage starts by choosing CHs among candidate nodes according to the equation:

$$T(n) = \frac{P}{1 - p * \left(r \, mod\left(\frac{1}{p}\right)\right)}, \quad if \; n \in \; G \qquad (8)$$

$$T(n) = 0 \qquad\qquad Otherwise$$

Where P is the CHs probability (percentage of the node to become CH), r is the current round index, G is the set of nodes that were not chosen as CHs in the last epoch (1/P rounds). Node n selects a random number *RN(n)* between 0 and 1 and compares it with the calculated T(n). Node n is selected as cluster head if $RN(n) < T(n)$, otherwise, the next node is examined as a CH candidate. WSN nodes use this distributed process to performs the decision on CH selection depending on the amount of remaining energy. After 1/P rounds, the process is reset to start a new selection. CH is known as a bridge-node between sensors and the BSN to minimize energy dissipation during data transmission by adopting a clustering strategy as depicted in Figure 9.

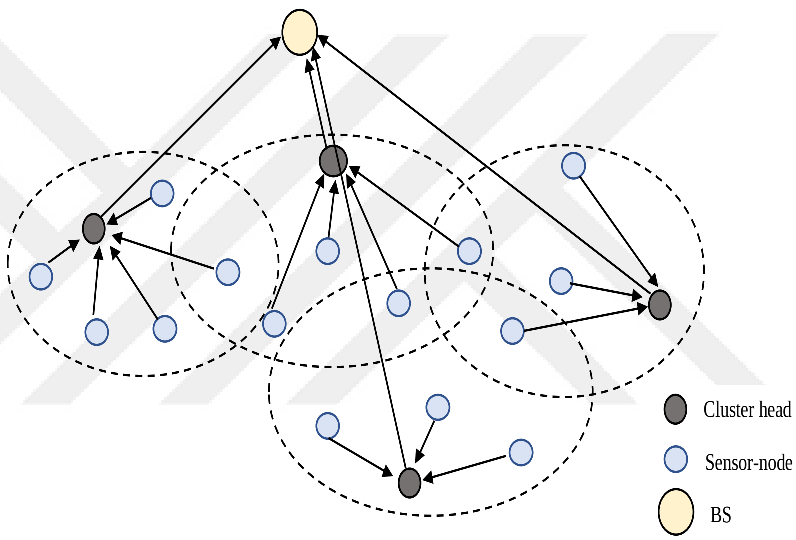


Figure 9. Clustering topology

This is positively reflected in the WSN life cycle, and then in the survivability of the network. After the selection of CHs, the formation of clusters begins by integrating nodes within the radio range as cluster members as shown in Figure 10. CHs advertise themselves by broadcast their ID using Carrier Sense Multiple Access (CSMA) MAC protocol to the surrounding nodes which in turn will determine the optimal CH to join based on the Received Signal Strength Indicator (RSSI). Sensor nodes within range receive this advertisement and if they are not CH, they join the cluster after sending a request message to the nearest CH. To reduce operating energy losses, the CH creates a TDMA slots transmission schedule for its cluster member, so nodes are switch-off when they don't have information to exchange. The clusters are formed; the steady-state phase starts by collecting data from sensors, sending it to the CH according to the predetermined schedule. CHs aggregates the data from the nodes in the clusters, then perform signal processing functions to compress the data into a single packet signal and sent it to BSN. The CH node must keep its receiver on to receive all the data from the nodes in the cluster. The aggregation process at this stage plays a positive role in reducing energy consumption, as it reduces the bandwidth and unnecessary communication traffic resulting from the nodes sensing similar data. After transmitting data from various sensor nodes to the CH, data is aggregated in a convenient form and finally transmitted to the BSN (Yao et al., 1998).

3.1.2. Communication and energy model used in LEACH

WSN is based on wireless communication where the energy dissipation model is the so-called first-order radio model presented in Figure 11. Communication activities between sensor nodes as transmitter-receiver are the cause of energy dissipation due to non-ideal electronics and the physical fading due to the wireless channel. The Transmitter (T_x) and the Receiver (R_x) circuits are considered analogous except the T_x amplifier. The circuit dissipation for T_x and R_x is (Kurt and Tavli, 2013):

$$E_{T_{x-i}} = E_{R_{x-i}} = L \times E_{elec} \quad (9)$$

Where $E_{T_{x-i}}$ and $E_{R_{x-i}}$, are the T_x and R_x in-circuit dissipation, L is the transmitted/ received bits number while E_{elec} is a constant depending on electronic circuits.

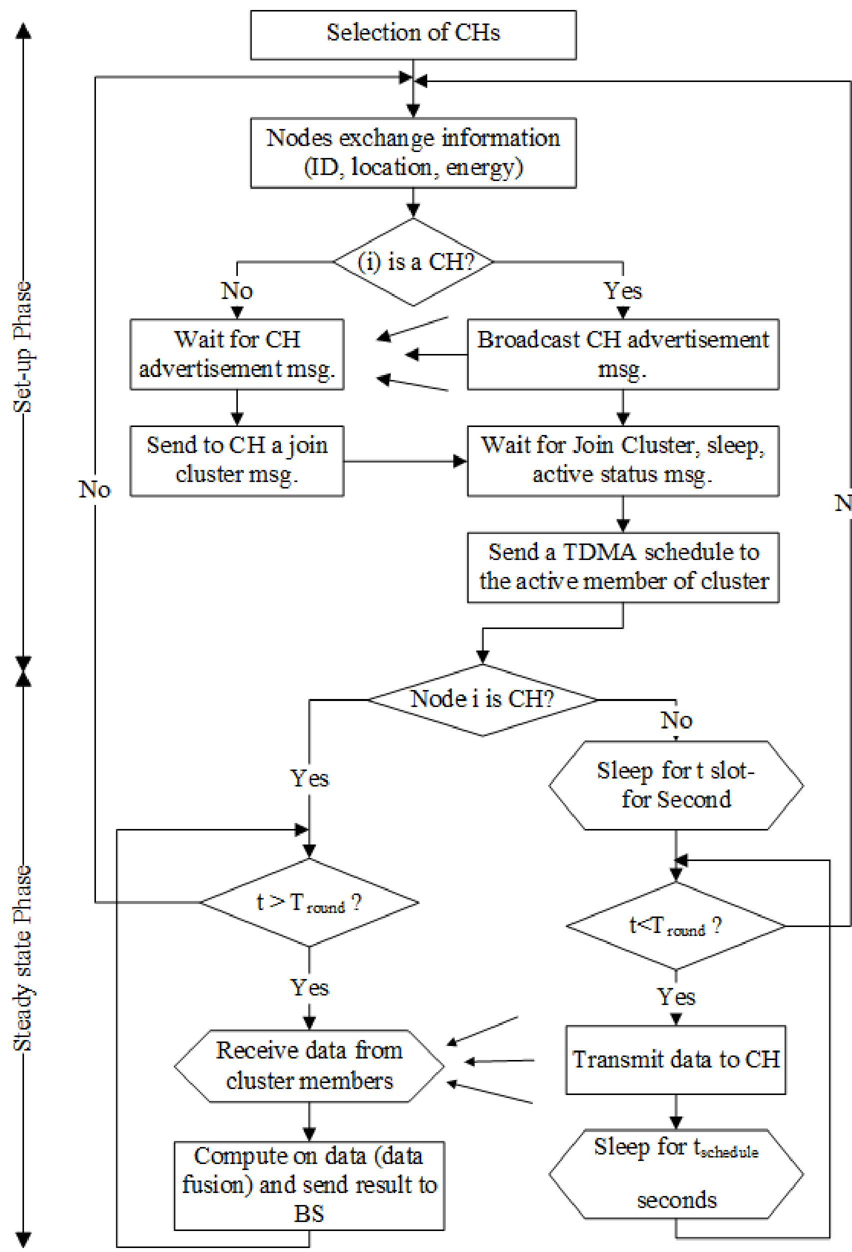


Figure 10. LEACH Algorithm

Because of the limited nodes inter-distance, the signal energy fading (E_f) between (T_x) and (R_x) is equal to:

$$E_f = \varepsilon \times d^2 \times L \quad (10)$$

Where d is the T_x-$R_x$distance, and ε is the amount of consumed energy/ bit in the RF-amplifier.

For large nodes inter-distance networks, the multi-path fading model is adopted with d^4 instead of d^2 in (3). The channel between two sensor nodes is considered as symmetric in energy losses characteristics where the total consuming energy E_{T_x} and E_{R_x} for L-bit transmission/ reception are:

$$E_{T_x} = L(E_{elec} + \varepsilon \times d^2) \quad (11)$$

$$E_{R_x} = L \times E_{elec} \quad (12)$$

3.2. The communication process and energy dissipation in LEACH

The communication process in the LEACH protocol takes place through several data exchange operations. The energy dissipation is caused by transmission activities and data collection, aggregation, and processing. According to 11 and 12. It is a function of both data size and the distance separating nodes (Heinzelman, Chandrakasan and Balakrishnan, 2000). The approximated energy dissipation resulting from the transmission activities in one cluster and for one iteration can be deduced from Figure 12 presenting communication in one iteration. The WSN is considered with N nodes and K clusters.

<u>Announcement process to the BSN:</u>

- CH send a request message to BSN for connection purpose. The consumed energy by CH in (a) is:

$$E_{CH-a} = L_C \times (E_{elec} + \varepsilon \times d^{\alpha}_{to\ BSN}) \quad (13)$$

  Where $d^{\alpha}_{to\ BSN}$ is the distance between CH and BSN, L_c is the request control packet length, and α is either 2 or 4 for free space or multi-path fading model respectively.

- BSN returns an allocated TDMA schedule for each CH to transfer data. The consumed energy in CH due to schedule receiving from BSN (operation b) is:

$$E_{CH-b} = L_t * E_{elec} \quad (14)$$

  Where, L_t, is TDMA scheduling packet length.

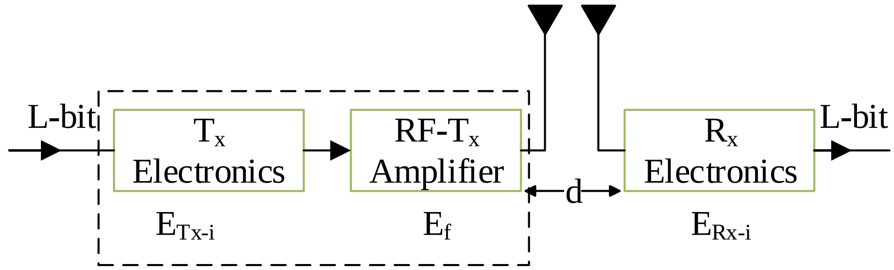


Figure 11. RF energy modeling

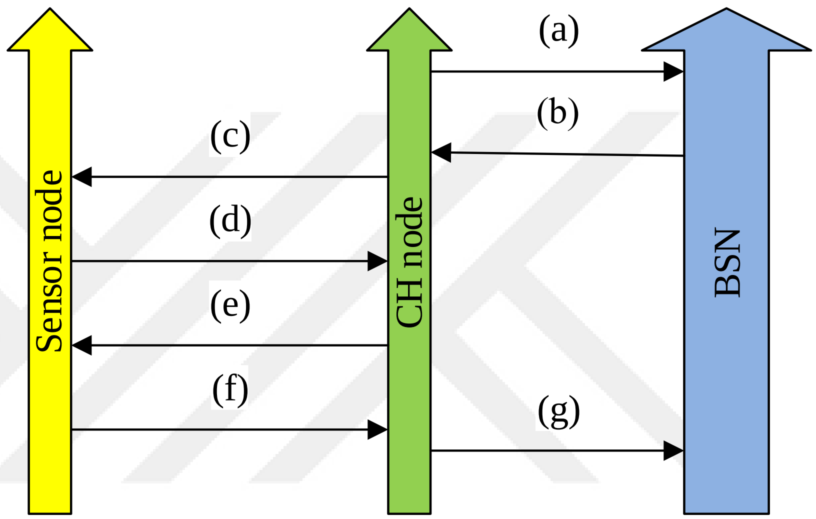


Figure 12. Communication in One Iteration

Announcement process to the sensor nodes- cluster formation:

CH sends an advertisement message to all the neighboring nodes contains its ID, its energy level, the position, and the header to distinguishes the message as an announcement message using a non-persistent CSMA MAC protocol. A sensor node receives CHs messages and evaluates signals power for the selection of appropriate cluster (with better signal intensity). It replies to this message to confirm its desire to be part of the new-formed cluster by a join message including node-ID, CH-ID, its location, node energy level.

- The energy expended by CH in the operation (c) resulting from sending advertisement is:

$$E_{CH-c} = L_C \times (E_{elec} + \varepsilon \times d_{max}^{\alpha}) \quad (15)$$

Where d_{max}^{α} is the maximum distance at which the CH must send control messages to cover all network nodes.

- Energy lost by a sensor node due to the reception of (K) advertisements from various CHs is:

$$E_{Non-CH-c} = K * [E_{elec} * L_C] \quad (16)$$

- The energy consumed by a sensor node resulting from the join message to the CH as in the operation (d) is:

$$E_{Non-CH-d} = L_C \times (E_{elec} + \varepsilon \times d^{\alpha}_{to\ CH}) \quad (17)$$

Where $d^{\alpha}_{to\ CH}$, is the distance between the CH and its member node.

- The energy consumed in the CH resulting from the receiving join requests as presented in is:

$$E_{CH-d} = \left(\frac{N}{K} - 1\right) * E_{elec} * L_C \quad (18)$$

Where $\frac{N}{k} - 1$, is the number of sensor-node in one cluster.

<u>Data transmission scheduling- cluster formation</u>

CH deduces the group of nodes associated with it in the cluster and sends a TDMA schedule to cluster members informing them in which time slot they will be able to transfer the data during the steady-state phase. This schedule serves to conserve non-CH node energy and avoids the collision between data messages. The radio of each non-CH node can be turned off until the node's allocated transmission time.

- The energy spent in the CH resulting from sending the TDMA schedule to all its member nodes in (e) is:

$$E_{CH-e} = L_t \times (E_{elec} + \varepsilon \times d^{\alpha}_{max}) \quad (19)$$

- Sensor node energy dissipated by the TDMA schedule reception is:

$$E_{Non-CH-e} = E_{elec} * L_t \quad (20)$$

This operation (e) declares the end of the set-up phase and the starting of the steady-state phase.

<u>Data transmission from sensor node to CH</u>

- Energy consumption in the sensor node due to the operation (f) is:

$$E_{Non-CH-f} = L_d \times (E_{elec} + \varepsilon \times d^{\alpha}_{to\ CH}) \quad (21)$$

Where L_d is the data packet length from node to CH.

- Energy losses of the CH by receiving data from cluster members is given by:

$$E_{CH-f} = (\frac{N}{K} - 1) \times E_{elec} \times L_d \quad (22)$$

<u>Data Aggregation and transmission to BSN</u>

Many steps are energy-consuming, but most of them are neglected when calculating the energy gain achieved by this protocol.

- Energy consumed in the CHs resulting from the aggregating of data received from the sensor-node is:

$$E_{CH-agg} = E_{DA} \times (\frac{N}{K}) \times L_d \quad (23)$$

Where, E_{DA}, is the data aggregation energy per bit.

- Energy from data transmission CH-to-BSN:

$$E_{CH-g} = L_d \left(\frac{N}{K}\right) \{E_{elec} + \varepsilon \times d^{\alpha}_{to\ BSN}\} \quad (24)$$

From the above the total energy dissipation for CHs and non-CH sensor-node, for one round can be approximated by:

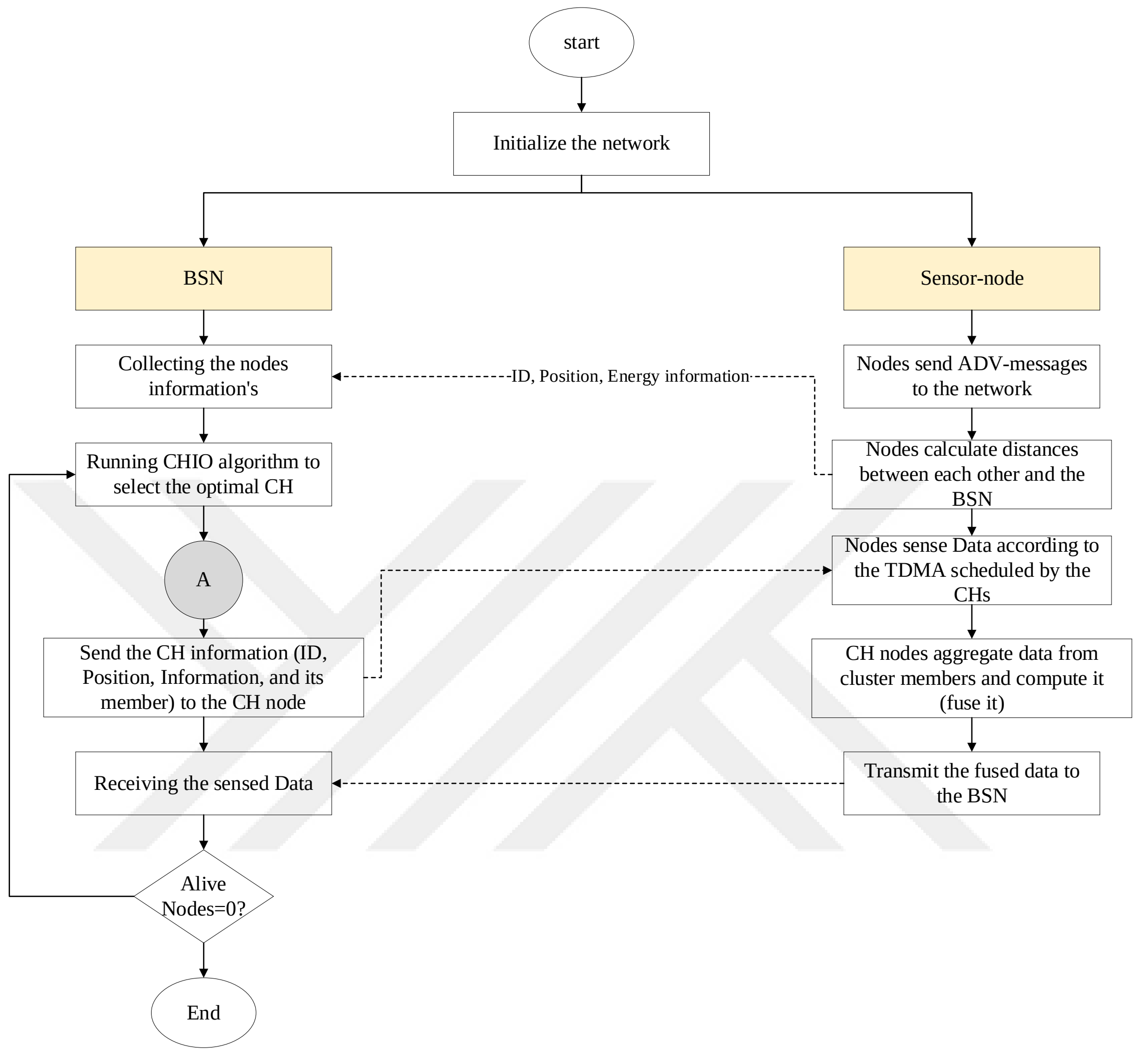
$$E_{CH-diss} = E_{CH-a} + E_{CH-b} + E_{CH-c} + E_{CH-d} + E_{CH-f} + E_{CH-agg} + E_{CH-g} \quad (25)$$

$$E_{Non-CH-diss} = E_{Non-CH-c} + E_{Non-CH-d} + E_{Non-CH-e} + E_{Non-CH-f} \quad (26)$$

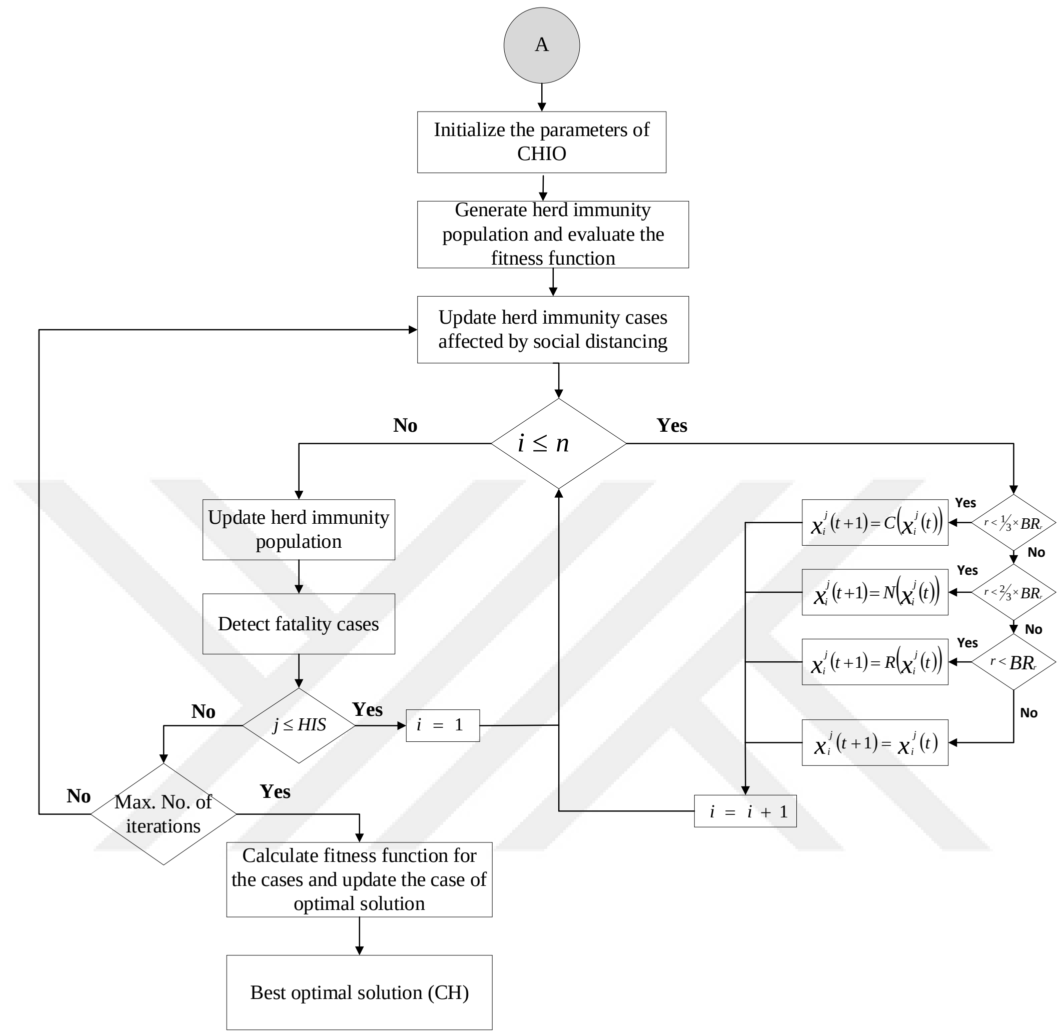
3.3. Proposed Energy Efficient CH Selection

3.2.1. The Proposed Protocol

The proposed clustering-based protocol LEACH-CHIO, is a centralized algorithm that is running based on instructions from the BSN to produce the optimal CHs that minimize the fitness function for the current round. It operates as LEACH, which consists of several rounds with two phases namely: set-up phase and steady-state phase. Furthermore, the BSN provides members for each cluster regarding the shortest distance and neighboring nodes list. The grouping of nodes is dynamically deployed randomized per round. Where n stands for nodes, which are the cases of herd immunity population, either immuned or susceptible and represent the CHs. The round begins with a set-up phase through which the nodes send their information to the BSN including current energy level, ID, and cross-distance between all nodes and between the nodes and BSN. In turn, the BSN does the selection of CHs depending on the remaining energy by operating the proposed protocol. It selects the top nodes in terms of energy level, energy consumption in the network, and adopting the shortest distance between the communication elements to perform its task as CH to the end of the current round. The shortest distance can be considered by the nodes themselves by calculating the distance between each other and between BSN, relying on the received signal strength that comes from the advertisement messages each sensor node sends. After that, it transmits these data to the BSN for utilizing it in the process of selecting CH and its members. The GPS has not been used in this protocol, to reduce the cost of energy, where it is sufficient to exchange advertising messages between nodes for determining their locations. For sending the advertisement messages CSMA-MAC protocol is used. After the BSN identifies the CHs and their selected members for the current round, they send an announcing message to the rest of the network containing the identity of the CHs and their cluster members. Then, the second phase of the round starts when the CH creates a TDMA schedule for each node within its cluster and based on which they send the sensed data in a specific period. This serves to avoid collision between the cluster member data and also contributes to node energy saving. The second phase here is the same as the second phase in LEACH protocol, where it turns to sleepy mode after transmitting the data at the specified time. While the CH node must keep its receiver on to receive all the data from the nodes in the cluster. Moreover, CHs aggregates the data from the nodes in the clusters, then perform signal processing functions to compress the data into a single packet signal and finally transmitted to the BSN. This entire process is represented as shown in the flowchart in Figure 13.



A. Communication process between BSN and the nodes.



B. Running CHIO algorithm to select optimal CHs.

Figure 13. Flowchart of CHIO algorithm for the optimal selection of CH.

In Table 1 the synonyms of CHIO algorithm parameters with its corresponding in WSN is presented.

Table1. Synonyms of CHIO and WSN Parameters.

CHIO Algorithm Parameters	**WSN Parameters**
C_0	Number of CHs.
Max_{Age}	Number of rounds where the energy level of nodes assumed to be depleted.

HIS, HIP	Field’s nodes.
n	Problem (Field) dimension.
Max_{itr}	Number of algorithm rounds.
Social Distancing	Cross-distance between nodes, CHs, and BSN.
Susceptible and Cases	Normal nodes.
Infected Cases	Candidate CHs.
Immune Cases	Sensing nodes that Cannot be chosen as CHs due to their lower energy level.

3.2.2. Proposed Fitness Function

Optimal CH selection is done by minimizing the predefined fitness function based on (Karaboga, Okdem and Ozturk, 2010). For the present work, a fitness function consist of three fitness values has been selected in which it has a very important role in expanding exploration and exploitation within the herd immunity population. The fitness value should be inversely proportional to the amount of energy consumed to choose the optimal CH, meaning that the best choice of CH is with the largest fitness value. The first fitness value is to find the highest energy level for the node (battery level) as shown in the following equation:

$$f^{E.level} = 1 - e^{\tau} \tag{27}$$

$$\tau = -\varphi \frac{min_{j=1}^{m}(E_j^{current})}{min_{j=1}^{n}(E_i^{current}) - min_{j=1}^{m}(E_j^{current})} \tag{28}$$

Where φ is a parameter to adjust the convexity degree of the fitness function and it specified to 20.72 (Karaboga, Okdem and Ozturk, 2010), i is node index, n is the network node number, m is CHs number, j is CH index for the current round, and $E^{current}$ is the node current energy level.

The second fitness value is achieved through reducing the energy consumed by taking into consideration the distance between nodes and CH and between the CH and the BSN, which can be seen by the following equation:

$$f^{distance} = \left[w.\sum_j^n\left(\sum_i^{mj} d_{ij}^2 + b_j^2\right)\right]^{-1} \quad (29)$$

Where mj is nodes number in j^{th} cluster, j is the index of the cluster, b_j is the distance between the BSN and j^{th} CH, d_{ij} is the distance between i^{th} node and j^{th} CH and w is the multiplication of constant value (α) by time.

The third fitness value, includes one of the quality-of-service QoS parameters, which is the data packets delay of the clusters, that can be defined by the total number of data packets received in a certain period that's directly proportional to the number of cluster members (It takes more time in TDMA schedule), it can be represented by the following equation:

$$f^{delay} = \left[max_{i=1,\dots,n}(m_i + 1)\right]^{-1} \quad (30)$$

Where n is cluster number and m_i is the number of i^{th} cluster member.

CH is the node that consumes more energy within the network as it sends the fused data after collecting it from the sensor nodes to the BSN. After a certain energy level, those nodes that were selected as cluster heads will have insufficient energy to complete these operations if they are selected again as CH, it is best to treat it as a medium-sensing node only. The proposed equation for the fitness function is:

$$f = \delta.f^{E.level} + \beta.f^{distance} + \sigma.f^{delay} \quad (31)$$

Where, δ, β and σ are weight parameters for the fitness function its values between [0, 1] and must not exceed one when combined. It's used to assign a single fitness value to the fitness functions mentioned in the previous equations to determine whether this node is going to be selected as CH depending on its energy level.

3.2.3. Solution Representation of LEACH-CHIO

For example, the solution representation of clustering a WSN with 100 node and 5 cluster heads in LEACH-CHIO protocol can be implemented, in the following way:

a. Initialize CHIO parameters and the herd immunity population (100 nodes) with five randomly selected CHs for each individual.

60	77	1	20	99

Where, (60, 77, 1, 20, and 99) are the node numbers.

b. Evaluate the fitness function for each individual, where for each node:

- Calculate the distance between the node and all the CHs in the network.
- Assign the node to a CH, where the minimum distance between the CH and the node has been achieved.
- Compute the fitness function ($f = \delta . f^{E.level} + \beta . f^{distance} + \sigma . f^{delay}$).

c. Update the optimal solution of the herd immunity cases affected by social distancing and the fatality cases.

- The minimum C_o (Immune rate) will take 1 status infected by corona. The previous individual case study of (60, 77, 1, 20, and 99), will be examined relying on the reproduction rate BR_r, to determine whether the gene x_i^j r the node has preserved in its current state or affected by social distancing.

60	77	1	20	99

For example, in this case if $r \geq \frac{1}{3} BR_r$ then the individual considered infected by corona. So, this equation $x^j(t+1) = Cx_i^j(t) = x_i^j(t) + r \times (x_i^j(t) - x_i^c(t))$ is implemented for this case. The current case study is represented as follow:

60.3	77.9	1.6	20.7	99.4

By rounding to the nearest integer to give a discrete variable, the case study is then represented as follow:

60	78	2	21	99

– Detect the fatality cases. After updating the herd immunity population, the immunity rate of the currently infected case is monitored. If the case has not developed from infected to immune after a certain number of iterations as represented in the Max_{Age} parameter, the current case will be considered dead. The case will be rebuilt from scratch by using this formula:

$$x_i^j(t+1) = lb_i + (ub_i - lb_i) \times U(0,1)\,, \forall i = 1,2, \dots, n$$

~~60~~	~~78~~	~~2~~	~~21~~	~~99~~

25	42	65	11	83

d. Repeat the steps from a to d, till the maximum number of CHIO algorithm rounds is reached.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Simulation characteristics

For performances evaluation of the newly-proposed algorithm, the simulation of four scenarios is performed as presented in Table 2. There are five case studies for each scenario that differ in its number of nodes, as shown in Table 3. These case studies are selected to examine the behavior of LEACH and LEACH-CHIO protocols for various node number networks and with variety of cluster numbers for every network.

Table 2. Scenarios

Scenario	Number of clusters	Number of rounds
1	5	1500
2	5%	1500
3	10%	1500
4	15%	1500

Table 3. Case studies for each scenario

Number of nodes in case studies	Initial Energy (J)	Deployment Area	BSN Location	Number of rounds
20	0.1	(100,100)m^2	50,100	1500
40	0.2	(100,100)m^2	50,100	1500
60	0.3	(100,100)m^2	50,100	1500
80	0.4	(100,100)m^2	50,100	1500
100	0.5	(100,100)m^2	50,100	1500

Scenario 1 evaluate the case of fixed cluster number equal to five, for all its case studies, while in the other scenarios the cluster number is variable depending on the number of nodes in the network according to the equation:

$$Clusters\ number = number\ of\ nodes \times \frac{P}{100} \tag{32}$$

Where P (percentage of the node to become CH) equal to 5%, 10%, and 15%.

The number of rounds is fixed for all simulations to 1500, which is approved to be enough for results analysis. The total energy for deployed sensors is a function of the sensor-node number. It is selected to be the same for all simulations, equal to 0.05 J/sensor-node. Other characteristics of energy dissipation due to transmission, reception, data aggregation is listed in table 4 according to the model and setting adopted in the development of LEACH protocol (Heinzelman, Chandrakasan and Balakrishnan, 2000). Same approach is used for various data packet length. The dependence of these values will not affect the conclusions of the simulation because it is a comparative study between LEACH and LEACH-CHIO.

Table 4. Simulation Parameters

Parameter	Value
Transmitter Electronics (E_{elec})	50 nJ/bit
Receiver Electronics (E_{elec})	50 nJ/bit
Data Aggregation Energy (E_{DA})	50 nJ/bit
Transmitter Amplifier (ϵ_{fs})	10 pJ/bit/m^2
Transmitter Amplifier (ϵ_{mp})	0.0013 pJ/bit/m^4
Data packet length L_d	6400 bits
Control packet length- L_t and L_c	200 bits

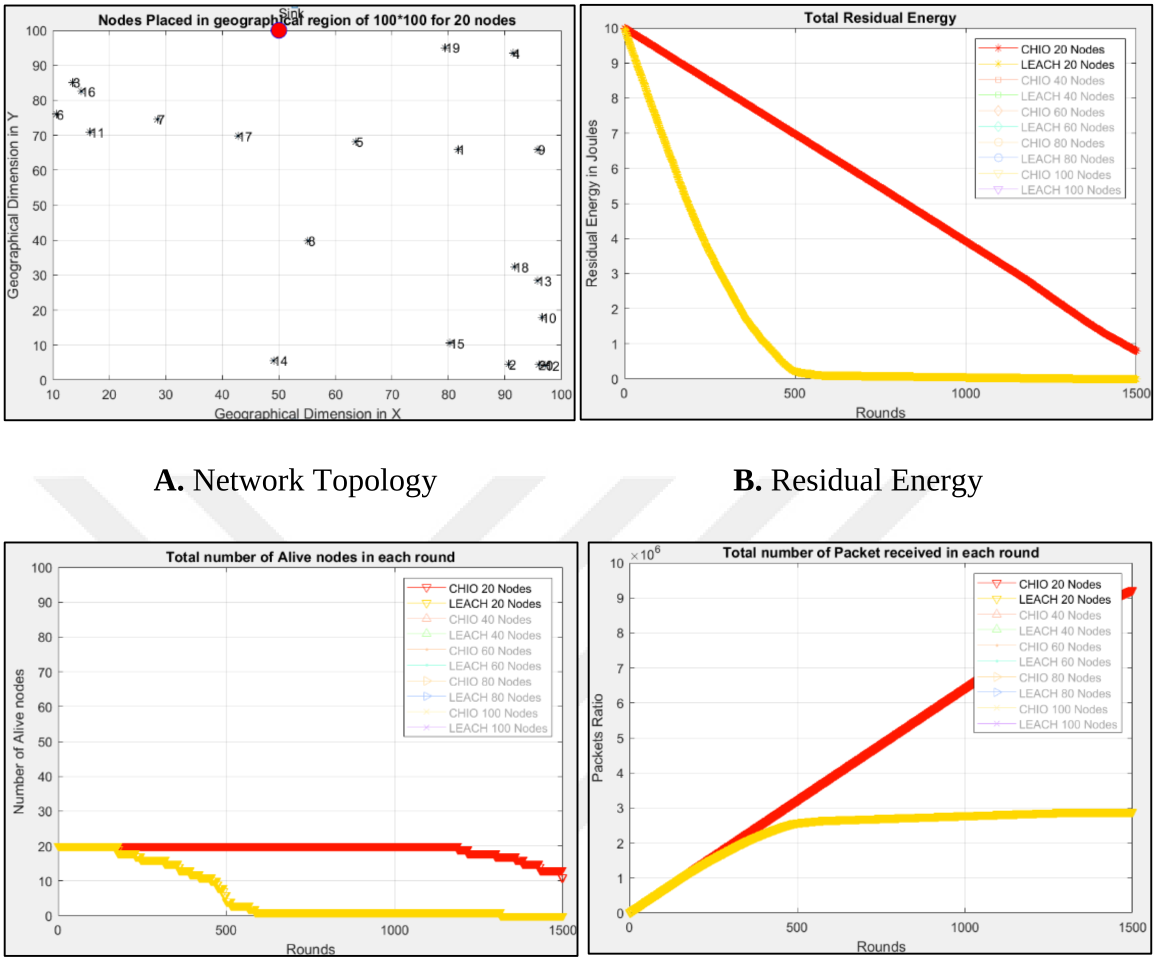
4.2 Simulation Results

4.2.1 Result of scenario-1 (5 clusters)

Scenario 1 is performed with fixed cluster number for all case studies, equal to five. A WSN consist of 20 nodes distributed randomly on 100×100 m^2 research area by the program is presented in Figure 14.A. In Figure 14.B a comparison of the proposed protocol (LEACH-CHIO) and LEACH protocol in terms of residual energy is shown. Both protocols are simulated with the same initial energy of 0.1 Joules. In LEACH, energy begins decreasing directly, but practically vanish after 583 rounds, while it still exists in case of LEACH-CHIO till it reaches 0.008011 J at the ends of 1500 round. Noticing that the residual energy is positively reflected on the number of alive nodes as shown in Figure 14.C, that after 1500 round no node is alive in case of LEACH protocol while 11 alive nodes remaining in LEACH-CHIO protocol. In turn the number of live nodes has been also positively reflected to the number of packets received as depicted in Figure 14.D, in which after the rounds end there will be 2889000 packets received in LEACH, and 9215000 packets for LEACH-CHIO

As middle point of comparison, round 500 is taking to demonstrate the difference between both protocols. The energy of LEACH at this point is 0.004518 J, while in LEACH-CHIO is 0.06895 J. This presents an improvement on the energy conservation of near to 1500% in the proposed algorithm. At this round the alive nodes in LEACH are 5 while LEACH-CHIO preserved all its node alive. The total number of packets received in LEACH at round 500 reached 2576000, while LEACH-CHIO has transmit 3200000 data packets.

The second case study is a 40-node WSN topology distributed as in Figure 15.A. Results of the residual energy are represented in Figure 15.B, noticing that the protocols start with a 0.2 J as an initial energy. LEACH energy begins to decrease directly till it vanishes after round 545. While the energy of LEACH-CHIO decrease till it reaches 0.004027 J at the end of simulation. as depicted in Figure 15.C unlike LEACH-CHIO that has all its nodes alive at round 545. At round 214, the energy of LEACH is almost the half with an amount of 0.1 J, while LEACH-CHIO still has 0.1695 J, which is nearly 84.75% of its original energy.



A. Network Topology

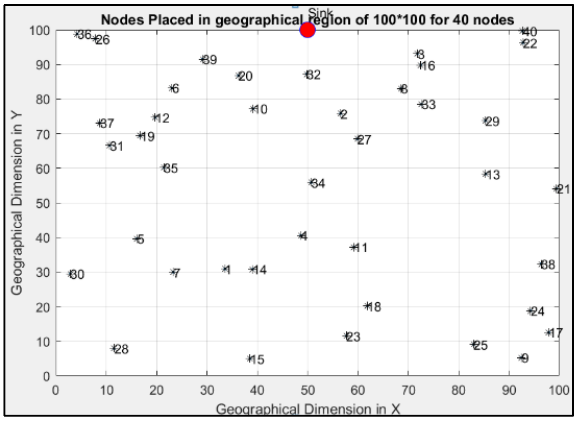
B. Residual Energy

C. Alive Nodes

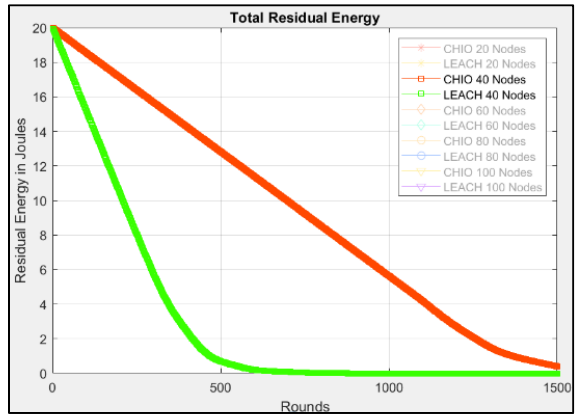
D. Packets Received

Figure 14. 20-Node WSN with 5 Clusters.

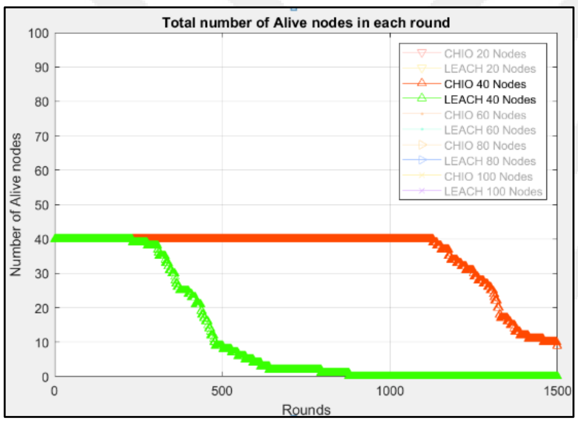
Nodes are starting to die in LEACH at round 269, while in LEACH-CHIO, nodes are starting to die at round 1200. After 1500 round the number of alive nodes in CHIO is 9. In Figure 15. D the packets received which is affected by the number of alive nodes also shows that after round 877 LEACH protocol curve stop to increase due to the zero energy and leads to a total of 2834000 packets received at the end of rounds while in case of CHIO there was a total of 8556000 packets.



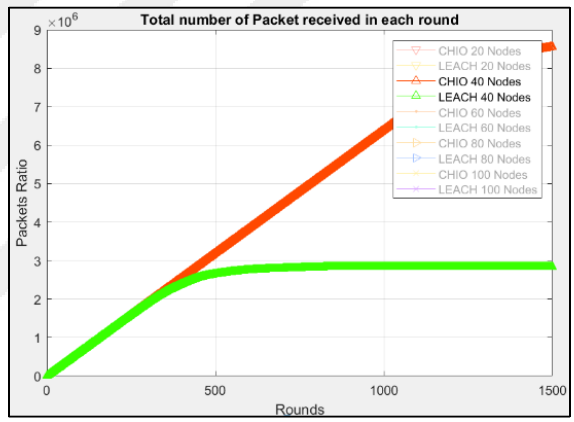
A. Network Topology



B. Residual Energy



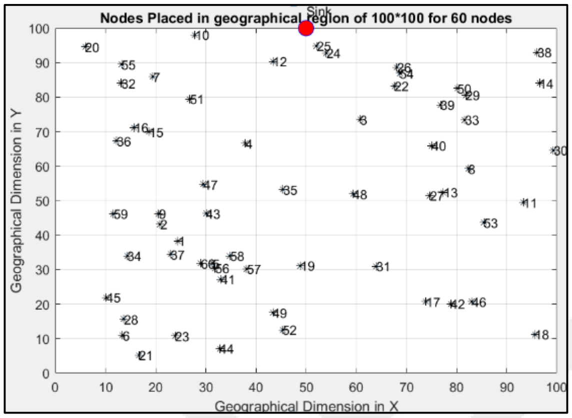
C. Alive Nodes



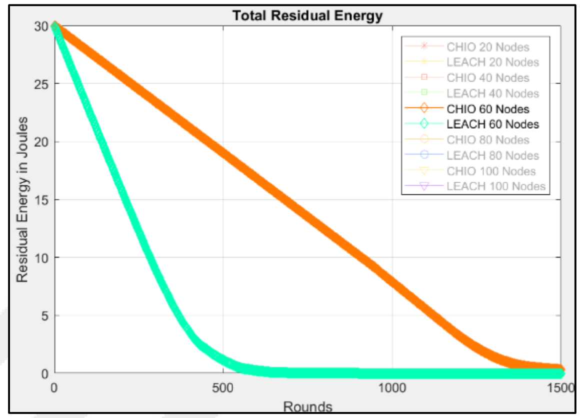
D. Packets Received

Figure 15. 40-Node WSN with 5 Clusters.

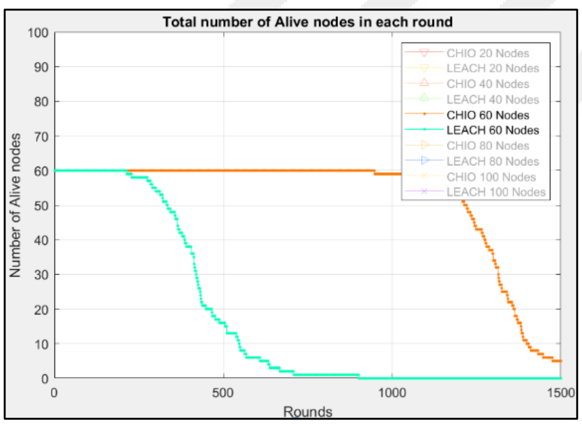
A 60-node WSN is presented in Figure 16.A. The comparison in the residual energy of LEACH-CHIO and LEACH is depicted in Figure 16.B and it shows that both protocols start with an energy of 0.3 J. LEACH protocol drops all its initial energy after round 520, but the LEACH-CHIO still have 0.00321 J, representing 34% of its initial energy at the end of round 1500. Examining LEACH protocol at round 200, shows that half of its energy is already vanished, while all its nodes still alive. The number of alive nodes in Figure 16.C is also affected by the residual energy, resulting the death of all nodes in LEACH will at round 902 while LEACH-CHIO still have its all nodes alive and that number starts to decrease after round 949 till it reaches 5 nodes at round 1500. The number of packets received in Figures 16.D shows that at the end of the rounds LEACH will have transmitted 2806000 packets and LEACH-CHIO 8409000 packets.



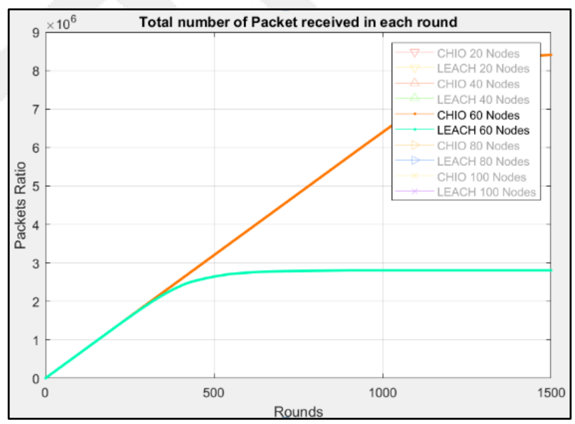
A. Network Topology



B. Residual Energy



C. Alive Nodes

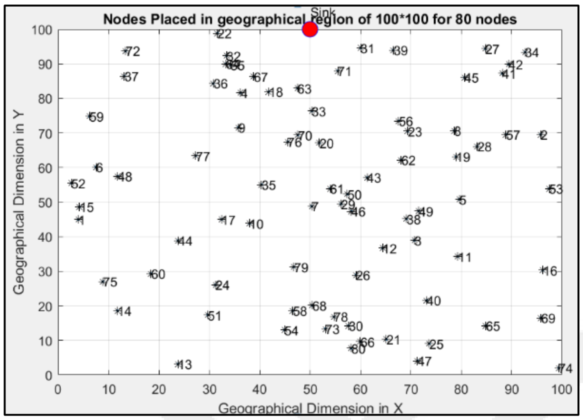


D. Packets Received

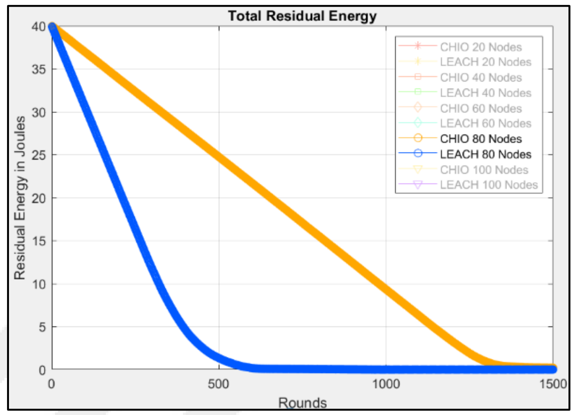
Figure 16. 60-Node WSN with 5 clusters.

Case study of 80-node WSN is presented in Figure 17. It turns out that the residual energy in the LEACH-CHIO protocol is always better than LEACH, in which at the end of the rounds LEACH-CHIO will have energy of 0.00217 J while the energy of LEACH vanished at round 504, when LEACH-CHIO reserved 61.45% of its initial energy. The effect of residual energy on alive nodes is evident in Figure 17.C, where at round the 500, 16 nodes are alive in LEACH which is 20% of the total number of network nodes, while LEACH-CHIO preserves all its nodes up. The first node dies at round 1099 in LEACH-

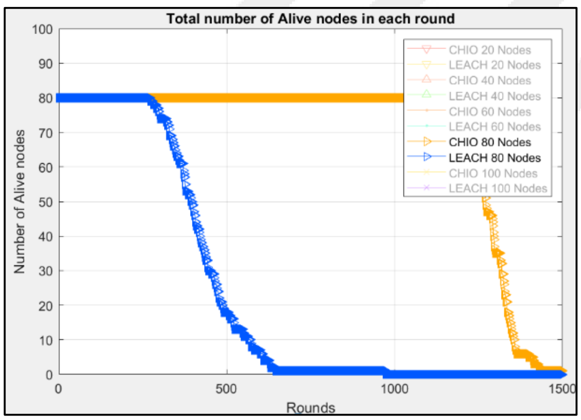
CHIO and at the end of simulation rounds, one node still up. Figure 17.D represents the number of received packets which are 2802000 and 8247000 for LEACH and LEACH-CHIO respectively.



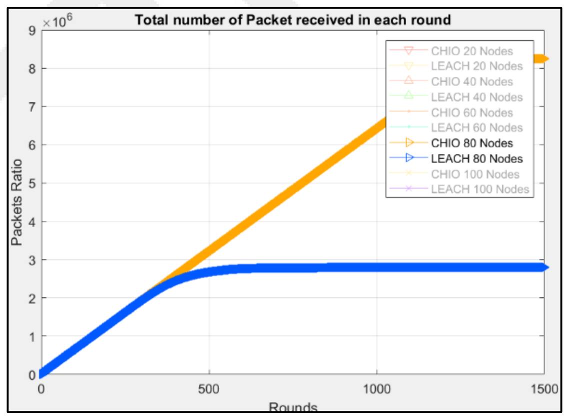
A. Network Topology



B. Residual Energy



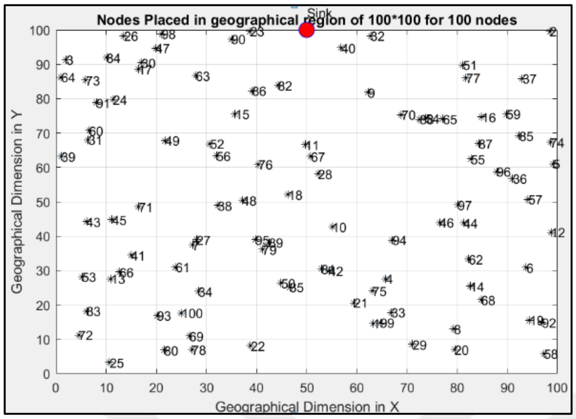
C. Alive Nodes



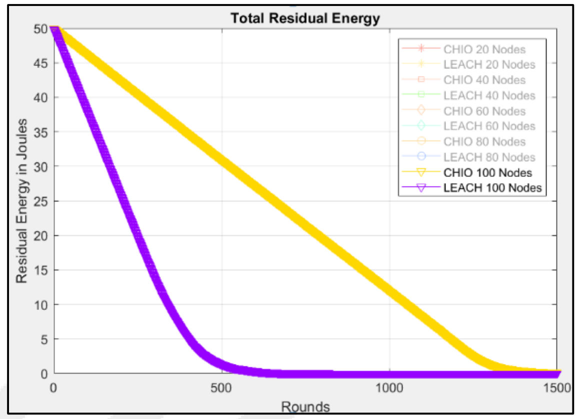
D. Packets Received

Figure 17. 80-Node WSN with 5 clusters.

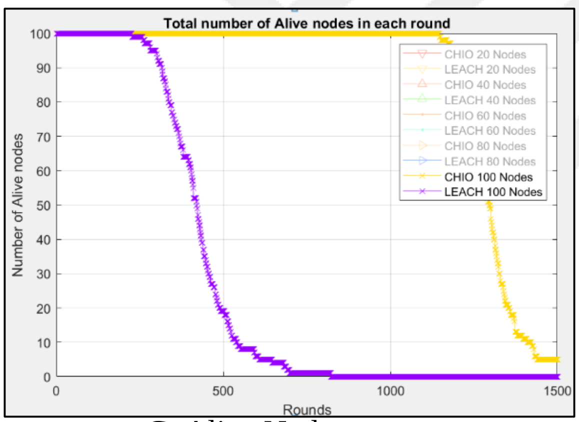
The last case study in the present scenario is a 100-node WSN as shown in Figure 18. Figure 18.B exhibits a comparison between LEACH-CHIO and LEACH in residual energy showed that after 520 rounds LEACH energy is vanished, while LEACH-CHIO still have 0.1869 J which is 37% of the initial energy at this stage with all nodes alive as in figure 18.C. At the end of round 1500, five nodes are up in the LEACH-CHIO and the residual energy is about 0.00093 J. The number of received packets in the WSN of 100 nodes for LEACH is 2722112 while for LEACH-CHIO is 8323455 packets as depicted in Figure 18.D.



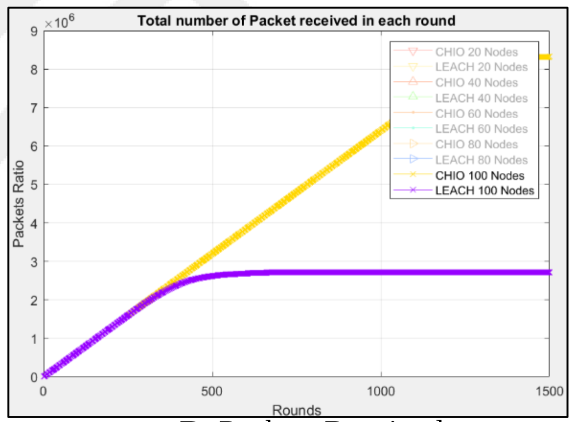
A. Network Topology



B. Residual Energy



C. Alive Nodes



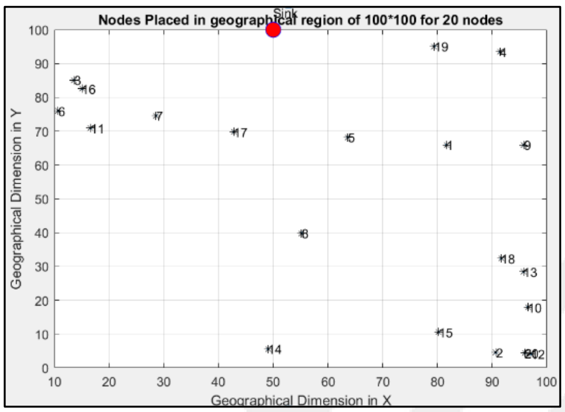
D. Packets Received

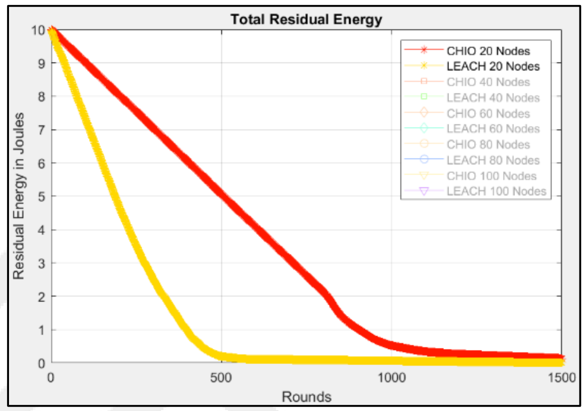
Figure 18. 100-Node WSN with 5 Clusters.

4.2.2 Results of scenario-2 (5%)

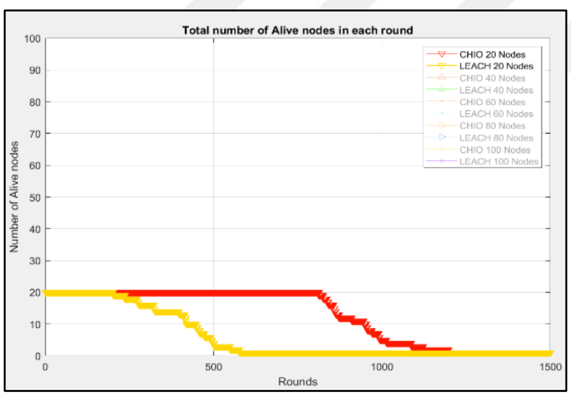
The results of all case studies of scenario-2 confirm the results found by their peer case studies of the scenario-1. In this scenario the number of clusters for all case studies are variables according to the number of nodes, and equal to 5% of the total number of nodes in the WSN. Figure 19 presents the case study of 20-node WSN within a single cluster. The total residual energy of LEACH at the end of simulation rounds for this case study is 0.00002272 J while for LEACH-CHIO is equal to 0.00135 J as shown in Figure 19.B. At the midpoint of simulation (round 750), LEACH-CHIO has preserved 26.21% of its initial energy, while LEACH is almost vanished with an amount of 0.0009362 J. Figure

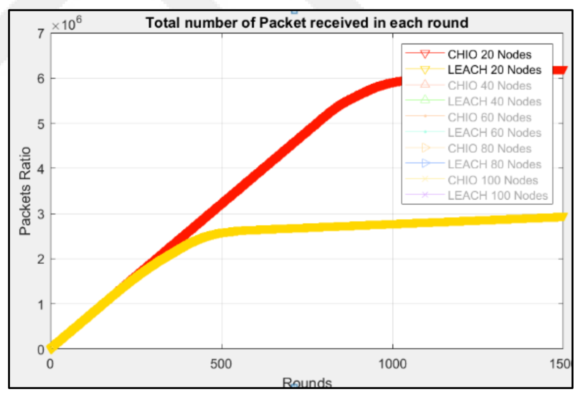
19.C shows the total number of alive nodes during the 1500 rounds, where LEACH-CHIO start to lose its first node after round 812 when LEACH has only one alive node. LEACH will transmit a data packet of 2949000 whereas LEACH-CHIO had 6206000 packets received as it depicted in Figure 19.D.





A. Network Topology **B.** Residual Energy

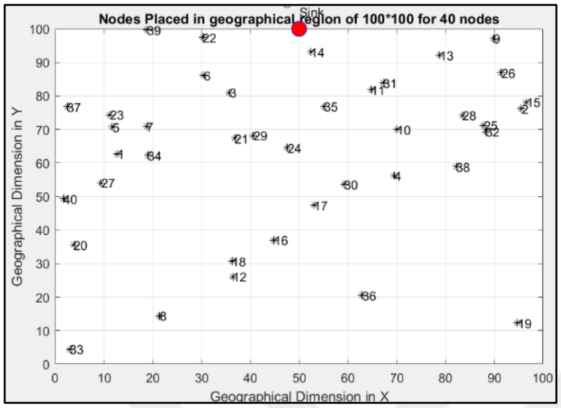




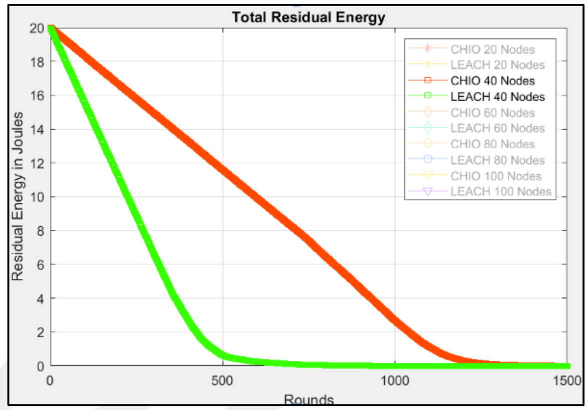
C. Alive Nodes **D.** Packets Received

Figure 19. 20-Node WSN with 1 Cluster

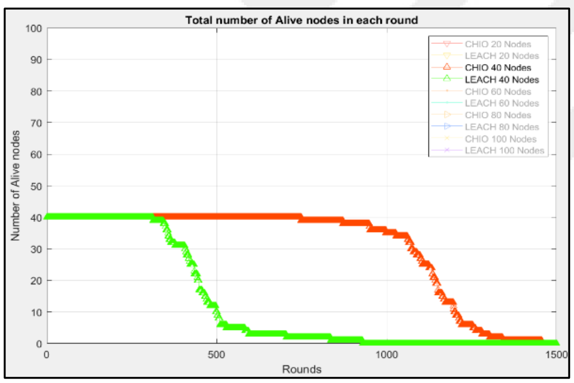
The second case study is of 40-node WSN partitioned into two clusters as shown in Figure 20. The total residual energy of LEACH and LEACH-CHIO is presented in Figure 20.B, and it shows that after 510 rounds the energy of LEACH is disappeared, while LEACH-CHIO still has 25.6% of its initial energy (0.04119 J), and keep decreasing until it reaches zero at round 1457. At this stage, 38 alive nodes are present in the LEACH-CHIO while all nodes are dead for LEACH as appears in Figure 20.C. At round 500, nearly 58% of the initial energy of LEACH-CHIO has been preserved, with all its nodes alive, while LEACH have only 3.1% of its initial energy with 10 alive nodes. The total number of packets received at the end of simulation for LEACH is 2992000 and in the case of LEACH-CHIO is 7261000 as it shown in Figure 20.D.



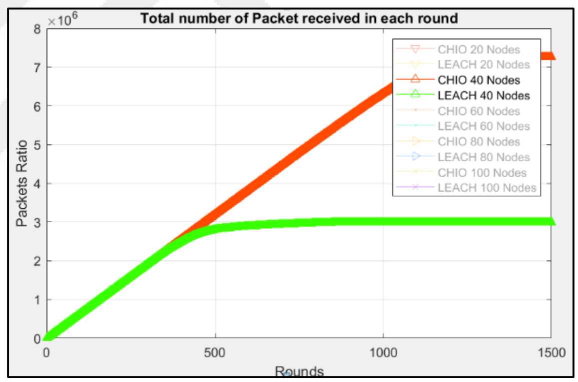
A. Network Topology



B. Residual Energy



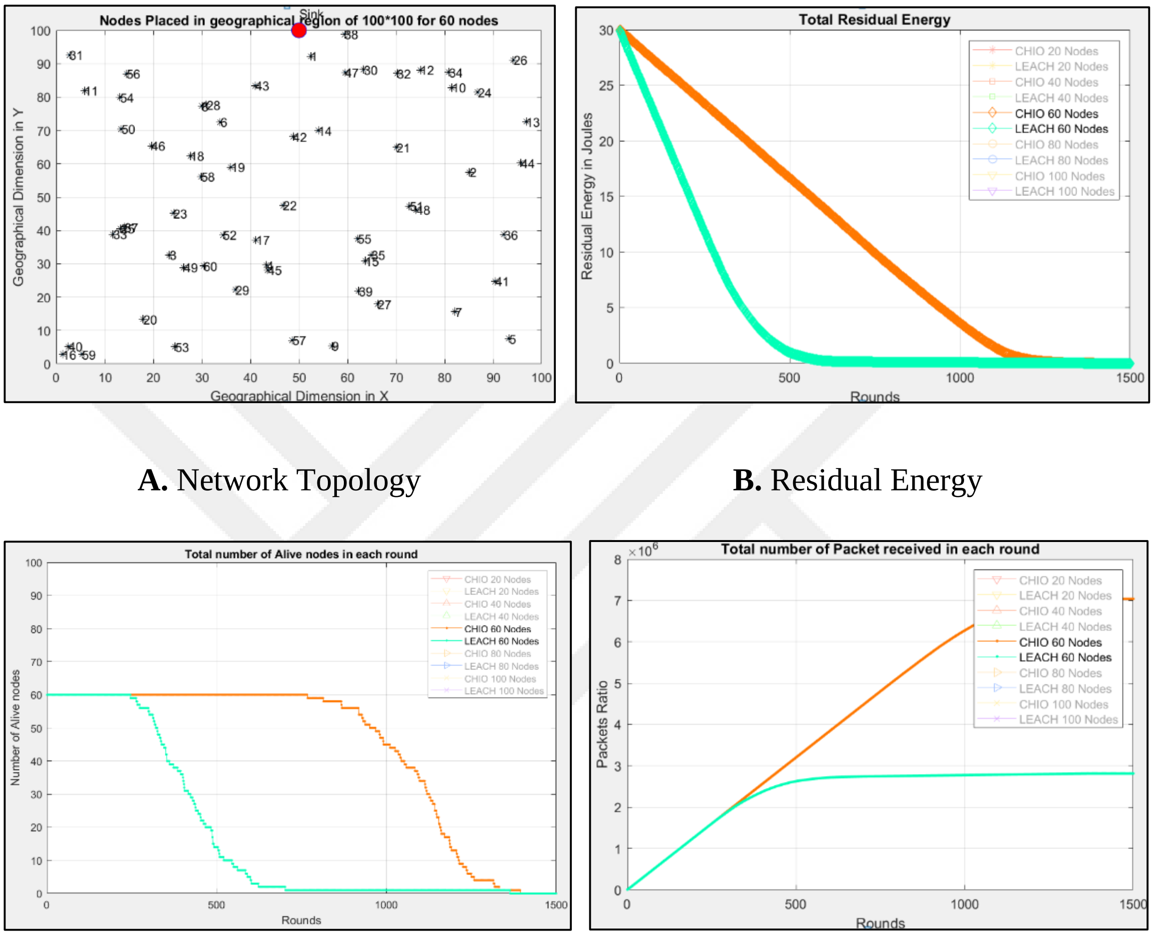
C. Alive Nodes



D. Packets Received

Figure 20. 40-node WSN with 2 Clusters.

A simulated research area of 60-node WSN with 3 cluster is shown in Figure 21. The comparison of residual energy for both LEACH and LEACH-CHIO protocols is shown in Figure 21.B. The results of comparison showed that after more than 500 rounds LEACH energy starts to vanish, while LEACH-CHIO still has got 55.3% of its initial energy. Figure 21.C showed that the residual energy reflects positively on the number of alive nodes, so after round 416 half of LEACH nodes dies, while LEACH-CHIO lost half of its nodes after round 1120, where it still has 10.5% of its initial energy. The residual energy also affects the received packets as in Figure 21.D. At the end of simulation LEACH protocol seemed to transmit a number of packets equal to 2814000 and in case of LEACH-CHIO, an improved packet number of 7038000 is shown.



A. Network Topology

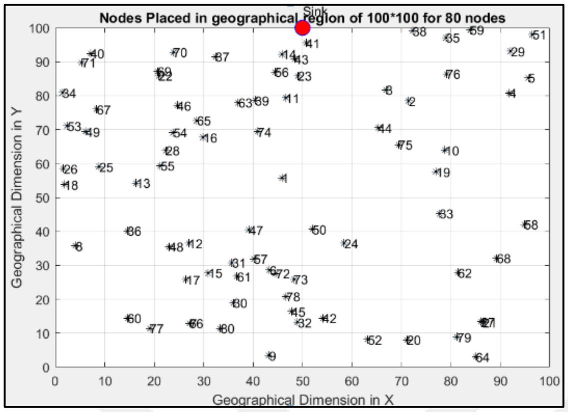
B. Residual Energy

C. Alive Nodes

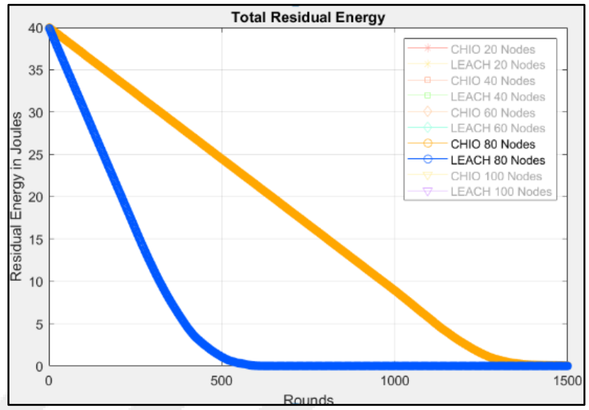
D. Packets Received

Figure 21. 60-node WSN with3 Clusters.

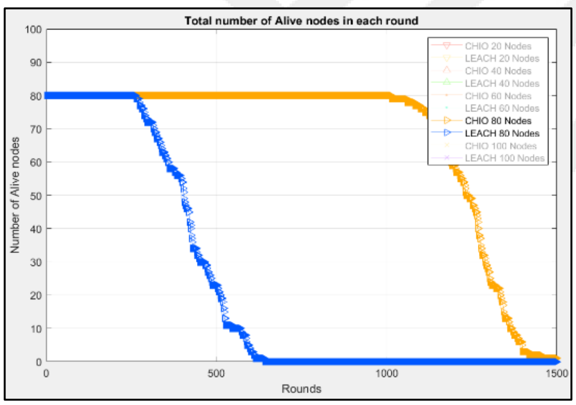
A WSN topology of 80 nodes is presented in Figure 22. Both protocol LEACH and LEACH-CHIO start with an initial energy of 0.4 J and after 633 rounds all the energy of LEACH drained out, but in the case of LEACH-CHIO, it still has 50.9% of its initial energy as in Figure 22.B. The LEACH protocol sees half of its nodes died at round 424 while LEACH-CHIO has all its nodes alive. The improved protocol starts losing nodes at round 1014until it reached one node at the end of the simulation as appearing in Figure 22.C. The comparison of packets delivered between the two protocols is shown in Figure 22.D. At the end of rounds, LEACH has 2766000 as a total of received packets while LEACH-CHIO has 8062000.



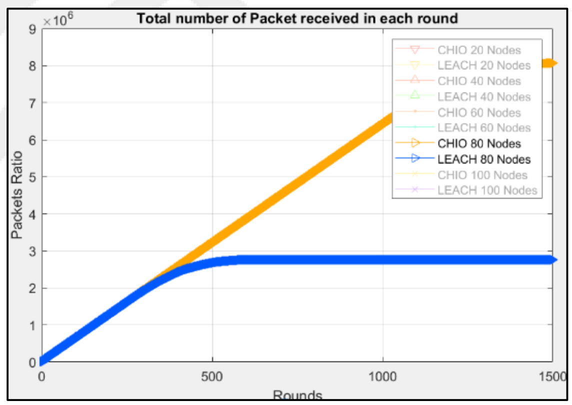
A. Network Topology



B. Residual Energy



C. Alive Nodes



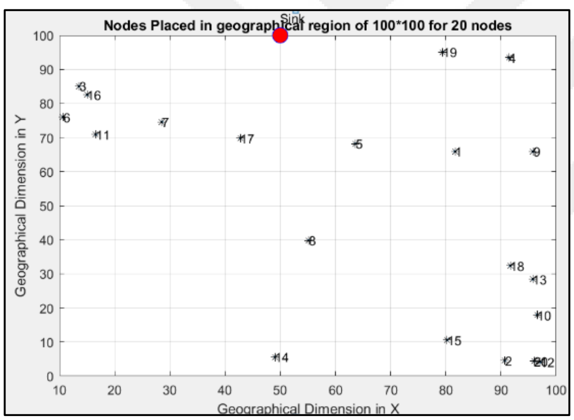
D. Packets Received

Figure 22. 80-node WSN with4 Clusters.

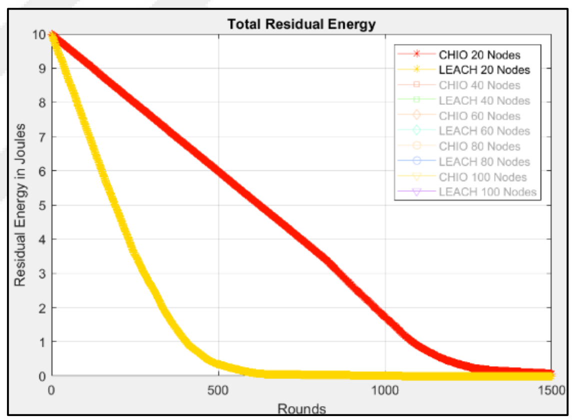
The simulation of the case study of 100-node WSN with 5% (5 clusters) is the same of the case study that has been presented in the previous scenario-1, figure 18.

4.2.3 Results of scenario-3 (10%)

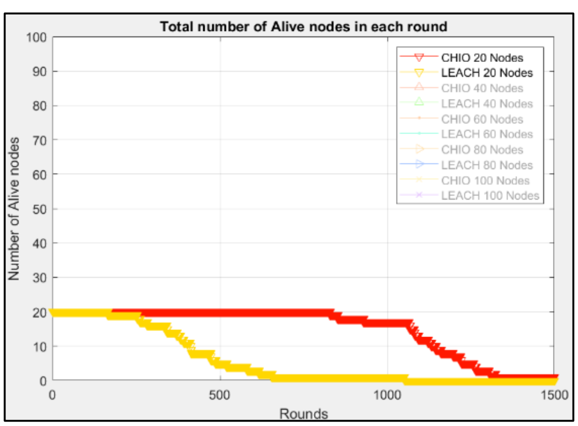
The number of clusters for all case studies is variable, and it's 10% of the total number of nodes in the network. The first case study is a 20-node WSN within two clusters as shown in Figure 23. The comparison between LEACH and LEACH-CHIO protocols for residual energy is presented in Figure 23.B. The energy of LEACH starts to vanishes at round 582, whereas it is equal to 0.05325 J for LEACH-CHIO. At the midpoint of simulation, round 750, LEACH has 3.5% of its initial energy with 5 alive nodes, while LEACH-CHIO has preserved 59.83% of the initial energy, with all of its nodes alive. LEACH-CHIO keeps one node alive at the end of simulation as it presented in Figure 23.C. Figure 23.D shows that at the end the total number of packets received in LEACH is 2842000 and in LEACH-CHIO is 7312000.



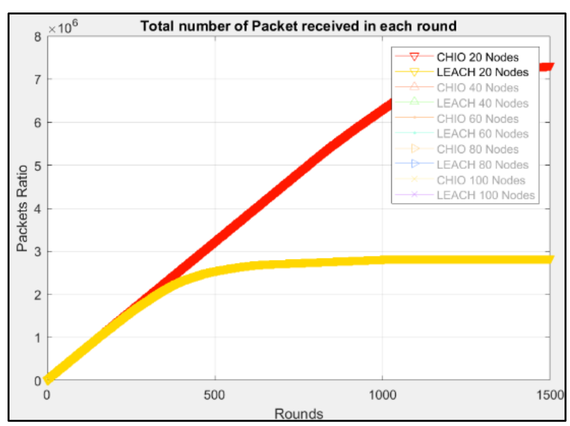
A. Network Topology



B. Residual Energy



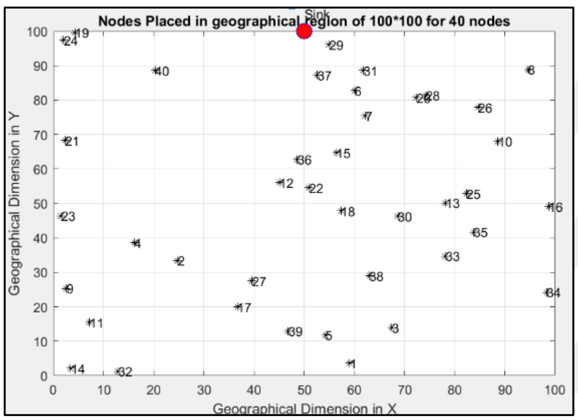
C. Alive Nodes



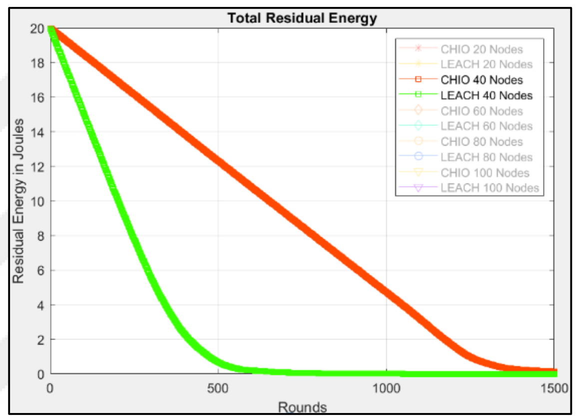
D. Packets Received

Figure 23. 20-node WSN with 2 Clusters.

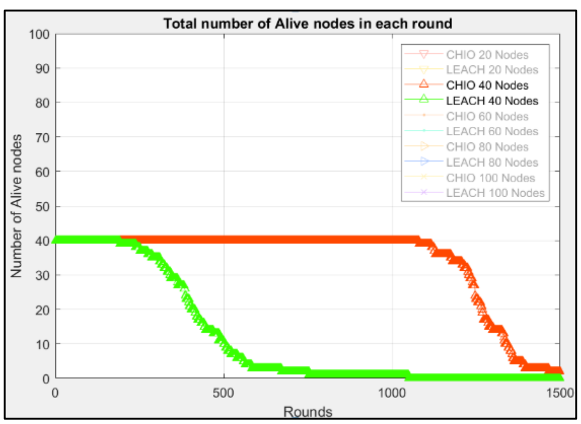
Figure 24 presents the network topology of 40-node WSN with four clusters. At the end of the simulated rounds LEACH-CHIO protocols has an energy of 0.001424 J while the energy of LEACH starts to drained out at round 523. At round 500, 10 nodes still alive in LEACH protocol with a total residual energy of 0.006717 J. While LEACH-CHIO still has 61.55% of its initial energy with all nodes up. The good performance of LEACH-CHIO is also reflected in the number of packets received, with a total number of up to 8194000 for LEACH-CHIO while the number of received packets in LEACH has reached 2788000 as it presented in Figure 24.D.



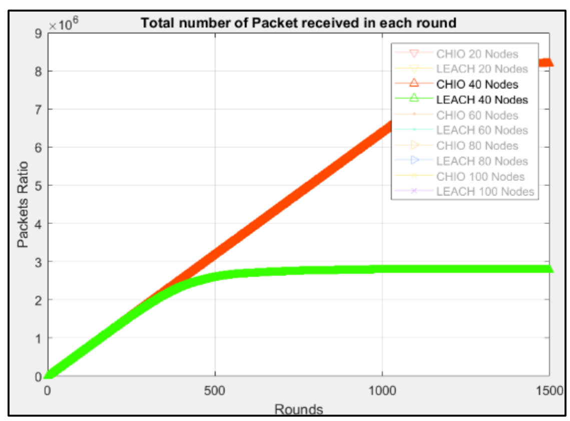
A. Network Topology



B. Residual Energy



C. Alive Nodes

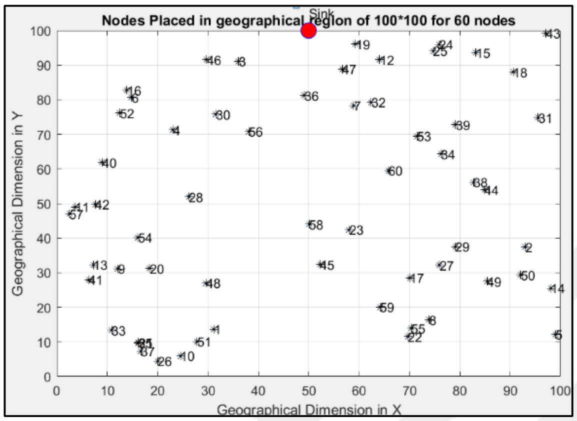


D. Packets Received

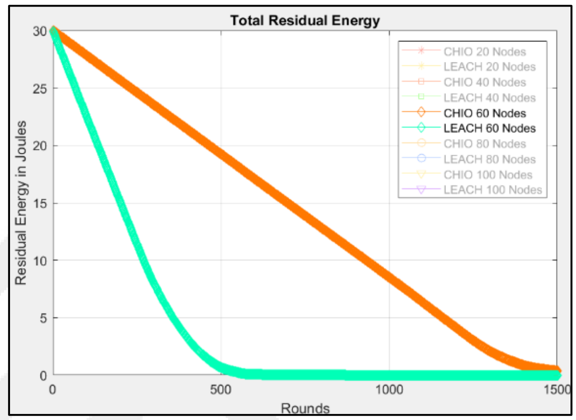
Figure 24. 40-node WSN with 4 clusters.

The comparison results of the last three case studies (60, 80, and 100 WSN nodes) are terms of topology, residual energy, alive nodes and the total number of packets received is presented in the Figures from 25 through 27. All show a net improvement of LEACH-

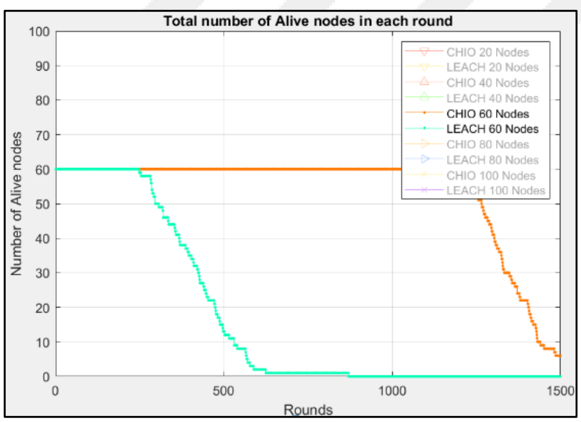
CHIO protocol compared to LEACH, in terms of residual energy, alive nodes, and received packets.



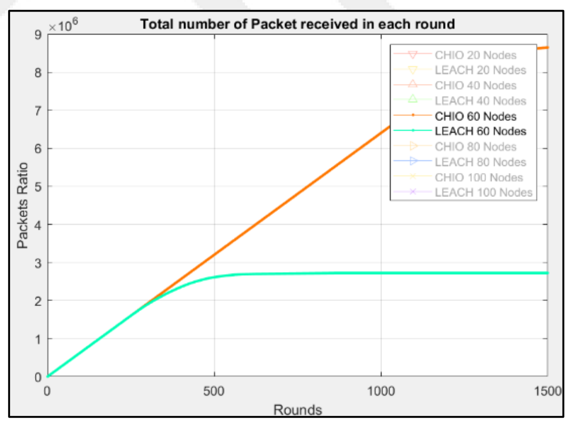
A. Network Topology



B. Residual Energy

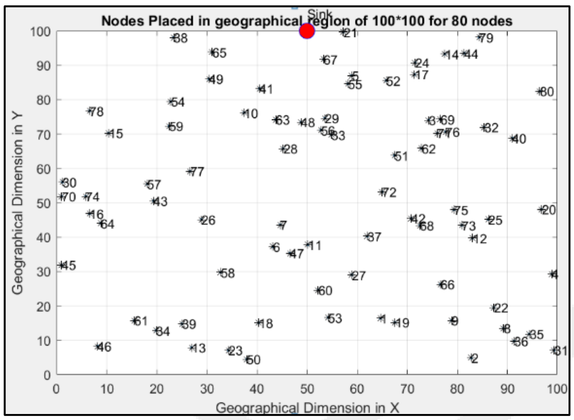


C. Alive Nodes

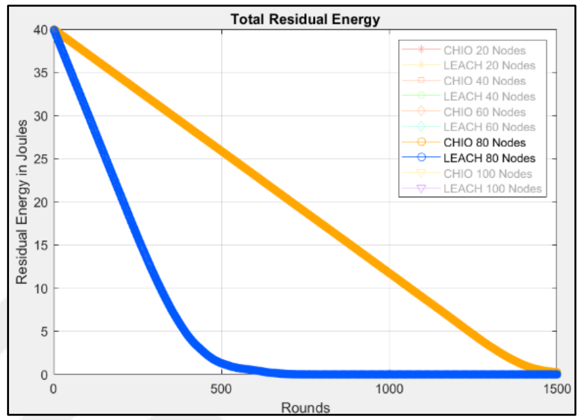


D. Packets Received

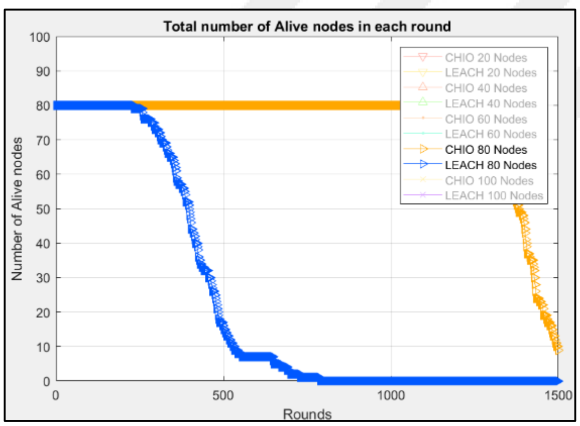
Figure 25. 60-node WSN with 6 clusters.



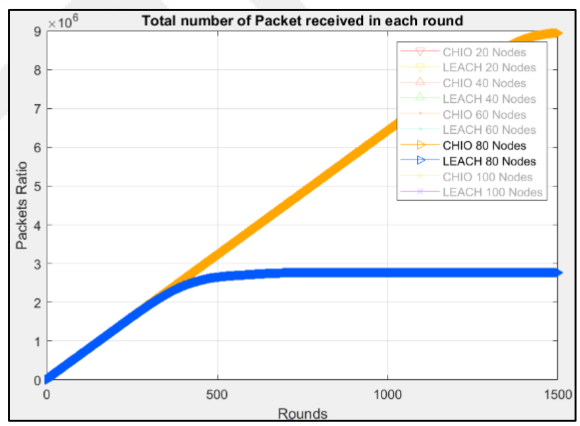
A. Network Topology



B. Residual Energy

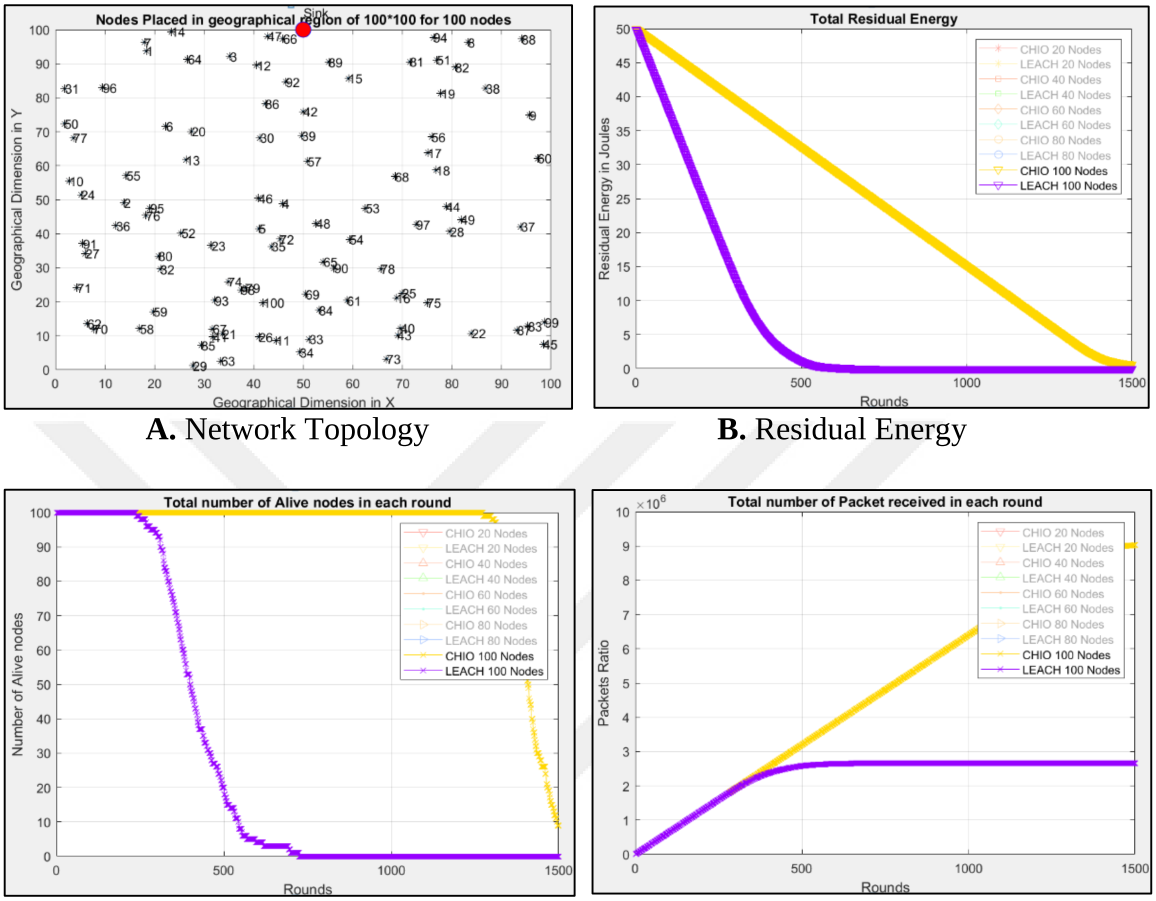


C. Alive Nodes



D. Packets Received

Figure 26. 80-node WSN with 8 clusters.



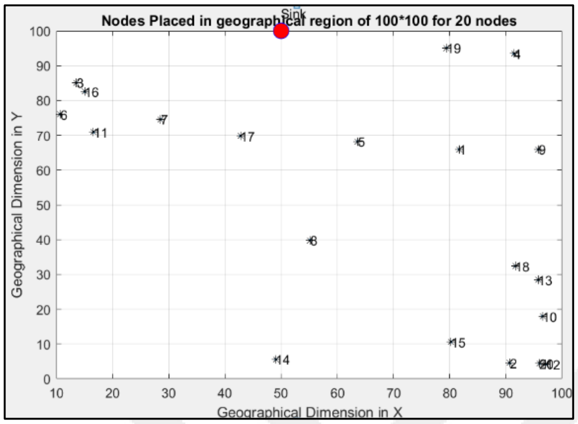
A. Network Topology **B.** Residual Energy

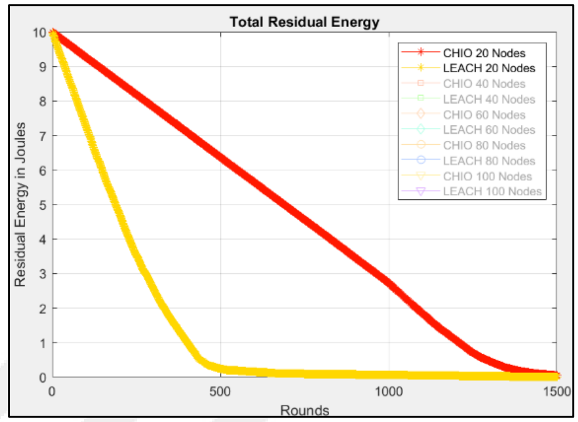
C. Alive Nodes **D.** Packets Received

Figure 27. 100-node WSN with 10 clusters.

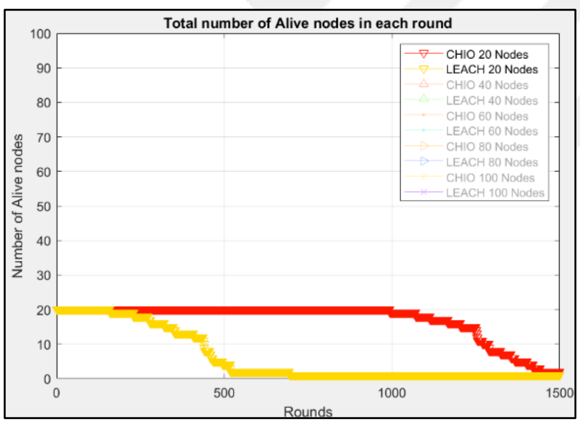
4.2.4 Results of scenario-4

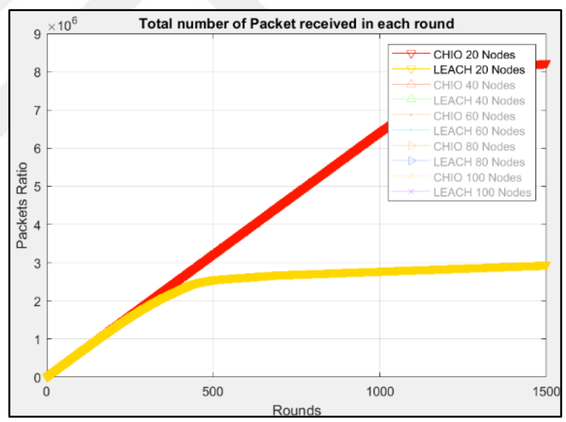
In this scenario the number of clusters for all case studies is variable and it's 15% of the total number of nodes in the network. Results for case studies of scenario-4 with 20, 40, 60, 80, and 100 nodes with 3, 6, 9, 12, and 15 clusters respectively, are depicted in Figures 28, 29, 30, 31, and 32.





A. Network Topology **B.** Residual Energy

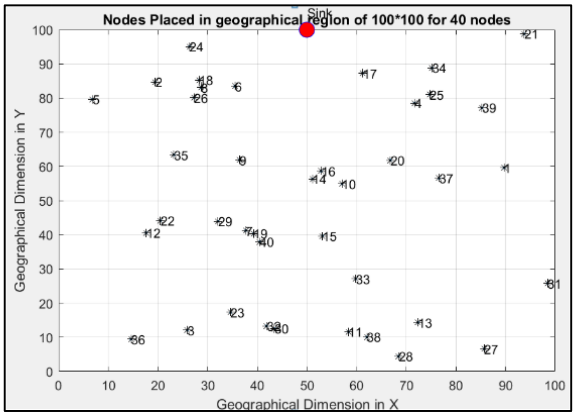


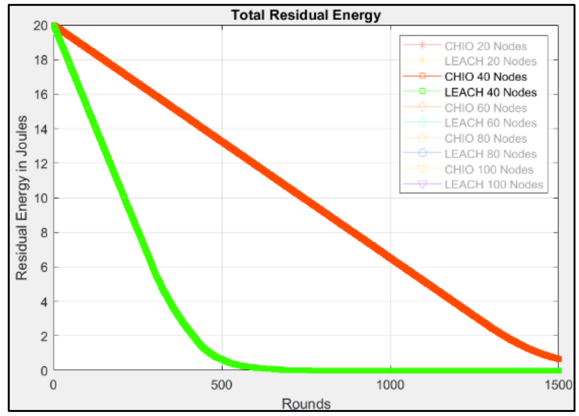


C. Alive Nodes **D.** Packets Received

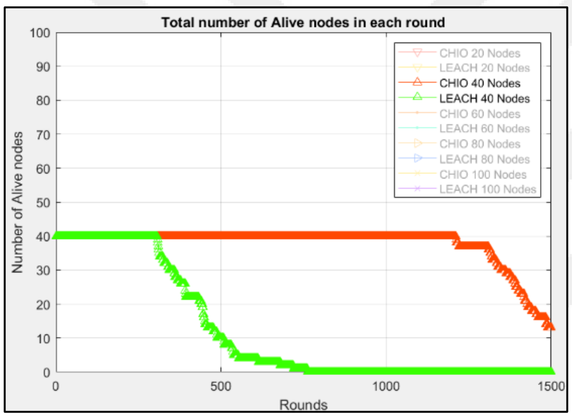
Figure 28. 20-node WSN with 3 clusters.

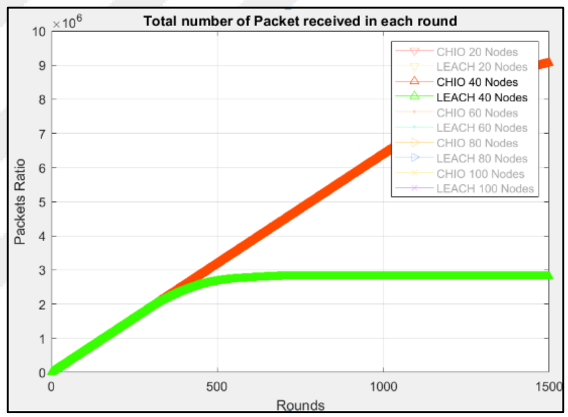
The comparison of residual energy between LEACH-CHIO and LEACH protocols for the five case studies is shown in Figures 28.B, 29.B, 30.B, 31.B, and 32.B. In Figure 28.B, half of the LEACH protocol energy is drained out after round 189 while in the LEACH-CHIO case half of the energy is vanished after round 689. That will leave the LEACH-CHIO with an energy equals to 0.0004974 J at the end of the rounds and LEACH with 0.00002204 J. In the second case, LEACH lost all its energy at round 761, leaves the LEACH with zero energy at round 1500 and 0.006688 J for LEACH-CHIO.





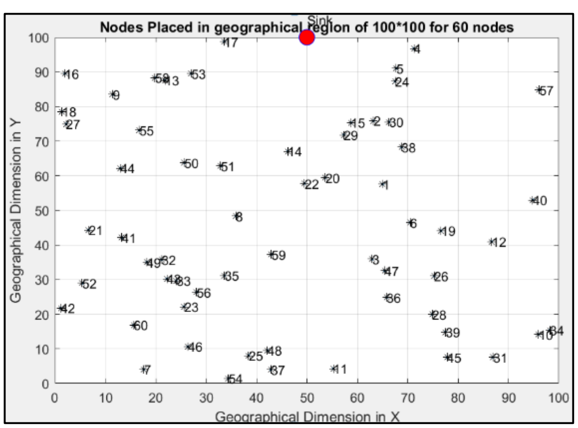
A. Network Topology **B.** Residual Energy

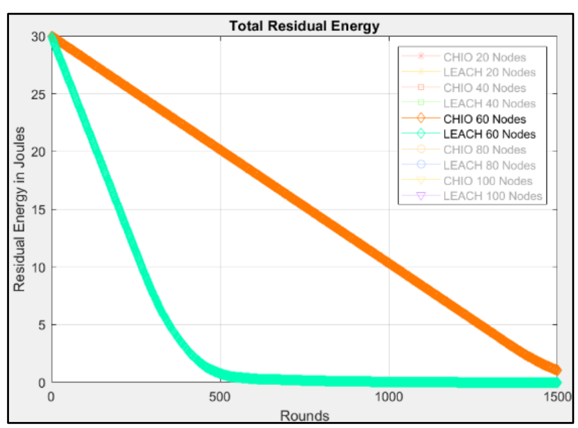




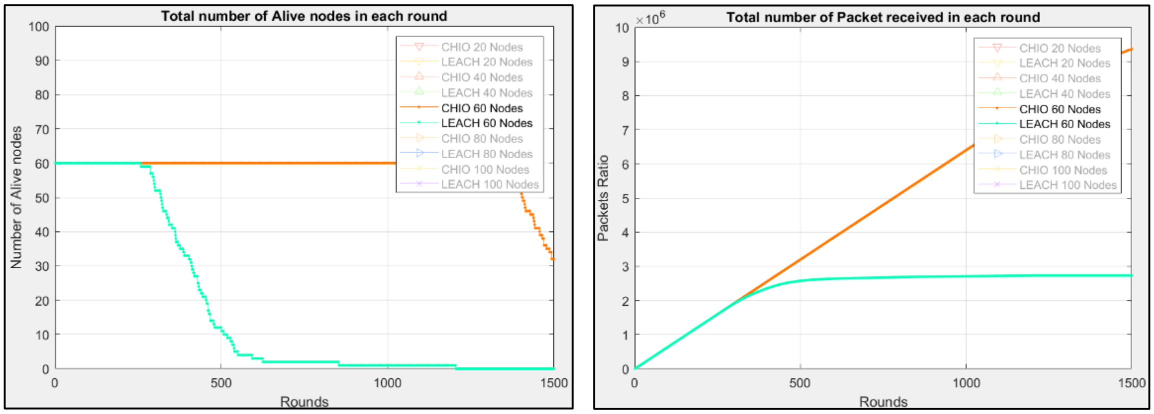
C. Alive Nodes **D.** Packets Received

Figure 29. 40-node WSN with 6 clusters.





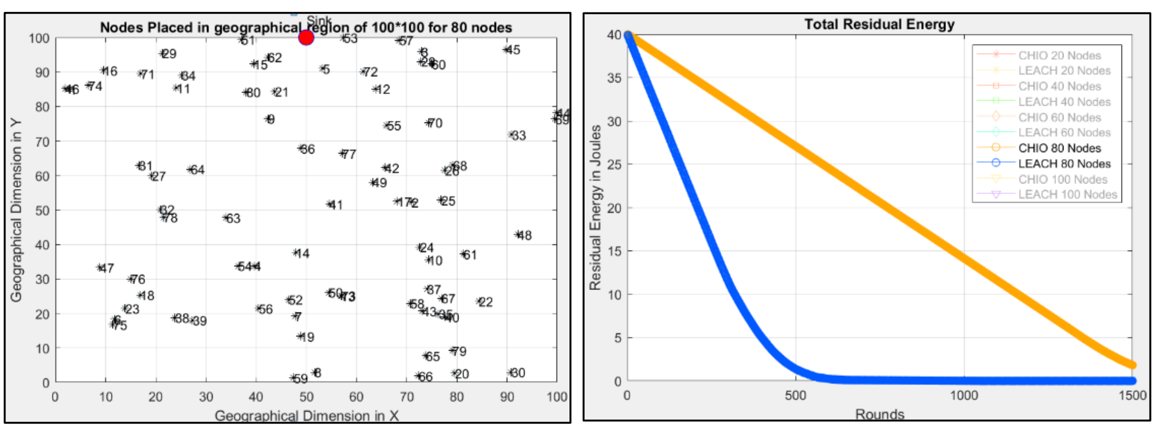
A. Network Topology **B.** Residual Energy



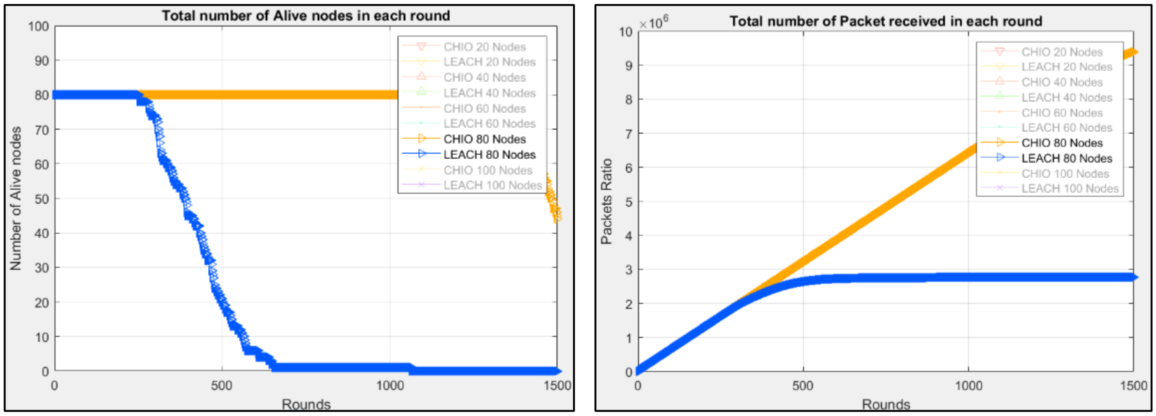
C. Alive Nodes **D.** Packets Received

Figure 30. 60-node WSN with 9 clusters.

Figures 29.C, 30.C, 31.C, 32.C, and 33.C presents the total number of alive nodes during the simulation rounds for the five case studies. At the end of simulation for the first case of LEACH, protocol one node still up while two nodes are up in the case of LEACH-CHIO. At round 761 in a WSN of 40 nodes, LEACH protocol will lose all its nodes, unlike LEACH-CHIO that still has all the nodes alive and starts losing then till reaching the end of the simulation with 13 nodes alive. For the rest of case studies which are 60-node, 80-node, and 100-node, comparable results can be deduced.



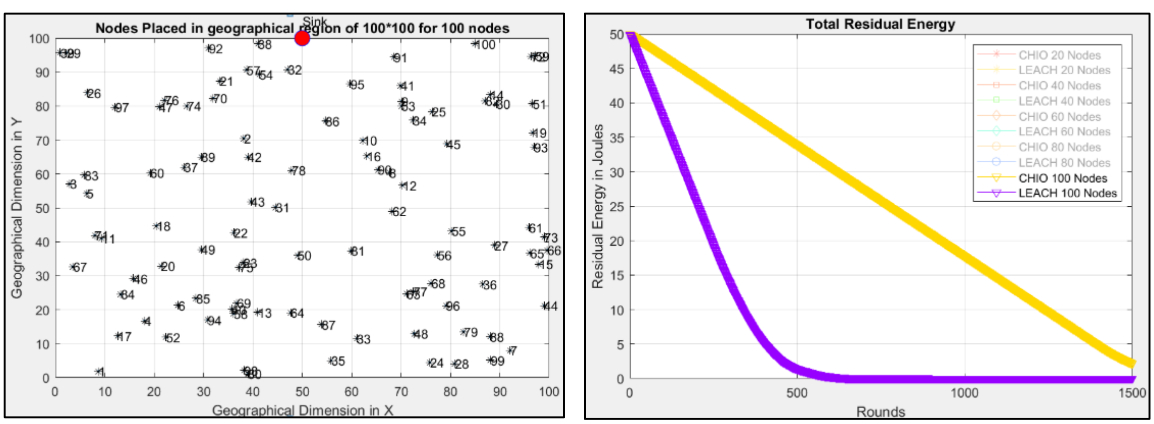
A. Network Topology **B.** Residual Energy



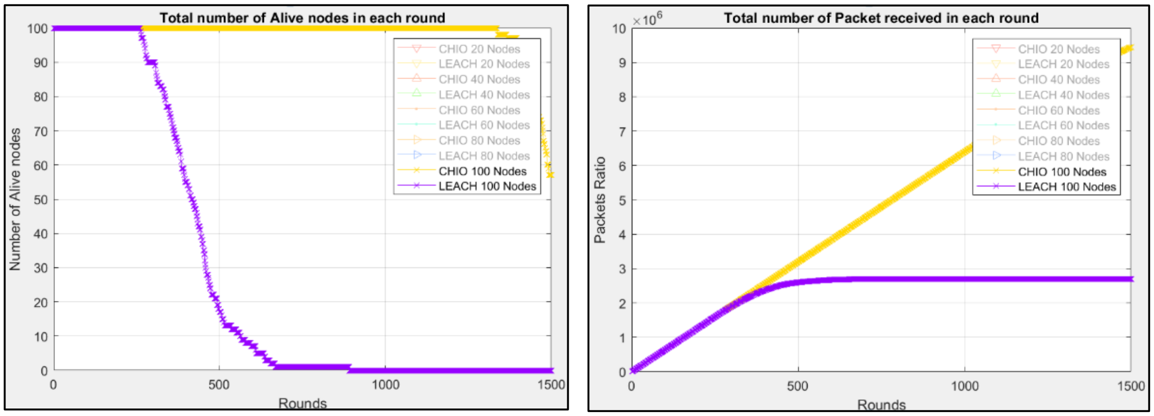
C. Alive Nodes **D.** Packets Received

Figure 31. 80-node WSN with 12 clusters.

The residual energy plays an important role in influencing both the number of alive nodes and the number of received packets directly, as shown in Figures 29.D, 30.D, 31.D, 32.D, and 33.D. The total number of received packets during the simulation process of 20, 40, 60, 80 and 100 nodes WSN for LEACH protocol are 2950000, 2819000, 2732000, 2777000, and 2704000 respectively, while in case of LEACH-CHIO are 8228000, 9060000, 9361000, 9384000 and 9439000.



A. Network Topology **B.** Residual Energy



C. Alive Nodes **D.** Packets Received

Figure 32. 100-node WSN with 15 clusters.

4.2.5 impact of cluster numbers on energy dissipation

To clarify the effect of cluster number on both protocols performance, the results of the previous four scenarios are used for a comparison for only the 100-node WSN. The results for 5% (5 clusters), 10% (10 clusters), and 15% (15 clusters) for both LEACH and LEACH-CHIO, are shown in the figures 33 and 34. The comparison is done to test the optimum number of clusters for the proposed algorithm (LEACH-CHIO). The optimum number of clusters in LEACH, has been determined analytically to be five (Heinzelman, Chandrakasan, and Balakrishnan, 2000). According to the experiment, it has also been proved the effectiveness of choosing 5%. Last node dies at rounds 1045, 725, and 892 for 5%, 10%, and 15% respectively, confirming this analytical conclusion. Prolong in the lifetime of the sensors network, provides an increase in the total number of data packets received by the BSN. In addition, it has also decreased the network energy consumption, which leads to getting the extreme benefit from the WSN.

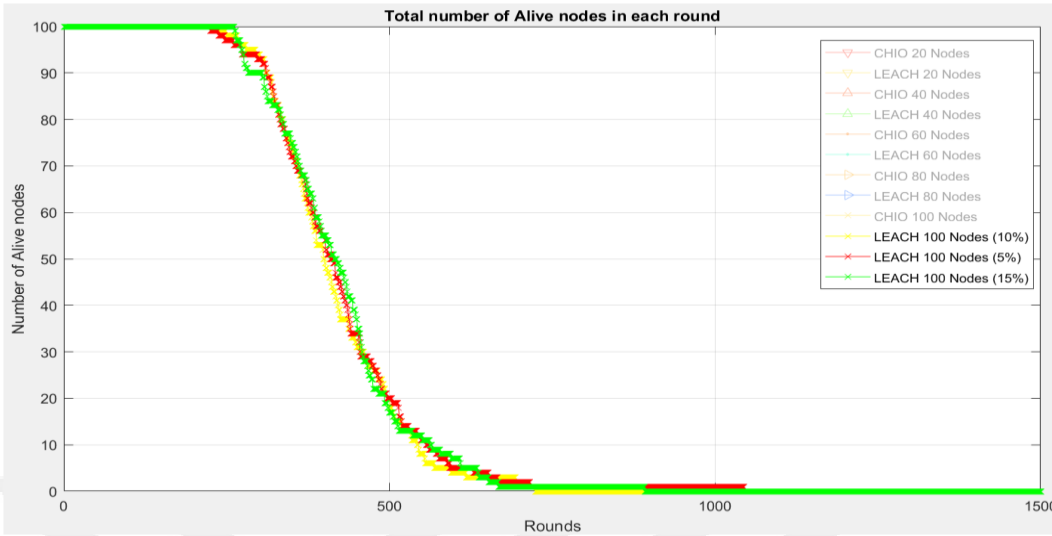


Figure 33. LEACH of 5%, 10%, and 15% clusters.

In Figure 34, the proposed LEACH-CHIO protocol is examined in the same context with 5%, 10%, and 15% clusters. Results have shown that the protocol is performing better for higher cluster number (15%). The node death process starts at round 1018 for the case study of 5 cluster, while it is in rounds 1275 and 1338 for 10 and 15 clusters respectively. This proves that the greater the number of clusters, the longer it leads to a prolonged lifecycle of the network sensors, which in turn leads to an increase in the number of data packets received by the BSN, and a reduction in the energy consumption within the network.

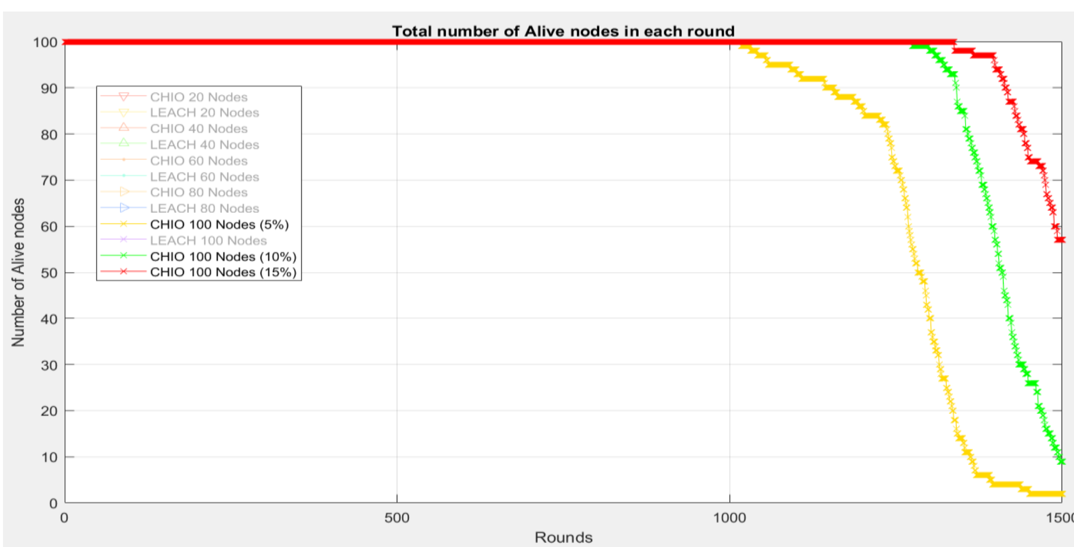


Figure 34. LEACH-CHIO of 5%, 10%, and 15% clusters.

4.2 Results Discussion

In the experiments above we have simulated four scenarios for a WSN with different number of nodes and clusters using LEACH-CHIO in comparison to LEACH alone. A clear difference (improvement) is shown with the use of LEACH-CHIO, coming as a result of the optimal selection of CHs. In scenario-1 five case studies was simulated with 5 clusters depending on the number of nodes in the WSN as indicated in Table 2. While in the scenario number 2 a WSN has been simulated with a cluster of 5% from the total number of nodes, that means when a WSN research area consist of 20 nodes, a one cluster is presented, and for a 100 WSN nodes, 5 will be the number of clusters in the current research area. Scenario number 3 was based on the selection of 10% of the total number of nodes as clusters. Finally, 15% of the total number of nodes was selected as clusters for scenario number 4.the results presented the total residual energy of the nodes, the total number of alive nodes and the total number of packets received in the network.

The residual energy has been positively affecting the number of alive nodes which in turn has also been positively affects the received packets.

The residual energy proportionated to the number of alive nodes, the lower the energy the lower the number of the alive nodes, taking into consideration that even if the node residual energy not sufficient to complete its operations, it considered alive till it reaches the minimum allowable energy level. And it can be shown evidently when comparing the percentage of residual energy after a certain number of rounds to the number of alive nodes in that round.

Certainly, the number of received packets will also be in direct proportion to the number of alive nodes. When all the nodes die, the packet transmission process will stop in the WSN and can be observed by stopping the increase in the received packets line in the Figures and remaining at a constant level in the case of LEACH. While in WSN based LEACH-CHIO it can be observed that the increase of received packets remains in a linear form till the end of the rounds. And keeping in mind that restimulating one of the case studies will shows a slight difference in the results, due to the random distribution of the nodes by the program.

In addition, a comparison of a WSN of 100 nodes with 5% of CHs and 100×100 m^2 field between LEACH (Heinzelman, Chandrakasan and Balakrishnan, 2000), LEACH-B (Tong and Tang, 2010), ESO-LEACH (Nigam, and Dabas, 2018), LEACH-PSO (Ahmed et al., 2019), and LEACH-CHIO algorithms, has been made with the same simulation parameters, as presented in table 5. The comparison presented is between the residual energy, alive nodes, and packets delivered to the BSN. The results show an improvement of the WSN by using LEACH-CHIO algorithm compared to others in terms of residual energy, which will be positively reflected to other performances.

Table 5. Results Comparison Table.

Algorithm	Residual Energy at round 750	Residual Energy at the end of simulated rounds	Alive Nodes at round 750	Alive Nodes at the end of simulated rounds	Backets Delivered to BSN
LEACH	0.0811 J	0 J	1	0	12800
LEACH-B	0.005 J	0 J	100	0	----
ESO-LEACH	0.035 J	0.003 J	60	0	----
LEACH-PSO	0.20 J	0.00019 J	100	2	----
LEACH-CHIO	0.2122 J	0.002214 J	100	2	8161000

CHAPTER FIVE

CONCLUSION

5.1 Conclusion

LEACH protocol has considered as one of the well-known hierarchical routing protocols in terms of performance in the WSN. One of the drawbacks of the LEACH protocol is the use of a pseudo-random process for selecting CH which leads to the fast power consumption of the WSN. This energy is consumed by the communication processes between the node and between the CHs of the BSN. Thus, many researchers are taking serious steps regarding optimizing this protocol to reduce power consumption and extending the life of the network. The optimization is usually applied to the selection of CHs because optimized selection leads to the energy consumption minimization. One of the latest optimization protocols that appeared recently is CHIO, which is adopted in this research for the purpose of extending the life of the wireless sensor network. It aims to optimize the process of CHs selection in LEACH by selecting the sensor-node with the highest energy. Four scenarios have been simulated for a WSN with different number of nodes and clusters using LEACH-CHIO in comparison to LEACH alone. A clear difference (improvement) is shown with the use of LEACH-CHIO, coming as a result of the optimal selection of CHs. For every scenario, five case studies have been simulated with 20, 40, 60, 80, 100 network nodes, and with different number of clusters. The first scenario is simulated for a fixed number of cluster equal to 5 for all case studies, while the number of clusters is variable according to the node number, with 5%, 10%, and 15% for scenarios 2, 3, and 4 respectively. The most interesting comparison is performed in the scenario number 5, where the cluster number is equal to 5% of the total number of nodes. Thus, for 20-node WSN there is only one cluster, two clusters for 40-node WSN, and finally, 5 clusters for the 100-node WSN. The importance of this scenario comes from the previous known result of maximum performance of LEACH in the case of 5% cluster number.

To clarify the effect of cluster number on both protocols performance, the results of the four scenarios are used for a comparison. The results presented the total residual energy of the nodes, the total number of alive nodes and the total number of packets received in the network. The comparison is done to test the optimum number of clusters for the proposed algorithm (LEACH-CHIO), since the optimum number of clusters in LEACH, has been determined analytically to be five (Heinzelman, Chandrakasan, and Balakrishnan, 2000). By observing the simulation results for the four scenarios, the network improvement is clearly seen when 15% of the nodes are used as CHs. Where for the last case study (100 nodes), the number of live nodes reached 57 nodes at the end of the simulation (1500 round), While in the LEACH protocol, all nodes are dead after the 750th round. The residual energy of LEACH-CHIO after the simulation rounds end was equal to 0.02186 J, leaving the LEACH with zero energy. As the residual energy plays an important role in influencing both the number of alive nodes and the number of received packets directly. So, LEACH-CHIO has transmitted 9439000 data packets compared to LEACH that has only transmitted 2704000 packets. This proves that the greater the number of clusters, the longer it leads to a prolonged lifecycle of the network sensors, which in turn leads to an increase in the number of data packets received by the BSN, and a reduction in the energy consumption within the network.

Future works

Many research ideas can be noticed as future work related to the present work:

1. CHIO is adjustable depending on the variables of events and the statements issued by the World Health Organization regarding the epidemic. So, we recommend modifying the protocol to accommodate the expected changes to the variables of the algorithm in the future.
2. Comparing the performance of LEACH-CHIO with one of the LEACH successor's protocols can also be suggested.
3. Wide geographical range of WSN deployment can be suggested to observing the effect of the distance with the same percentages of CH selection. Since LEACH-CHIO is a centralized algorithm, so may by maximizing the distance a decline in

the performance happens. In addition to examining the performance of LEACH-CHIO with increasing the number of sensor-nodes to 1000 nodes for example.

4. I have noticed during my research the disappearance of a research paper that collects all the energy-aware protocols based on LEACH with an optimization algorithm for selecting the optimal CH. So, I suggest another future work to be adopted is making survey research to summarize the performance results comparisons between all the optimization protocols.

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RESUME

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