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Fault Tolerance in WSNs Using Artificial Intelligence Techniques

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This study is wholeheartedly dedicated to

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To my dear brothers and my lovely grand mother

To my whole family

No words can describe your dedication and your sacrifices.

to my friends who helped me finished this project

I will always appreciate all they have done

I sincerely thank all of you for making this project possible.

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I dedicated this dissertation to

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Also, I dedicated this work to all my family and friends

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List Of Abbreviations

FT : Fault tolerance.

FD : Fault detection.

SN : Sensor node.

LEACH : Low-Energy Adaptive Clustering Hierarchy.

SPIN : Sensor Protocol for Information via Negotiation .

MLP : The Fuzzy Machine Learning Perceptron.

EER : Energy Efficient Routing .

AI : Artificial Intelligence .

ML : Machine Learning.

ANN : Artificial Neural Network.

ACO : Ant Colony Optimization.

CI : Computational Intelligence.

GA : Genetic Algorithm.

RL : Reinforcement Learning.

SI : Swarm Intelligence.

WSN : Wireless Sensor Network.

FL : Fuzzy Logic.

DFLBCHSA : Distributed Fuzzy Logic-Based Cluster Head Selection Algorithm.

Abstract

The work presented in this thesis is about enabling the fault tolerance property in wireless sensor networks using artificial intelligence approaches. Basically, The fault-tolerance property is defined by the network's capacity to continue operating properly in the presence of sensor failure.

In wireless sensor networks (WSNs), sensor nodes are prone to failures due to various reasons. However, failures caused by sensor battery depletion are the most common. For this reason, one of the main issues in the WSNs is developing an energy-efficient fault tolerant routing protocol to enhance the network lifetime.

One way to achieve energy efficiency and fault tolerance would be through the use of a clustering techniques. In this work we propose an approach based on reinforcement learning and ant colony optimization to deal with the problems of sensor nodes clustering and routing in a WSN with the ultimate goal of reducing energy costs to extend the network lifetime.

The performance analysis and the obtained results show that our proposed protocol efficiently optimizes the network lifetime by minimizing energy consumption and enhance the fault tolerance preventive aspect compared to the well-known LEACH protocol.

Keywords*:* Wireless sensor network, Fault tolerance, clustering, energy efficiency, network lifetime, artificial intelligence, cluster head, routing protocols.

Résumé

Cette thèse présente des travaux sur l'activation des mécanismes de tolérance aux pannes dans les réseaux de capteurs sans fil en utilisant une approche d'intelligence artificielle. La propriété de tolérance aux pannes du réseau se caractérise par sa capacité à continuer à fonctionner correctement en cas de défaillance d'un capteur.

Dans les réseaux de capteurs sans fil (RCSF), les nœuds de capteurs sont sujets à des pannes pour diverses raisons. Cependant, les pannes causées par l'épuisement de la batterie du capteur sont les plus courantes. Pour cette raison, l'un des principaux problèmes des RCSF est de développer un protocole de routage tolérant aux pannes et économe en énergie pour améliorer la durée de vie du réseau.

Une approche d'atteindre l'efficacité énergétique et la tolérance aux pannes serait d'utiliser une technique de clustering. Dans ce travail, nous proposons une approche basée sur l'apprentissage par renforcement (RL) et l'optimisation des colonies de fourmis (ACO) pour traiter les problèmes de clustering et de routage des nœuds capteurs dans un RCSF dans le but ultime de réduire les coûts énergétiques pour prolonger la durée de vie du réseau.

L'analyse des performances et les résultats obtenus montrent que notre protocole proposé optimise efficacement la durée de vie du réseau en minimisant la consommation d'énergie et améliore l'aspect préventif de la tolérance aux pannes par rapport au protocole LEACH bien connu.

General Introduction

General Introduction

Wireless sensor networks are composed of a group of sensors that can communicate with each other and provide information by collecting readings from various sensors. Such nodes have the ability to take decisions, process data and communicate through the wireless channel transmission to achieve common objectives. However, the battery-powered sensor nodes are mostly deployed in some harsh environments where manual maintenance is not an option.

During data collection, the energy decreases in the nodes and the lifetime of the network decreases. In order to maximize the lifetime of the network, the power consumption of individual nodes must be reduced. In order to enhance network lifetime, many solutions provide various techniques to optimize energy usage across the network. However, improvements are still required to complete a better performance.

WSN limitations have resulted in routing techniques that differ from those of traditional wireless networks. Because energy constraints are highly proposed in the WSN, several techniques have been developed to reduce sensor node energy usage. We are interested in hierarchical routing protocols because they are better in energy efficiency. Hierarchical routing allows nodes to group into (clusters) to improve energy in the network of sensors.

Artificial intelligence approaches such as reinforcement learning and ant colony optimization are introduced in this work to enhance the clustering techniques and improve the routing and paths finding methods to achieve better energy usage and reliable communication mechanism in the network.

This thesis is divided into 4 chapters :

- *The first chapter : introduction to wireless sensor networks*.

  This chapter begins with an introduction to the fundamental ideas and the evolution of wireless sensor networks. Then, covering the various layers, define the topologies, protocols, and existent models. Finally, the chapter entails WSNs applications and challenges to demonstrate the necessity for a fault tolerant system.

- *The second chapter : introduction to artificial intelligence.*

  In this chapter, we present a conceptual distinction between related terms and concepts such as artificial intelligence, deep learning, and machine learning. The history of AI and its applications and approaches were provided. Finally, a brief introduction and description of reinforcement learning and ant colony optimization approaches also represented.

- *The third chapter : Fault tolerance techniques.*

  This chapter begins with an introduction to the fault tolerant systems origins and representing the faults taxonomy. The means to achieve an efficient fault tolerant system in WSNs and the related work of researchers are also included in this chapter. Finally, a discussion of the problematics and challenges that threaten the effectiveness of fault tolerance strategies in the field of Wireless Sensor Networks.

- *The last chapter : The proposed approach to deal with fault tolerance in wsn*.

  The final chapter is arranged to introduce the proposed protocol for fault tolerance and energy usage optimization. The suggested algorithm phases are clearly detailed. The simulation part is offered to analyze and compare the results to the well-known Leach protocol.

Chapter 1 : Introduction to Wireless Sensor Networks

1. Introduction :

For more than sixty years, the main goal of the computer industry has been to use them in data processing operations to perform arithmetic, logic, etc. This is because computers are able to perform these tasks in record time with an accuracy that humans cannot match.

After a lot of time and effort. Thanks to the superiority of computers in data processing, scientists and researchers have finally introduced computers into the field of control.

Computers can now be associated with environments, record some of the factors present in that environment or control some of the devices in it. Connect a surveillance camera to a computer, monitor an area, record activity in that area, detect intrusions or connect a thermometer to control the air conditioner, turn the air conditioner on or off at a certain temperature, and many more examples. The role of the computer today is not limited to data processing ,but extends to the environment; recording some environmental factors, or automatically controlling devices .

For a long time, the connection of computers to measurement or control equipment was limited to direct cable connections between the computer and these equipment's. This wired connection undoubtedly limits the applications computers can provide in this field.

On the other hand, there has been continuous scientific development in recent years in the following areas: Electronics and wireless communications, have made it possible to create battery-powered wireless sensors that are small, low-cost, and versatile because they can transmit wirelessly over a wide range of distances.

The creation of these wireless sensors enabled a new technology called Wireless Sensor Networks, or WSNs for short. The latter in turn, creates a bridge between the world of information technology and the nature in which we live.

Wireless sensor network (WSN) based systems have been listed as one of the 21 most important technologies of the 21th century [1]. Given the diversity of these applications, this new technology is attracting increasing interest. However, the implementation of applications based on these systems presents many challenges in the operational reliability of these systems.

In this chapter, we will introduce WSN history, applications, architectures, and the main challenges.

2. WSNs Definitions :

According to [2] A wireless sensor network (WSN) is a wireless network consisting of autonomous devices that cooperatively monitor environmental conditions, such as temperature, sound, pollutants, and so forth.

Wireless Sensor Networks (WSNs) can be defined as a self-configured and infrastructure-less wireless networks to monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants and to cooperatively pass their data through the network to a main location or sink where the data can be observed and analysed. A sink or base station acts like an interface between users and the network. One can retrieve required information from the network by injecting queries and gathering results from the sink. Typically, a wireless sensor network contains hundreds of thousands of sensor nodes [3].

WSN is a wireless network that contains spatially distributed self-governing devices using sensors to monitor environmental and physical conditions. The WSN system incorporates a gateway that supply wireless connectivity back to the wired world and distributed nodes [4].

Wireless sensor networks (WSNs) consist of small nodes with sensing, computation, and wireless communications capabilities. These networks are widely used in many applications such as environment monitoring, disaster forecast, battlefield detection, traffic control, and disease diagnosis. Such a wide field of applications in wireless networking motivated the interest researchers to investigate an array of wide issues related to the nature of wireless ad hoc and sensor networks [5].

3. Origin and History of Wireless Sensor Networks [6] :

1950 : Military era

As with many advanced technologies, the origins of WSN can be seen in military and heavy industrial applications, e.g. The first wireless network to bear any real resemblance to a modern WSN was the Sound Surveillance System (SOSUS) [7], developed by the U.S. military in the 1950s to detect and track Soviet submarines. The network uses underwater acoustic sensors hydrophones that are distributed across the Atlantic and Pacific Oceans. This sensor technology is still in use today, but for a more peaceful function of monitoring marine life and volcanic activity.

1980 : Civilian era

Following investments in the 1960s and 1970s to develop the hardware for today's Internet, the U.S. Defense Advanced Research Projects Agency (DARPA) [8] launched the Distributed Sensor Network (DSN) program in 1980 to address the challenges of implementing distributed/wireless sensors formally Check the network. With the birth of DSN [9] and its entry into academia through partner universities such as Carnegie Mellon University and MIT Lincoln Laboratory, WSN technology quickly found a foothold in academic and civilian scientific research.

1990 : Consumers era

Governments and universities are eventually beginning to use WSNs in applications such as air quality monitoring, wildfire detection, natural disaster prevention, weather stations, and structural monitoring.

As engineering students entered the corporate world of then-tech giants such as IBM and Bell Labs, they began to drive the use of WSNs in heavy industrial applications such as wastewater treatment, power distribution, , and specialized factory automation.

The Evolution challenges :

While demand for WSNs has been strong, it has proven challenging to outpace these limited applications. Military, scientific/technical, and heavy industrial applications over the past few decades have relied on bulky, expensive sensors and proprietary network protocols. These WSNs prioritize functionality and performance at the expense of other factors such as hardware and deployment costs, network standards, power consumption, and scalability.

The combination of high cost and low capacity hinders the widespread adoption and deployment of WSNs in a wider range of applications.

4. WSNs Components :

Nodes (sensors) are small devices that measure, process, store, and transmit environmental data. This data may correspond to measurements of pressure, temperature, gas, sound, vibration,etc.

They mainly consist of the following components:

- ***Processor unit*** **:** (Calculating unit) or Processing unit, for example a microprocessor, which is capable of processing digital data.

- ***Memory unit*** **:** is a unit for storing information, for example data and available algorithms.

- ***Measurement system*** **:** is an acquisition unit that connects nodes to the physical world by measuring physical quantities (temperature, pressure, etc.).

- ***Telecommunications modules*****:** allow sending and receiving signals from other nodes, such as short-range radios . This Unit is in charge of transmitting and receiving the data produced by the processing unit, thus giving the sensors the ability to communicate with the other components of the network. The communication is carried out via a wireless medium which can be of optical, ultrasonic or radiofrequency type.

- ***Power unit*** **:** usually consists of non-interchangeable stacks, and most often a secondary power sources that harvest energy from the environment, such as through the use of solar panels, which has huge financial costs.

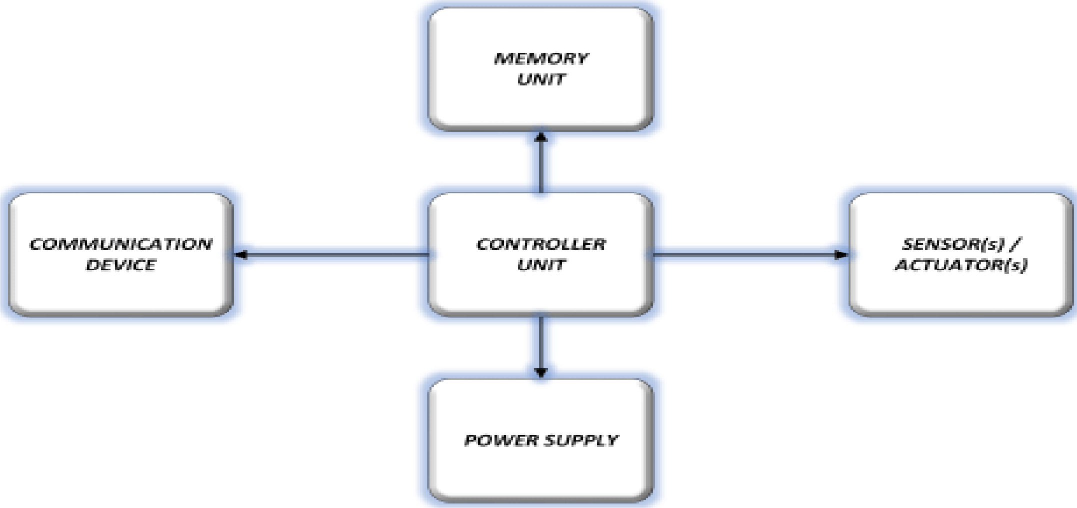

Figure 1 Components of a sensor node in WSN [61]

5. Sensors Types : [6]

The Core of any WSN lies in the sensors. Over the past decade, many have developed various Sensor Technologies:

- Microelectromechanical systems (MEMS) :
    - pressure sensors,
    - pyroelectric effect sensors,
    - acoustic sensors .
- CMOS-based sensors [10] :
    - temperature,
    - humidity,
    - capacitive proximity,
    - chemical composition .
- LED sensors :
    - ambient light sensing,
    - proximity sensing .

Sensors in WSNs can be categorized based on their functionality into (2 technologies):

- **Generic (multi-purpose) nodes :**

  A generic (multi-purpose) sensor node’s task is to take measurements from the monitored environment. It may be equipped with a variety of devices which can measure various physical attributes such as light, temperature, humidity, barometric pressure etc.

- **Gateway (bridge) nodes :**

  Gateway (bridge) nodes gather data from generic sensors and relay them to the base station. Gateway nodes have higher processing capability, battery power, and transmission (radio) range.

6. Energy management scheme :

It is important for a sensor node to have an efficient energy management scheme for the restricted source, and the application requirements must be controlled in line with the available power. In WSNs, energy management is referred to as a collection of rules for controlling different energy supply methods and efficient use of the managed energy in a sensor node. The main goal should be to manage energy in a way that ensures no node runs out of power and the network is always functional.

Power for wireless sensor nodes can be split into two main technology categories: energy storage and energy harvesting :

6.1 Energy Storage :

The most common power source for a sensor node is battery which can either be replaced or recharged based on the deployment conditions. Replacing discharged batteries becomes inefficient as sensor networks grow in size. Additionally, a battery large enough to power a sensor node for years would dominate the node's entire size, making it neither attractive nor useful. Regardless of rechargeable technology, the battery chemistries frequently include hazardous heavy metals and pose disposal problems.

6.2 Harvesting Technologies : [11]

In general, the goal of energy harvesting is to convert energy from one form to another that can be used to power electronic devices.

Since current battery technology prevents the widespread deployment of these networks, there is a clear need to investigate fresh options to power sensor networks/nodes. Sensor networks may function for significantly longer periods of time (years rather than months) and perhaps at a cheaper cost and with less weight if they are capable of harvesting energy from their local environment.

During energy harvesting, nodes draw energy from energy sources. Possible energy sources are solar cells, vibrations, fuel cells, noise and mobile phone suppliers . In terms of energy absorbing from the environment, solar cells are currently a mature technology for harvesting energy from light. The use of mobile energy suppliers such as robots to supplement energy is also underway. The robot will be responsible for charging itself and then delivering the energy to the nodes.

7. Wireless Sensors Networks architectures :

A wireless sensor network (WSN) is a network of a large number of nodes (sensors) that may transmit information over multiple hops to one or more aggregation points called sinks and data is transmitted over a wireless connection.

Wireless sensor networks should have limited power consumption because sensor nodes are deployed in locations that do not allow frequent maintenance.

For this reason, sensor nodes use short-range radios to save power when transmitting data. On the other hand, the delay depends on the number of intermediate nodes or forwarding nodes between sender and receiver. Multiple hops increase latency while reducing power consumption. In fact, latency can be reduced as nodes wake up more frequently, but at the cost of higher power consumption due to idle sensing.

7.1 WSNs management Requirements :

The sensor technologies are not capable of managing the network by themselves, rather there are some requirements that must be met. Enabling wireless sensor applications and services requires an important attention to two main parts :

1. ***Services :*** it is important to develop services that enhance applications and improve system performance and network efficiency.

2. ***Communication :*** communication protocols assist in finding paths for transmission of sensed events, and they must be able to extend the lifetime of a network despite some of the limitations of sensor nodes in a network and the harsh environments in which the sensor nodes are to operate.

8. Wireless Sensor Networks services :

There are two fundamentals' Categories of services which are developed to coordinate and manage sensor nodes and enhance the overall performance of the network in terms of power, task distribution, and resource usage.

Sensor provisioning services : Provisioning correctly allocates resources such as power and bandwidth optimization, it evolves :

- Coverage : coverage is important because it affects the number of sensors to be deployed, the location of those sensors, connectivity and power consumption .
- Localization : each sensor node tries to determine its own location (position) after deployment .

Sensor management and control services: management and control services play a major role in WSNs because they provide support for middleware services:

- Synchronization : Time synchronization in a wireless sensor network is important for routing and power conservation . Global time synchronization allows the nodes to cooperate and transmit data in a scheduled manner .

- Security : [12] WSNs are vulnerable to threats and risks. Attackers can compromise sensor nodes, alter data integrity, plant fake messages, and waste network resources. Unlike wired networks, wireless nodes broadcast their messages onto the medium. Therefore, security issues need to be addressed in WSN.

- Compression and aggregation : Depending on the importance of the data, both data compression and aggregation can reduce communication costs and increase the reliability of data transmission.

9. Communication Protocols [13] [14] :

Since sensor nodes are limited in energy, processing power, and storage space, new communication protocols and management services are required to meet these demands.

Most common communication protocols follow the OSI Model. Basically, in sensor network we need five layers: application layer, transport layer, network layer, data link layer and physical layer.

Implementation of protocols at different layers can significantly impact power consumption, end-to-end latency, and system efficiency. It is important to optimize communication and minimize energy consumption. Traditional network protocols do not work well in WSN because they were not designed to meet these requirements.

It is important to develop a reliable and energy-efficient protocols to support various WSN applications. Depending on the application, a network can consist of hundreds or thousands of nodes. Each sensor node uses the protocol to communicate with the other nodes.

9.1 Transport layer :

The function of this layer is to provide reliability and avoid congestion. Transport layer protocols in WSNs should support multiple applications, variable reliability, packet-loss recovery, and congestion control mechanism.

Packet-loss recovery : Packet loss may be due to bad radio communication, congestion, packet collision, full memory capacity, and node failures. The effects of packet loss are felt as network performance drops including the Lack of communication quality, Incomplete data

There are two Principals approaches for packet recovery:

*1. **Hop-by-hop retransmission** :* demands that an intermediate and internal node cache the packet information in its memory .

*2**. End-to-end retransmission** :* the source caches all the packet information and performs retransmission when there is a packet loss.

Congestion control : helps reduce retransmission and prevents sensor buffer overrun. As in packet-loss recovery, there are two approaches to congestion control:

Hop-by-hop control: requires every node along the path to monitor buffer overflows .

End-to-end control: relies on the end nodes to detect congestion. Congestion existence is flagged when timeout or redundant acknowledgements are received.

There are tradeoffs between hop-by-hop and end-to-end mechanisms : Depending on the type of application, its reliability and time sensitivity, one mechanism may be better than the other.

9.2 Rooting layer :

One of the most significant functions of the Network Layer is to make routing decisions to transport sensory input from its sources to the control station, hop by hop. However, routing is a difficult challenge in WSNs due to the unique characteristics that distinguish them from traditional wireless networks such as MANET or cellular networks.

WSN routing systems differ from the standard routing protocols in various ways :

Sensors lack a global ID and must be self-organized. This is in contrast to computer networks, which have IP addresses and a central device for control. This is why IP-based routing systems are incompatible with WSNs.

Another critical challenge for the network layer in WSNs is position awareness, because applications are often interested in a specific phenomenon that happens in a specific area of the monitored environment. As a result, a locating system, such as the Global Positioning System, is required (GPS).

However, due to practical issues like as hardware size, form factor, cost, and power limits, having a GPS system in all nodes for a large-scale network is not viable, and this necessitates the development of novel localization algorithms tailored to WSNs that take into account their inherent limitations.

WSN nodes, on the other hand, are limited in terms of energy, CPU speed, and storage capacity, therefore the network layer must avoid introducing unnecessary processing overheads. Also, the network protocols of a WSN must be designed to be scalable.

9.3 Medium Access Control (MAC) :

A typical MAC difficulty is to schedule available data for transmission (across the whole network) and offer a method for each node to select when and how to use the shared media to transmit its data.

Traditional wireless network MAC protocols fall into two broads :

- scheduling-based .
- collision free .

Scheduling based protocols :

Scheduling based protocols avoid collisions by using a centralized scheduling mechanism to decide when a node can begin transmitting.

TDMA (Time Division Multiple Access) : is a scheduling-based protocol that has sparked a lot of attention in wireless networks. Essentially, it entails partitioning the shared channel into N time slots and enabling just one node to broadcast in each time period. This centralized system necessitates a central (base) station that arranges medium access to other nodes; hence, nodes must be within the base station's coverage radius to be linked to the entire network.

Collision-free protocols :

Avoiding collisions is accomplished by assigning alternative radio channels (frequencies or codes) to each communication action between two nodes, allowing for simultaneous data transfer without interference or collision. In wireless communications, there are two basic collision-free approaches :

CDMA (Code Division Multiple Access) : while TDMA protocols allocate the entire spectrum to a node for a portion of the time, CDMA protocols distribute the entire spectrum to a node for the entire period. In fact, CDMA employs unique codes to disperse the base band data before transmission. Each code allows for the identification of a single communication among all simultaneous broadcasts on the shared spectrum.

FDMA (Frequency Division Multiple Access) : consists of splitting the whole bandwidth into distinct frequency bands and allocating a portion of the spectrum to each pair of communication nodes (all the time). As a result, simultaneous transmissions on many radio channels are conceivable with no issues.

9.4 Cross layers :

Power management layer :

It is in charge of controlling the power level of sensor nodes used for processing, sensing, and communication.

Connection management layer **:**

It is in charge of configuring or reconfiguring sensor nodes in order to maintain network connectivity.

Task management plane **:**

It is in charge of distributing functions across sensor nodes in order to extend network lifetime and enhance energy efficiency.

Radio power management **:**

The modulation strategy employed by a radio can have an effect on a node's energy usage. To minimize energy usage, energy-efficient modulation techniques are required.

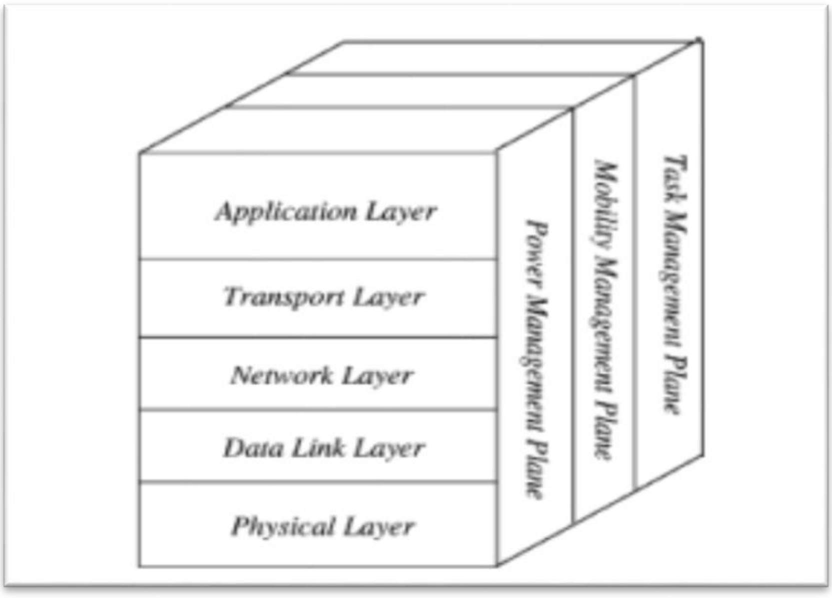

Figure 2 WSN layers [62]

10. Wireless Sensors Networks Models [15] :

The model is critical in Wireless Sensor Networks (WSNs) for reducing restrictions such as limited energy, latency, computing resource crises, and communication quality. Wireless sensor networks are very dependent on the application and system model. Algorithms/protocols designed based on one system model often do not produce the same results or demonstrate the same effectiveness when applied to another system model. Therefore, it is important to define the system model before presenting the algorithm/protocol/architecture. To employ wireless technology in various applications, a good grasp of network architecture is required.

10.1 Flat/Unstructured Topology :

This is actually the case of no topology or the absence of any defined topology. In flat topology, each sensor plays equal role in network formation.

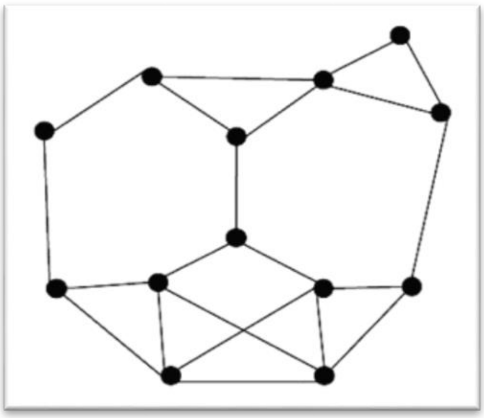

Figure 3 Flat/Unstructured Topology [15]

While adopting flat topology, all protocols attempt to find good-quality routes from source nodes to sink nodes by some sort of flooding. Flooding is a method in which a node broadcasts data and control packets received to the rest of the network's nodes. This method is repeated until the last node is reached. It should be noted that this method does not account for the energy limits imposed by WSNs. As a result, when employed for data routing in WSNs, it causes two problems: implosion and overlap. Due to the fact that flooding is a blind approach, duplicate packets may continue to circulate in the network, leading sensors to receive those duplicate packets, resulting in an implosion problem. Furthermore, if two sensors feel the same region and broadcast their sensed data at the same time, their neighbors will get duplicate packets.

10.2 Chain Based Topology :

To reduce data transmission energy dissipation, the protocols in this topology build transmission chain(s) linking the deployed sensor nodes. In a chain that serves as the sink, a leader is chosen. Along the chain, all sensor nodes interact with one another. A node delivers data to the next node, which is known as the successor node of the previous node, in order to reach the leader node. When a successor node receives data from a predecessor node, it transmits the data to its successor node, which then forwards the data to the leader. All sensor nodes relay their sensed data to the leader node in this manner (s). This kind of communication makes data collection easier.

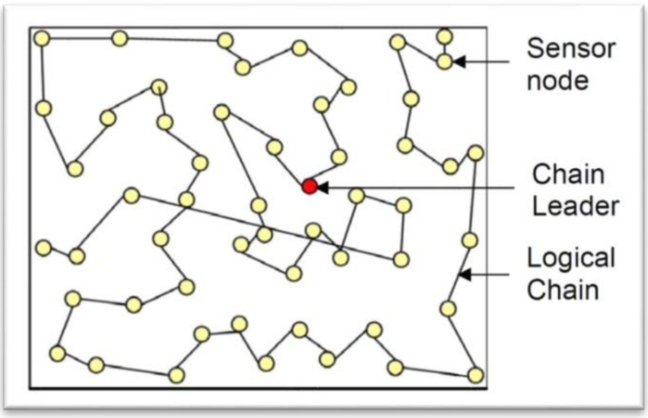

Figure 4 Chain base topology [15]

10.3 Tree Based Topology :

All of the installed sensors form a logical tree in this topology. A leaf node sends data to its parent nodes. In turn, after aggregating data with its own, a reception node receiving data from the child node delivers data to the receiver's parent node. Data flows from leaf nodes to the root node, which serves as the sink in this case. The objective of building a logical tree is to minimize flooding and to send data through unicast rather than broadcast. The topology can conserve energy in this manner.

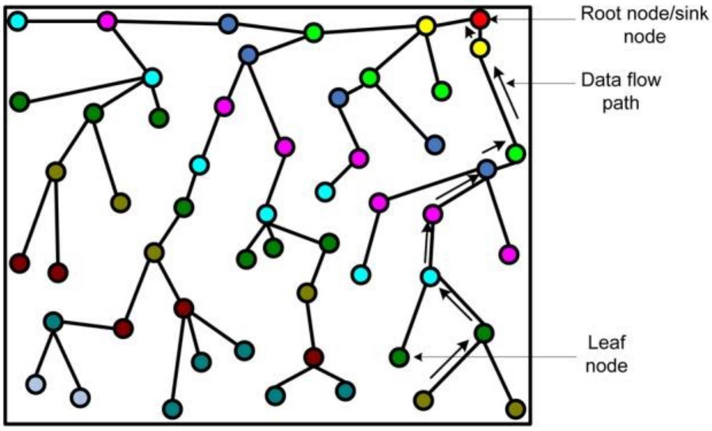

Figure 5 Tree besed topology [15]

10.4 Cluster based Topology :

Cluster-based topologies have been widely utilized in WSNs for a variety of protocols, including data collecting, target tracking, one-to-many, many-to-one, one-to-any, or one-to-all communications, routing, and so on. Clustering is especially effective for applications that need to scale to hundreds or thousands of nodes. In this context, scalability means the requirement for load balancing, effective resource use, and data aggregation. When connecting with the base station, several routing protocols employ clustering to establish a hierarchical structure and reduce path cost.

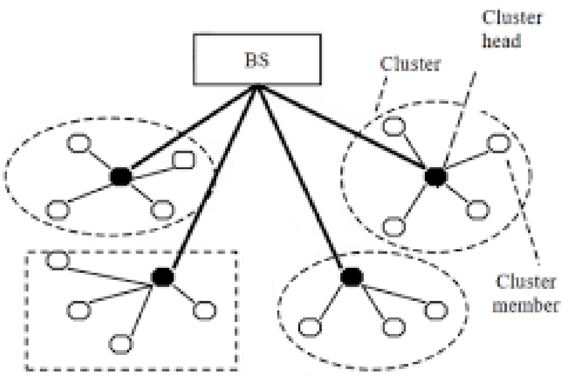

Figure 6 Cluster based Topology [63]

10.4.1 The Clusters Classification :

There are numerous ways to classify the clusters. Homogeneous or heterogeneous clusters, as well as static or dynamic clusters, are two of the most popular categories. The former categorization is based on the qualities and functioning of the sensors in the cluster, whereas the latter is based on how the cluster was formed.

10.4.2 The Clustering Process :

The design of the clustering process is one of the most significant factors for the efficient functioning of a WSN , since the efficiency of using a hierarchical scheme to communicate between network elements is investigated.

During the cluster process, three major phases may be distinguished in all cluster-based protocols :

- Cluster head election phase .
- Cluster formation or set up phase .
- Steady-state phase .

- **Cluster head election phase :** It is possible to employ either a static distribution of the SN and the CH, or perhaps a dynamic approach for sensor placement and CH selection.

- **Cluster formation or set up phase** : Clusters can arise in a variety of ways, including the ones listed below :

    - By Election Phase : In this strategy, all sensors broadcast their data to all other sensors, resulting in the establishment of a knowledge base. They establish clusters based on local expertise and then choose a leader.

    - Probabilistic Method : Protocols employ this strategy, in which each sensor selects a real number randomly, like in LEACH [16] (from 0 to 1). If the number exceeds a certain threshold, the sensor considers itself the cluster leader and sends invitation signals to all other sensors. As a result, clusters develop.

    - Base Station Assignment : The base station forms clusters in this technique. After the sensors are deployed, all nodes interact with the base station and

- attempt to construct ideal nodes depending on the information in the base station. Although this approach can construct ideal clusters, it is rarely employed due to the cost of communicating all sensors to the base station. The BCDCP protocol is an example of this (Base station Controlled Dynamic Clustering Protocol).

- **Steady-state phase :** This phase is longer than the preceding one and permits the data to be collected. Members communicate their collected data during their respective slots using scheduler methods similar to those used in TDMA. This allows them to save energy by turning off their communication interface outside of their slots. The data is then aggregated by the CHs, who merge and compress it before sending it to the sink node.

Table 1 Clustring based topology

<table>
<tr><th>Advantages</th><th>Drawbacks</th></tr>
<tr><td>
❖ Energy consumption reduced (prolonged network lifetime) .
❖ greatly improve a sensor network's scalability.
❖ efficient data aggregation .
❖ improved channel bandwidth utilization .
❖ routing respect the many-to-one and one-to-many communication paradigms .
❖ provides more reliability than tree-based .
</td><td>
The main issue is the non-uniform clustering

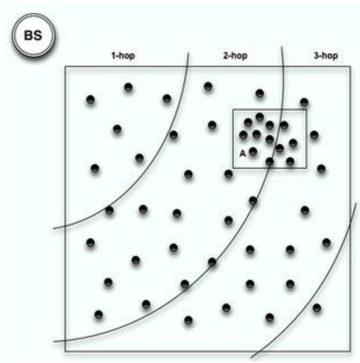

Figure 7 non-Uniform clustering [60]
</td></tr>
</table>

There is a good chance that the majority of cluster heads are located on the same side of the network, with few cluster heads on the other side, or worse no cluster heads in a certain location. As a result, non-uniform clustering occurs. The following issues arise as a result of non-uniform clustering :

- The total energy dissipation rises due to the long-distance communication between a cluster member and the cluster head.
- The availability of network connectivity cannot be guaranteed.
- The rate of energy dissipation varies greatly amongst sensors, even when they are in the same cluster. As a result, energy distribution is uneven.
- Some sensors burn energy quickly and perish as a result of particularly long-distance connections. As a result, the network lifespan shortens.

11. Wireless Sensors Network Applications [12] :

WSN applications are divided into two types: monitoring and tracking. Indoor/outdoor environmental monitoring, health and wellness monitoring, power monitoring, inventory location tracking, industrial and process automation, and seismic and structural monitoring are all examples of monitoring applications. Objects, animals, persons, and automobiles may all be tracked using tracking programs. While there are several applications, we will explain a few examples that have been installed and proven in the real world.

1. ***Green house surveillance :*** It is necessary to monitor the various climatic parameters in various regions of a large green house in order to test the automated system in a green house. However, employing a wired network makes the entire system inelegant and expensive. However, for the same sort of problem, a wireless sensor network with sensor nodes equipped with radio will be a cost-efficient solution.

2. ***Targeting****:* Sensor networks can be integrated into intelligent projectile or missile guiding systems.

3. ***Forest fire detection :*** In a forest, sensor nodes are distributed at random and thickly. Sensor nodes can alert users to the exact location of the fire before it spreads uncontrollably. Optical systems are commonly found in sensor nodes. They are also outfitted with power rummage techniques like as solar cells. The nodes will collaborate to execute disperse sensing and overcome several hurdles.

4. ***Environmental applications :*** WSN applications include tracking the movements of birds, insects, and tiny animals. Environmental monitoring of crops and animals, macro devices for large-scale earth monitoring, and planetary survey Detection of forest fires and floods.

5. ***Health Applications*** **:** Diagnostics, medication management in hospitals, tele-diagnosis of human physiological data, and monitoring and tracking of patients and clinicians inside a hospital are only a few of the health applications of the WSN.

6. ***Undersea Explorations*** **:** There are several minerals found beneath the seas or oceans. These minerals contain gases, oils, and so on. A number of gas and oil pipes, as well as optical cables, are installed beneath the sea. Underwater sensor networks are utilized to investigate these resources. UWSN are used to investigate mineral resources and track coastal regions.

7. ***Agriculture*** *:* The use of wireless sensor networks in agriculture is becoming more popular; employing a wireless network frees the farmer from the upkeep of wiring in a tough location.

8. ***Home (office) Intelligence*** *:* Wireless sensor networks can be used to make human living environments more convenient and intelligent. Wireless sensors, for example, can be used to remotely read utility meters in a home, such as water, gas, and electricity, and then send the readings to a remote center via wireless communication.

12. Challenges in WSNs [17] :

To develop an application employing sensor network technology, the user must overcome a number of obstacles, including design and deployment, localization, data aggregation and sensor fusion, energy mindful routing and clustering, scheduling, security, and quality of service, among others.

- **Fault tolerant Communication :** Sensor nodes can become defective and unreliable when deployed in an uncontrolled or hostile environment.

- **Scalability :** A scalable system is one whose performance rises according to the capacity increased after adding hardware. The number of sensor nodes distributed in the sensing region might be in the hundreds, thousands, or even millions.

- **Low latency:** The situations that the framework deals with are urgent and must be identified by the operator quickly. As a result, the framework must recognize and notify occurrences as fast as feasible.

- **Transmission Media:** A wireless medium connects communicative nodes in a multi-hop sensor network. Traditional wireless channel difficulties (e.g., fading, high error rate) may also have an impact on the operation of the sensor network.

- **Coverage Problems:** The coverage problem, which represents the level of service that a specific sensor network can deliver, is a basic challenge in wireless sensor networks. Because of the variety of sensor networks and the breadth of their uses, the coverage problem is characterized from different perspectives.

- **Energy Consumption :** It is one of the most serious problems in wireless sensor networks. Sensor nodes are supplied with a battery that serves as an energy source. The sensor network can be installed in hazardous conditions, making recharging or changing batteries difficult. The energy consumption is determined by the sensor nodes' principal functions, which include sensing, data processing, and communication.

- **Geographic Routing:** Geographic routing is a routing principle that is based on geographic location data. It is primarily intended for wireless networks and is based on the concept that the source transmits a message to the destination's geographic location rather than the network address.

- **Sensor Holes :** A routing hole is a location in the sensor network where either nodes are not available or the available nodes are unable to participate in the actual data routing for a variety of reasons. Identifying holes is especially difficult since conventional wireless sensor networks are made up of lightweight, low-capability nodes that are uninformed of their geographic position.

- **Coverage Topology :** The coverage issue represents how successfully sensors monitor or track a region. In recent years, the research community has paid close attention to the coverage and connection issues in sensor networks. This topic may be expressed as a decision problem, with the objective of determining whether every location in the sensor network's service area is covered by at least k sensors.

13. Conclusion :

In this chapter, we were interested in the presentation of Wireless Sensor Networks, where we describe their definitions, motivation, including brief history, functioning, architectures and characteristics as well as the different communications layers. Finally, the chapter entails WSNs applications and reveal the constraints that challenge the wsn evolution and also prevent a proper functioning of the services (WSNs applications) .

Chapter 2 : Introduction to Artificial Intelligence

1. Introduction :

In a 1967 McKinsey Quarterly article, "The Manager and the Moron," Peter Drucker noted that "the computer makes no decisions; it only carries out orders. It's a total moron, and therein lays its strength. It forces us to think, to set the criteria. The stupider the tool, the brighter the master has to be, and this is the dumbest tool we have ever had " [18]

Originally coined in the 1950s, the term "artificial intelligence" initially began as the simple theory of human intelligence being exhibited by machines .

Generally speaking, Artificial Intelligence is a computational concept that enables a machine to understand and solve complicated problems in the same way that people do. For example, we could complete a task, make mistakes, and learn from them. As part of its self-improvement, an AI or Artificial Intelligence is expected to work on a problem, make some mistakes in addressing the problem, and learn from the mistakes in a self-correcting manner. AI is a subfield of computer science that studies intelligent systems, and it can be described as an ability of machine to perform tasks that require human judgment, learning or problems solving skills.

AI has grown deeply engrained in many aspects of society, frequently operating in the background of our personal electronic devices. AI uses variety of techniques such as Speech recognition, virtual agents, Heuristic Search, Reasoning and Logic and machine learning.

2. History of Artificial Intelligence :

The term "artificial intelligence" was first used in 1956, when Marvin Minsky [19] and John McCarthy [20] (a computer scientist at Stanford) convened the eight-week-long Dartmouth Summer Research Project on Artificial Intelligence (DSRPAI) at Dartmouth College in New Hampshire. This workshop, which kicked off the AI Spring and was supported by the Rockefeller Foundation, brought together persons who would eventually be regarded as the founding fathers of AI. Among those who took part were computer scientist Nathaniel Rochester, who subsequently created the IBM 701, the first commercial research computer, and mathematician Claude Shannon [21], who established information theory.

AI handled complicated issues throughout the 1990s–2010s, delivering solutions that were proven to be effective in a variety of application fields such as data mining, industrial robotics, logistics, business intelligence, banking software, medical diagnostics, recommendation systems, and search engines. AI researchers began to create and employ increasingly advanced mathematical techniques. There was general recognition that many AI issues had already been addressed by scholars in domains such as mathematics, economics, and operations research. The common mathematical language enabled greater collaboration with established sciences, transforming AI into a more rigorous scientific subject.

Artificial neural networks made a resurgence in the form of Deep Learning in 2015, when AlphaGo, a Google-developed program, defeated the world champion in the board game Go. Go is far more difficult than chess (for example, there are 20 potential moves in chess but 361 in Go from the start), and it was long thought that computers would never be able to beat humans in this game. AlphaGo obtained its excellent performance by employing a sort of artificial neural network known as Deep Learning. Today, artificial neural networks and Deep Learning serve as the foundation for the majority of AI applications. They serve as the foundation for image recognition algorithms utilized by Facebook, as well as speech recognition algorithms .

3. Definitions :

“Intelligence is the capacity of an information-processing system to adapt to its environment while operating with insufficient knowledge and resources.” [22]

Intelligence can be defined as a general mental ability for reasoning, problem solving, and learning. Because of its general nature, intelligence integrates cognitive functions such as perception, attention, memory, language, or planning. [23]

Artificial intelligence (AI) is the ability of a computer or a robot controlled by a computer to do tasks that are usually done by humans because they require human intelligence and discernment. Although there are no AIs that can perform the wide variety of tasks an ordinary human can do, some AIs can match humans in specific tasks. [24]

Artificial intelligence (AI) is a branch of computer science. It involves developing computer programs to complete tasks which would otherwise require human intelligence. AI algorithms can tackle learning, perception, problem-solving, language-understanding and/or logical reasoning. [25]

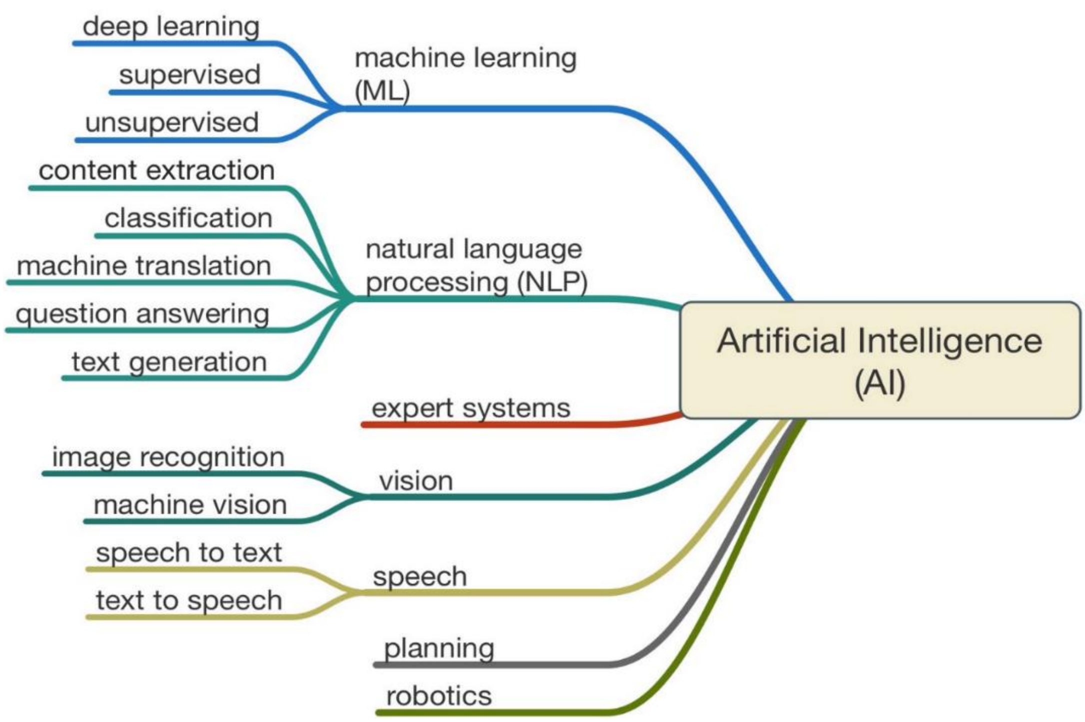

Figure 8 Achieving artificial intelligence

4. Achieving artificial Intelligence [26]

The term "artificial intelligence" was coined in 1955 to describe a new branch of computer technology. The market for AI technology is demanding and booming, and it is fast and drastically impacting different aspects of our everyday life. Many start-ups and internet behemoths are competing for their acquisition. This section will go through the most major Artificial Intelligence technologies:

- **Natural Language Generation :**

Even for humans, communicating effectively and efficiently can be difficult. Similarly, processing information by computers is a totally different process from that of the human brain, and it may be incredibly tough and complex. Natural Language Generation is a branch of artificial intelligence that turns text into data and assists computers in communicating ideas and concepts as plainly as possible. It is commonly used in customer service to generate reports and market summaries.

- **Speech Recognition :**

Speech Recognition is a technique for converting and transforming human speech into an usable and complete format that computer programs can process. Nowadays, the transcription and translation of human language into usable formats is common and rising quickly. Speech recognition services are provided by companies such as NICE, Nuance Communications, OpenText, and Verint Systems

- **Text Analytics and Natural Language Processing (NLP) :**

Natural language processing (NLP) is an artificial intelligence subfield that assists computers in understanding, interpreting, and manipulating human language. NLP enables computers to speak with humans in their native language by allowing them to read text, hear voice, analyze it, gauge emotions, and identify which portions are significant.

- **Robotic Process Automation :**

Robotic Process Automation refers to the operation of business processes that replicate and automate human functions. It is critical to remember that AI is not intended to replace humans, but rather to enhance and complement their abilities and aptitude.

According to UiPath Company, robotic process automation (RPA) is a software solution that makes it simple to design, deploy, and manage software robots that mimic human movements while dealing with digital systems and software. Software robots, like humans, can grasp what's on the screen, complete the correct keystrokes, traverse systems, discover and retrieve data, and do a variety of prescribed operations. However, software robots can do it faster and more reliably than humans, without the need to stand up and stretch or take a coffee break.

- **Machine Learning Techniques :**

Machine Learning is a branch of Artificial Intelligence as well as a subfield of computer science. Its goal is to create innovative ways that will allow computers to learn and hence grow more intelligent. Machine learning platforms are growing increasingly popular with the aid of algorithms, APIs (application programming interface), development, training tools, huge data, and apps. They are commonly used for classification and prediction.
Machine learning enables computers to enhance their performance at a task automatically by analyzing relevant data. It has been a major contributor to the AI boom over the last few decades, with applications ranging from search and product recommendation engines to systems for speech recognition, fraud detection, image understanding, and countless other tasks that previously relied solely on human perception and judgment. Recent advances in ML have been made possible by the availability of large data sets, advancements in semiconductors (particularly the development of GPUs—graphic processing units), the commoditization of cloud technologies, and increased participation in open research by universities and top technology firms.

- **Deep Learning Techniques :**

Deep Learning Platforms are a type of machine learning that uses neural circuits similar to those found in the human brain to evaluate data and develop patterns for decision making. Algorithms in this novel technology make use of artificial neural networks. Some of its uses include automatic voice recognition, picture recognition, and prediction of anything detectable in the digital space.

5. Relationship between AI, ML and DL [27]

No, artificial intelligence and machine learning are not the same, but they are closely related. Machine learning is the method to train a computer to learn from its inputs but without explicit programming for every circumstance. Machine learning helps a computer to achieve artificial intelligence.

The phrases AI, ML, and DL are frequently used interchangeably, which can be misleading at times. AI is a wide phrase that refers to any system that can execute activities that would normally need the intelligence of a person. AI is a subset of ML algorithms, while DL is a subset of ML algorithms.

6. Reinforcement Learning approach :

6.1 Introduction :

Existing machine learning methods can be classified based on the model's desired structure. The majority of machine learning algorithms are classified as supervised, unsupervised, or reinforcement learning. Machine learning algorithms in the first category are given a labeled training data set. This collection is used to construct the system model, which represents the learnt relationship between input, output, and system parameters. Unsupervised learning algorithms, unlike supervised learning algorithms, are not given labels (i.e., there is no output vector). An unsupervised learning algorithm's purpose is to categorize sample sets into various groups (i.e., clusters) by examining the similarity between the input samples. The third type of algorithm is reinforcement learning, in which the agent learns through interacting with its surroundings (i.e., online learning). Finally, because they share properties of both supervised and unsupervised learning approaches, certain machine learning algorithms do not immediately fall into this group. These hybrid algorithms (also known as semi-supervised learning) are designed to inherit the benefits of these primary groups while reducing their faults.

- ***Supervised learning algorithms :***

Classification algorithms are used in supervised learning, and they accept as input a dataset and the class of each piece of data so that the computer may learn how to categorize fresh data. Logic regression, classification trees, support vector machines, random forests, artificial neural networks (ANNs), and other techniques can be used for classification.

In the context of WSNs, supervised learning methods are widely employed to address a variety of problems, including localization and object targeting, event detection and query processing, media access control, security and intrusion detection, and quality of service (QoS).

- ***Unsupervised learning algorithms :***

It consists of clustering algorithms that take as input a dataset with several dimensions and split it into groups that meet certain requirements.

Unlike supervised learning, unsupervised learning is handled with data and a tool to interpret the qualities of the data rather than label data. The unsupervised learning method pushes you to find a variety of patterns in data. The output of unsupervised learning is a collection or cluster of data with similar properties.

- ***Reinforcement learning algorithms :***

The main characters of RL are the agent and the environment. The environment is the world that the agent lives in and interacts with. At every step of interaction, the agent sees a (possibly partial) observation of the state of the world, and then decides on an action to take. The environment changes when the agent acts on it, but may also change on its own.

The agent also perceives a reward signal from the environment, a number that tells it how good or bad the current world state is. The goal of the agent is to maximize its cumulative reward, called return. Reinforcement learning methods are ways that the agent can learn behaviors to achieve its goal.

Different environments allow different kinds of actions. The set of all valid actions in a given environment is often called the action space. Some environments, like Atari and Go, have discrete action spaces, where only a finite number of moves are available to the agent. Other environments, like where the agent controls a robot in a physical world, have continuous action spaces. In continuous spaces, actions are real-valued vectors.

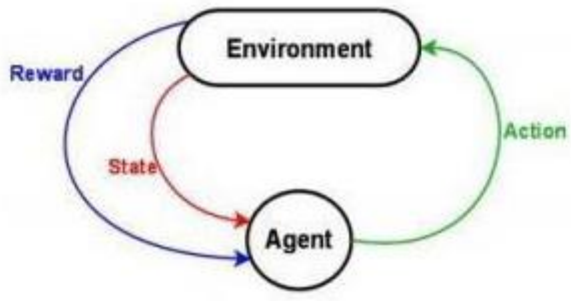

Figure 10 Reinforcement Learning Algorithm [28]

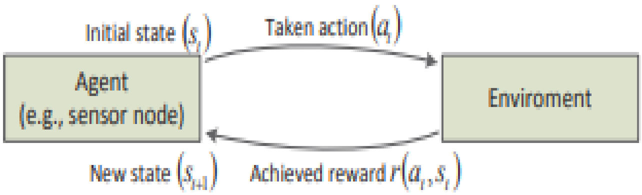

Figure 9 Q-learning [28]

Here are some important terms used in Reinforcement AI:

Agent*:* It is an assumed entity which performs actions in an environment to gain some reward.

Environment (e): A scenario that an agent has to face.

Action *The agent must perform an action in order to transfer from one state to the next state.*

Reward (R): An immediate return given to an agent when the algorithm performs specific action or task.

State (s)*:* State refers to the current situation returned by the environment.

Policy (π): It is a strategy which applies by the agent to decide the next action based on the current state.

Value (V)*:* It is expected long-term return with discount, as compared to the short-term reward.

Value Function: It specifies the value of a state that is the total amount of reward. It is an agent which should be expected beginning from that state.

Model of the environment*:* This mimics the behavior of the environment. It helps you to make inferences to be made and also determine how the environment will behave.

Q value or action value (Q)*:* Q value is quite similar to value. The only difference between the two is that it takes an additional parameter as a current action.

6.2 Q learning concept :

The letter 'Q' stands for quality in Q-learning. In this situation, quality denotes how valuable a specific action is in obtaining some future reward.

Q-learning is an off-policy reinforcement learning algorithm that seeks to find the best action to take given the current state. It's considered off-policy because the Q-learning function learns from actions that are outside the current policy, like taking random actions, and therefore a policy isn't needed. More specifically, Q-learning seeks to learn a policy that maximizes the total reward.

Q-Learning is a Reinforcement learning policy that will find the next best action, given a current state. It chooses this action at random and aims to maximize the reward.

$$Q(s_t, a_t) \leftarrow (1-\alpha) \cdot \underbrace{Q(s_t, a_t)}_{\text{old value}} + \underbrace{\alpha}_{\text{learning rate}} \cdot \overbrace{\left(\underbrace{r_t}_{\text{reward}} + \underbrace{\gamma}_{\text{discount factor}} \cdot \underbrace{\max_a Q(s_{t+1}, a)}_{\text{estimate of optimal future value}} \right)}^{\text{learned value}}$$

Figure 11 reward maximizing equation in Qlearning [65]

7. Ant colony optimization algorithm :

Ant Colony optimization is a semi-supervised algorithm and population-based metaheuristic that can be used to find approximate solutions to difficult optimization problems [29].

Optimization challenges are extremely relevant in both scientific and industrial fields. Time table scheduling, nurse time distribution scheduling, train scheduling, capacity planning, traveling salesman problems, vehicle routing challenges, Group-shop scheduling problems, and so on are some real-world examples of these optimization problems. For this reason, several optimization methods are being developed. One of them is ant colony optimization. Ant colony optimization is a probabilistic path-finding approach. The ant colony optimization approach is used in computer science and research to solve many computing issues.

There are many optimization problems where you can use ACO for finding the optimal solution. Some of them are:

- Stochastic vehicle routing problem (SVRP)
- Vehicle routing problem with pick-up and delivery (VRPPD)
- Redundancy allocation problem
- Traveling salesman problem(TSP)

7.1 Traveling Salesman problem (TSP) :

The traveling salesman problem (TSP) is considered one of the seminal problems in computational mathematics.

Traveling Salesman Problem is one of the best-known NP-hard problems where there is no precise algorithm to solve it in polynomial time. TSP is defined as a permutation problem with the goal of finding the path with the shortest length or minimum cost.

The traveling salesman problem (TSP) is the problem of finding a shortest closed tour which visits all the cities in a given set. In a symmetric TSP the distance between two cities is the same regardless of the direction of travel whereas in the asymmetric TSP the distance is different with regards to the direction of travel [30].

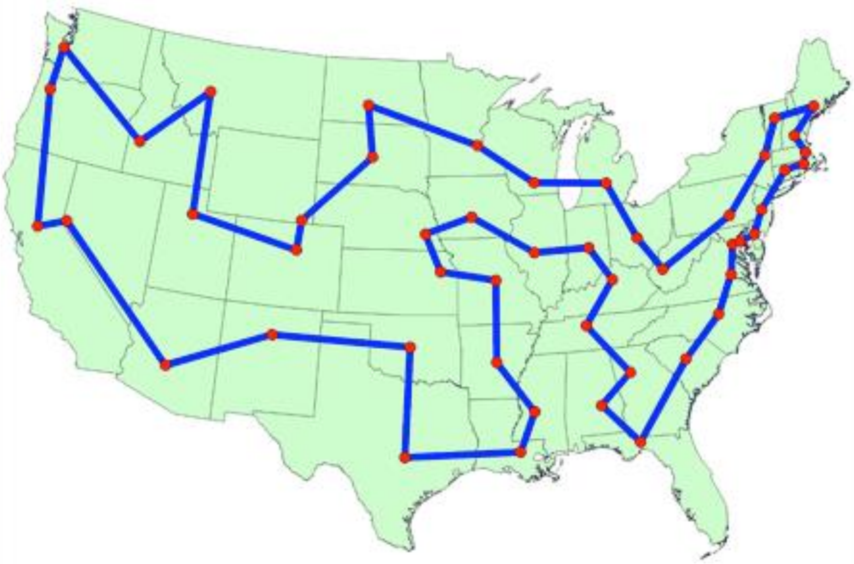

Figure 12 Traveling Salesman problem [66]

Conclusion :

The goal of this chapter was to identify and establish a common understanding of Artificial Intelligence and machine learning techniques.

The chapter clarify the role of artificial intelligence, and highlights its numerous branches. AI & ML are technologies that make machines 'think'. The field of artificial intelligence has made remarkable progress in the past five years and is having real-world impact on people, institutions and culture. The ability of computer programs to perform sophisticated language and image-processing tasks, core problems that have driven the field since its birth.

Nowadays, we are witnessing a growth in the number of AI -based systems and solutions which facilitate the optimization of services in the field of WSN.

Chapter 3 : Fault Tolerance Techniques

1. Introduction :

Sensor faults are considered the rule and not the exception in Wireless Sensor Networks (WSN) deployments [31]. Sensor nodes are fragile and can fail due to battery depletion or destruction by an external event.

Furthermore, due to environmental influences on their sensing components, nodes may record and relay inaccurate values. Links are also prone to failure, resulting in network partitions and dynamic changes in network architecture, resulting in data communication delays.

External or environmental conditions might cause links to fail permanently or momentarily. Because of the erroneous nature of communications, packets may be damaged.

In addition to these predetermined faults or failures, sensor networks frequently display silent failures that are unexpected and extremely system-related. A holistic fault management approach that addresses all fault issues does not exist.

Because of these unsolved issues, WSNs are very prone to failures. Faults are unavoidable, but precautions must be made to prevent them from propagating from lower to higher levels and causing dangerous scenarios. Making WSN a fault tolerant network is the correct technique to rescue it from breakdowns.

This chapter present a comprehensive introduction to fault tolerance concepts and the main means to achieve it correctly in the network.

2. Fault Tolerance Definitions :

Fault tolerance refers to a system's (computer, network, cloud cluster, etc.) capacity to keep running even when one or more of its components fail. The goal of developing a fault-tolerant system is to reduce interruptions caused by a single point of failure, while also assuring the high availability and business continuity of mission-critical applications or systems.

Fault tolerance is the ability to preserve the functionality of the network without interruption by preventing failure and/or restoring it. [32]

Failure begins with failing to fulfill a functional need, which leads to failing on one or more of the non-functional criteria, which leads us to the definition of fault tolerance which is to maintain the system working according to its non- functional requirements even in the presence of functional faults. [33]

3. Fault Tolerance Origin [34]:

SAPO: the first known fault-tolerant computer, was created in Czechoslovakia in 1951 by Antonn Svoboda. Its primary architecture consisted of magnetic drums linked by relays and a voting technique of memory fault detection (triple modular redundancy).

When an error was identified, the CPU employed triplication and voting (TMR), and the memory performed error detection with automated retries. The same team created a second computer (EPOS), which also had extensive fault-tolerance characteristics. These characteristics of these devices were inspired by the local lack of trustworthy components.

Several fault-tolerant systems have been created during the last 50 years, and they have finally been classified into three broad categories:

1) Long-life devices, like NASA space explorers, survive for a long time with such little maintenance.

2) Extremely reliable, real-time computers, such as those used to monitor nuclear power plants, need ongoing monitoring.

3) High-availability machines with extensive runtime, such as supercomputers utilized by insurance firms.

It was feasible to construct specialized hardware and software solutions from the scratch as fault tolerance evolved through time, but now chips include sophisticated, highly interconnected functionalities, and hardware and software must be created to fulfill a range of standards in order to be economically viable. As new technology and applications emerge, this sector is improving, new fault-tolerance methodologies are also required.

4. Non-functional requirements :

Considering various scenarios, we may state that a reliable system should meet one or more of the following non-functional attributes :

Table 2 Non functional requirements [33]

Attribute	Description
Reliability	Maintain proper and correct service.
Availability	When service is required, it should be available.
Integrity	cannot be altered without permission.
Safety	There are no dangers or threats to the system's users.
Confidentiality	Only those who are permitted should have access to the information.
Maintainability	the capacity to easily, quickly and not expensively be repaired

5. Threats (Faults) Taxonomy [35] :

A threat will violate one or more of its needed attributes. These threats may be detected. Others might be observed without interfering with system functionality. Other risks may be detected, affecting not just the system's functioning but also violating the system's requirements. Threats are classified into three types: faults, errors, failure.

To understand the idea of fault tolerance, it is necessary to distinguish between these three risks.

1. **Faults :** A threat begins as a fault, which is an abnormal condition or physical problem that occurs in specific areas of the system. It might be a physical (hardware) or software issue. It might have been introduced accidently or purposefully. Whatever the fault category, we must keep these defects contained so that they do not grow into something larger and more harmful.

2. **Errors :** Faults can be either active or passive. An active fault, such as a dead battery in a sensor, might be detected. A passive flaw could not be detected. A passive fault is a coding error or mistake. If a problem develops and is not addressed, it may spread and influence other sections of the system, transforming it from a defect to an error. Error is a noticeable phase that leads to the system not performing things correctly. When a fault creates an error, it is active; otherwise, it is dormant. When mistakes spread, they result in a failure.

3. **Failures :** A failure is a deviation from correct service that can take several forms known as service failure modes. It should be noted that many faults do not reach the system's exterior state and result in a failure. Because a service is a series of the system's external states, a service failure indicates that at least one of the system's external states deviates from the right service state. The deviation is referred to as an error. A lost connection between two nodes due to a drained battery in one of them is an example of an error. When a mistake spreads, it results in a failure. That is when the system begins to act in ways that are not expected of it. Continuing with our example of the dead sensor node, the failure here is the inability to convey data from that dead node.

Figure 13 Faults Tolerance phases [64]

6. Means to achieve fault tolerant System :

To achieve fault tolerant network, many methods are available :

- ***Fault prediction :*** includes the use of several models to predict possible faults. The prediction models employ several statistical approaches to forecast a component's defect depending on factors such as lines-of-code (LOC), technology maturity, programming language, and other parameters. These models may be augmented by historical data analysis of project data from internal sources to estimate fault probability and main locations of fault occurrence for a certain module or component. This contributes to the fault prevention and detection stages.

- ***Fault prevention :*** is the prevention of faults from occurring or being introduced in the system . If we can keep faults under control, we can avoid system breakdowns. The more defects we prevent, the fewer failures are likely. Fault prevention is a proactive method for identifying all potential sites where a defect might arise and closing those gaps. Business rules and requirements that are inadequate or confusing during the requirements phase may result in several faults throughout development.

- ***Fault detection :*** can be accomplished using multiple validation procedures Creating detailed test cases, continuous integration and testing, cross-verification utilizing a traceability matrix [36], automated testing, machine learning testing, and so on are all part of this. Continuous and iterative integration and testing is a powerful method for detecting flaws early. A solid monitoring and alerting system also aid in fault identification.

- ***Fault recovery :*** this either manually or automatically removes the issue from the system.

7. Fault-Tolerance in High-Availability Systems :

To improve reliability in High Availability Systems like WSNs, the fault tolerant system must cover some Objectives :

- **On-line maintenance:** It is important to make diagnostics and repair while the system is in service. The systems can also be made capable of contacting service centers after a failure of a hardware component is detected.

- **Power management :** There are several separate power providers. A single power supply failure should not cause the entire system to fail. Furthermore, many fault-tolerant systems have a battery system that can power at least the primary memory. The CPU may be put to sleep, and when power is restored, the system can be restarted quickly. This eliminates a potentially lengthy restart.

8. Advantages of fault-tolerant systems :

The main goal of developing fault tolerance is to avoid (or at least reduce) a situation in which the system's functionality becomes unavailable due to a defect in one or more of its components.

Fault tolerance is required for systems that preserve people's safety (such as air traffic control hardware and software systems) as well as systems that rely on security, data protection, data integrity, and high-value transactions.

Fault-tolerant systems are a good precaution against equipment failure, but they are extremely expensive to construct since they need a completely redundant set of hardware that must be coupled to the primary system.

9. Fault tolerance in Wireless Sensor Networks :

Sensor networks are tiny devices that are placed throughout an area of interest and consist of sensor batteries, a processing unit, and memory. These sensor nodes can be utilized in a variety of applications, including environmental monitoring, military applications, and health care applications. The resources available to these sensor nodes are limited, the most crucial component is the node's battery, if the battery dies, the node dies, and the network dies with it. These nodes detect data and communicate with other nodes or with base stations directly.

10. Problematics : [31]

There are 3 fundamentals problems to consider when it comes to implementing proper fault tolerant systems in wsn :

- **Fault coverage:**

  The limited energy capacity of wireless sensors, as well as the harsh conditions in which they may be installed, make this form of network extremely vulnerable. Thus, the loss of wireless links can be caused by the extinction of a sensor due to a depleted battery, or simply by an enemy's inadvertent or purposeful physical damage. Furthermore, the absence of physical protection for this sort of sensor, as well as the vulnerability of radio communications, are features that enhance the danger of network failures, etc.

  Given the high risk and wide range of failure types, the wsn should be organized around two tasks:
  One to provide application functionality (collect and transmit data, send alarms to allow the prevention of critical situations).
  And the other to monitor the system, specifically the status of sensors and connections.
  However, the resources (memory and energy) required to complete the second job are restricted.
  As a result, the charges will influence the system's dependability approach. A key concern emerges here: how can we assure broad coverage of the sorts of failures while using the sensors' limited resources as efficiently as possible?

  In reality, the proper operation of a WSN-based system is primarily tied to three essential aspects: the reliability of the measurements acquired from the environment, the reliability of the many pieces that comprise such a system, and the ultimate application of the reliability. A global approach should address these issues while keeping energy usage under control.

- **Heterogeneity :**

Sensor networks are collaborative and highly focused on a single field of application. Each application requires operational safety features that are compatible with its surroundings. Some apps have more effective mechanisms for this than others. Furthermore, many other types of sensors from various manufacturers are already in use in a variety of applications. Currently, sensor data processing is often application specific. Each application has its own set of sensors and processing algorithms.

Because of the variety of sensors and applications connected to this sort of network, it is extremely difficult to create generic dependability solutions with criteria that are completely independent of the applications and sensors. In fact, a generic solution may be used in a variety of situations.

- **Low Energy :**

A low battery status is a typical cause of inaccurate data. The battery level affects how long a sensor works and can decide or influence when a sensor begins communicating incorrect readings. We plotted battery voltage levels and temperature measurements using data from the real-world dataset. The temperature sensor began to fail around the voltage range that indicated a high risk of failure (e.g., for a stuck-at fault). When the battery voltage dropped, the temperature sensor values stayed constant for the duration of the operation. The majority of data errors are caused by sensor battery problems. When the voltage of the battery was less than 2.4V or more than 3V, Sensor battery supply has an impact on system performance by either adding noise or providing incorrect data (depending on the type of sensor and application).

11. Related work of fault tolerance in WSN:

Fault tolerance algorithms in WSNs have received a lot of attention in recent decades. This section discusses the primary conclusions for FT Algorithms, their fundamental assumptions, and how they handle several fault factors such as achieving reliability assurance, enhancing lifetime, energy saving and so on.

11.1 Clustering-based mechanisms :

Clustering is an effective approach for enhancing FT in WSNs. Clustering allows for scalable control of WSNs, as well as the effects of the clustering technique on energy savings and network control. This sort of technique is beneficial for achieving local communication, in which each CH gets data from cluster members and delivers aggregated data to the BS, also known as one hop communication. Data collected, on the other hand, may be sent to the BS via multiple hop communications.

In [37], Lai and Chen presented a distributed fault-tolerant solution for WSNs called CMATO (Cluster-Member-based fAultTOlerant). It regarded the cluster as a separate whole and used cluster member monitoring to locate and recover from the broken node in a timely and energy-efficient manner. Because the suggested technique incorporates network local information, it is versatile and may be used with other current clustering algorithms in WSNs. Simulation results demonstrated that proposed method outperformed the earlier fault-tolerant methods in terms of power consumption and fault coverage.

Bansal et al. developed a distributed and dynamic new CH selection using Fault Tolerant Election Protocol (FTEP) in [38]. The suggested technique used two-level clustering algorithms. In this protocol, if a CH fails or its residual energy falls below a certain level, the selection procedure is initiated based on power levels. To deal with CH failure, the selection procedure selects a CH node and a backup node. When the current CH fails, the backup node automatically takes on the role of CH. Simulation results showed significant power consumption when compared with existing clustering methods

Karim et al. [39] introduced a power efficient and fault-tolerant dynamic static clustering (FT-DSC) technique for WSN. The suggested protocol's major goal was to improve the performance of the DSC protocol by incorporating an FT mechanism. The performance of the provided protocol has been examined and compared to that of the DSC protocol. According to simulation data, the FT-DSC protocol outperforms the DSC protocol in terms of reliability and power economy.

In [40], R. Kumar and U. Kumar described a flexible, hierarchical clustering approach for homogeneous WSN. Their solution aimed to solve five problems: energy efficiency, scalability, FT, multi-level clustering, and load balancing. The Function Delegation protocol was used in their method to provide FT. The provided strategy was evaluated from many perspectives. The results showed that the suggested algorithm's performance and power efficiency were promising.

Cluster maintenance technique is designed by them for nodes having energy crunch as mentioned in [41]. First of all, nodes with highest residual energy are selected as primary cluster head, and nodes second in residual energy becomes the secondary cluster head. So, the technique is energy aware in nature and consequentially selects the cluster head as per the nodes' residual energy.

In [42], Kaur and Sharma presented the fault tolerant Two-level Clustering Protocol (FTTCP) for WSN. FTTCP checked CH for failure on a regular basis. The suggested method's goals are to correctly diagnose CH failure and to avoid unnecessary power consumption due by an inaccurate identification procedure. Using this strategy, each cluster member may recognize its own CH failure. To recover from a faulty CH, the backup node was chosen as the new CH. Selection of CH and back up node were based on remaining power of SNs. The simulation results demonstrated that the suggested protocol achieved excellent fault identification accuracy in hard environments while consuming slightly more energy than FTEP.

Chang and Huang [43] proposed a cluster-based FT approach and an unique fault model based on the behavior of SNs in heterogeneous WSNs. The suggested model identified the most likely erroneous SNs. This technique also used effective method to monitor and estimate the reputation of SNs in terms of message forwarding. The suggested FT technique may be implemented to evaluate its performance in terms of data correctness and dependability in WSNs.

Brust et al. suggested the clustering coefficient as a local factor for FT in WSNs in [44] and explained how to improve the clustering coefficient in a WSN topology by adding and deleting communication connections only. Modifications in topology could cause network failures. To determine the level of FT, the clustering coefficient metrics were examined. According to the results, the clustering coefficient in the WSN is highly connected with the FT.

Table 3 Fault tolerant Clustering based Mechanisms

Mechanism(s)	Clustering types			Major features achieved
	Single hop	Multi hop	Hierarchical	
CMATO [37]		*		• Energy efficiency • Fault coverage
FTEP [38]		*		• Energy efficiency
FT-DSC [39]	*			• Energy efficiency • Reliability.
Novel flexible, hierarchical clustering method [40]			*	• Energy efficiency
Cluster maintenance approach [41]	*			• Energy efficiency • Reliability. • Fault detection accuracy. • Fault recovery
FTTCP [42]			*	• High fault detection accuracy
Fuzzy knowledge-based Fault tolerance [43]	*			• Reliability.
Clustering coefficient and Fault tolerance [44]	*			• Degree of fault tolerance. • Reliability.

11.2 Cluster head selection mechanisms :

CH selection is a key stage in clustering since it is responsible for transferring and aggregating data in WSNs. In recent years, numerous works of literature have focused on CH selection, because picking the most accurate CH would improve the network's overall longevity and dependability. CH choices purely dependent on selection criteria established for specific applications and circumstances. Various CH selection approaches are given in this section :

LEACH protocol is measured as the best procedure for WSN routing [45]. The idea of LEACH is being contemplated as an inventiveness for several routing procedures. The goal of this protocol is to select sensor nodes being the CHs in various cycles so as the outcome of extreme power excess (in communication with sinks) is obtained and then dispersed in the entire WSN.

In centralized LEACH, also known as LEACH-C [46], a CH is picked by all participating nodes in the network and thereby shapes a cluster . Moreover, in the selection process of CH, the BS should be earlier aware of the degree of energy in accordance with nodes placement. As a result, the BS must select the best sensor to serve as the CH, while other nodes are assigned to CHs to shape different clusters. The benefit of this approach is that a higher number of cycles may be completed in a smaller network portion. However, because of the extra operational costs associated with transmission in a single hop, this is not practical for a network covering a large region.

If the central CH fails, Vice-LEACH (V-LEACH) provides an associate sensor inside the network to operate as a CH [47]. This is considered a single hop because it consists of only one CH throughout the whole WSN. The vice CH is selected on random basis; thus, this may be faraway, or would have a tiny quantity of energy as well as battery life. As a result, due to the increased distance of data transmission, it might expire instantly.

The authors in [48] proposed a distributed fuzzy logic-based cluster head selection algorithm (DFLBCHSA) to maximize the network energy efficiency and to minimize the delays in packet delivery. In the simulation outcome, it was observed that DFLBCHSA performed well in terms of a lesser number of dead sensor nodes, higher average remaining energy, and lesser delay in packet transfer.

In [49], Khandnor and Aseri introduced a threshold distance-based clustering routing algorithm that takes both mobile and nonmobile settings into account. The approach is based on LEACH and is known as LEACHDistance for the static environment and LEACHDistance-M for the mobility environment. In this protocol, the CH selection criteria are divided into static and mobile scenarios. During simulations, LEACHDistance-M outperformed LEACHDistance and other approaches in terms of network longevity, correlation, coefficiency, scalability, amount of data packets received by the BS, and energy efficiency.

Table 4 Fault tolerant Cluster head selection Mechanisms

Mechanism	CH Selection	Contributions	Limitations
LEACH [45]	Random	Increases the network lifetime and achieves better energy efficiency	Does not guarantee good CH distribution , assumes uniform energy distribution
LEACH-C [46]	Based on residual energy	A higher number of rounds is achieved in a small network area	Introduces extra overhead due to single-hop communication
Vice-LEACH [47]	Random	Prolongs the network lifetime	The CH may die soon due to long distance communication.
DFLBCHSA [48]	fuzzy logic-based	Maximize the network energy efficiency and to minimize the delays in packet delivery	High computational requirements
LEACHD [49]	Based on distance	Reduces the entire network energy consumption.	Selects CH based on distance, which may have low battery and thus could die soon.

11.3 Energy efficient fault tolerant mechanisms based on AI :

Evolutionary Algorithm based :

Evolutionary Algorithms (EA) represent the natural evolution Natural selection, survival-of-the-fittest, reproduction, mutation, competition, and symbiosis are all examples of adaptation processes with the goal of enhancing existence capacities.

Shamsul Wazed and al. [50] suggested a Genetic Algorithm-based strategy for scheduling relay node data collection that may greatly increase the lifetime of the relay node sensor network. They considered a two-tiered sensor network design in which more powered relay nodes serve as cluster heads and sensor nodes provide data directly to their respective cluster heads. They concentrate on non-flow-splitting routing techniques to increase the relay node network's lifespan. When compared to typical routing systems, his solution can increase network lifespan by about 200%.

Uday K. Chakraborty and al. [51] created a memetic algorithm based on differential evolution to address the routing problem in two-tier sensor networks, which solves routing difficulties for thousands of relay nodes. This technique employs a unique encoding scheme and the differential evolution mutation to create an enhanced search mechanism by combining differential evolution with local search. This method determines a path from each relay node to the base station via other relay nodes that minimizes the energy consumption of the most energy-consuming relay node and thereby increases network duration.

Reinforcement Learning based :

Reinforcement learning, in the context of machine learning and artificial intelligence (AI), is a type of dynamic programming that trains algorithms using a system of reward and punishment. A reinforcement learning algorithm, which may also be referred to as an agent, learns by interacting with its environment. The agent receives rewards by performing correctly and penalties for performing incorrectly. The agent learns without intervention from a human by maximizing its reward and minimizing its penalty.

Nesrine Ouferhat and Abdelhamid Mellouk [52] introduced an adaptive routing protocol called energy and delay efficient routing protocol for sensor network (EDEAR). Its goal is to determine the optimal path in terms of energy spent and end-to-end latency. RL changes routing tables, taking into consideration all of the dynamic characteristics that determine traffic. Routing optimization is based on changing traffic circumstances and decreasing transfer time.

Varun and al [53]. suggested a customized Q-Learning algorithm for WSN routing schemes. The author's primary objective is to create an EER algorithm using a modified QLearning technique to reduce the energy consumption of sensor nodes. This approach is a modified version of the existing Q-Learning method for WSN, which results in the convergence problem. The NS-2 simulation results demonstrate that the suggested and traditional Q learning methods provide the same outcomes.

Neural Network based :

Neural networks, also known as artificial neural networks (ANNs) or simulated neural networks (SNNs), are a subset of machine learning that provide the foundation of deep learning techniques. Their name and form are inspired by the human brain, and they replicate the way real neurons communicate with one another.

Neeraj Kumar et al. [54] use NN to handle the issue of EER and clustering in WSNs with the goal of optimizing network longevity. The suggested technique formulates the issue as linear programming with stated constraints. Adaptive learning in NN is used to pick cluster heads, which is followed by routing and data transmission. Define an efficient metric to be utilized in taking the pick of next hop in routing. In terms of residual energy and the number of living nodes, our NN-based approach outperformed the previous routing protocol LEACH. The outcome is superior than that of LEACH.

Table 5 Energy efficient fault tolerant mechanisms based on AI

Authors	Architecture	FT/FD Technique	EER	Features
Shamsul Wazed and al. **[50]**	Distributive Genetic Algorithm-based	GASH	Yes	• Energy efficiency • Redundant Rout Availability.
Uday K. Chakraborty and al **[51]**	Distributive memetic algorithm based	Memetic CH Protocol	Yes	• Energy efficiency • Reliability (routing)
Nesrine Ouferhat and Abdelhamid Mellouk **[52]**	Centralized RL based	EDEAR	Yes	• Energy efficiency • Reliability(routing)
Varun and al. **[53]**	Centralized RL based	Customized Q-Learning	Yes	• Energy efficiency • Reliability (routing)
Neeraj Kumar et al. **[54]**	Centralized NN based	NN Adaptive learning	Yes	• Energy efficiency • Reliability (routing)

Conclusion :

In this chapter we went over the fault tolerance definition, history and its importance in WSNs to provide an efficient and sustained network. An efficient fault tolerant system must perform fast and accurate faults prevention, detection or recovery.

A review of various fault tolerant algorithms designed for WSN covered in this chapter. Fault tolerance can be implemented at different levels of the wsn. Moreover, there are various means to achieve FT such as detection, prevention or recovery mechanisms.

Furthermore, many research papers shows that artificial intelligence has proven to be an effective field for extending network lifetime and preserving FT features in wsn.

Unfortunately, there is no universal fault tolerance system available that covers all the limitations and requirements of a WSN, simply because every WSN application has its own non-functional requirements that the FT system needs to maintain.

Regardless of the type of application, the FT system is a heavy system in term of cost and requirements (hardware and software) from one hand. On the other hand, the effectiveness of the fault tolerant system depends on different viewpoints.

If the application in the back-end which presents the WSN data to the users suffers a fault due to some software bug or hardware failure, like for example : incorrect sensing of temperature sensor readings can cause to over-cooling or over-heating in the room/physical space ,in this case the entire system is considered faulty [55].

Chapter 4 : Contribution: The proposed approach to deal with fault tolerance in wsn .

The Proposition

Introduction :

Due to the frequently changing network topology, it is a great challenging work to design energy efficient and fault tolerant routing protocols for Wireless Sensor Networks applications. Conservation of energy and fault tolerance are two major issues in the deployment of a wireless sensor network (WSN). Design of clustering and routing algorithms for WSN should incorporate both these issues for the long run operation of the network.

As resources are limited in WSNs, identifying how to improve resource utilization and achieve power-efficient load balancing is becoming a critical issue in WSNs. Traditional routing algorithms aim to achieve this by reducing energy consumption and prolonging network lifetime through optimized routing schemes in WSNs. However, there are usually problems such as poor flexibility, a single consideration factor, and a reliance on accurate mathematical models. ML techniques can quickly adapt to environmental changes and integrate multiple factors for routing decisions, which provides new ideas for intelligent energy-efficient routing algorithms in WSNs.

Numerous research problems are defined as optimization issues, like deployment coverage issue, data routing problem, cluster-head selection [56]. Thus, several routing protocols have been scheduled by researchers to reduce the energy consumption of network nodes. Low energy adaptive clustering hierarchy (LEACH) is considered as the most attractive one in WSNs.

In this work, we suggest an ameliorated efficient-energy fault tolerant routing approach based on the clustering method. The proposed technique supposed to provide a fault tolerant network from a preventive aspect, where network failures should be predicted and less reliable nodes (current energy, routing reliability) will be avoided.

Moreover, the proposed method is based on reinforcement learning technique to provide an efficient approach for sensors deployment (formation) and CH selection. WSN characteristics such as scalability, connectivity, signal noise ratio (SNR), and transceiver power consumption are covered by applying a multi-hop routing based on swarm optimization technique (SI) which is the ant colony optimization method (ACO).

1. Problematics :

A wireless sensor network, or WSN, is a group of wireless sensor nodes that function as a temporary network without the help of an established infrastructure or centralized management. But in these networks, energy is a limited resource. Additionally, deploying such networks in a hostile environment with no access created a fundamental issue with the sensors' energy source. A wireless sensor may run out of energy before completing its task since it is initially powered by a battery. A significant difficulty is maximizing the lifespan of these sensors and, by extension, the lifespan of networks.

Despite the diversity of applications and their requirements (nature of traffic, throughput and delay constraints, etc.), they all require that the underlying network be sufficiently robust and reliable to ensure the basic functions of a wsn, namely the coverage and connectivity.

Therefore, regardless of the application selected, the wsn must offer a level of fault tolerance according to the application's requirement in order to assure its correct operation.

In this chapter, we present our contribution which consists in proposing an approach that establish a uniform clusters formation. Moreover, the approach is based on a reinforcement learning technique for the cluster head selection with a routing protocol based on the ant colony optimization (ACO) technique to minimize the consumption of energy within the sensor nodes and thus extend the life of the network.

2. Clustering concept :

Sensors listen and gather information from the environment and send them to the base station (BS). Energy consumption is a major problem given that spent batteries are very difficult, expensive and usually impossible, to replace. Therefore, it is necessary to save energy wherever it is possible [57]. That is the reason why the routing protocols, which take into account energy efficiency, are a constant object of researching. There are different approaches to this problem. The protocol in our approach is considered hierarchical protocol. In this protocol, there is no direct communication of BS with each sensor node. There are selected nodes that play a special role in communication in hierarchical networks. These protocols start from the clustering concept. The whole network is divided into a certain number of smaller groups, called clusters, and each cluster has one node with special assignments Cluster Head (CH). Only CH has the ability to directly communicate with the BS. This method reduces the number of nodes which send data to BS. In the proposed approach the BS is located in the center of deployment area to provide uniform distances between clusters and base station. The uniform clustering can establish an equal energy dissipation in the network.

3. Proposed clustering approach :

Wireless Sensor Networks present vast challenges in terms of implementation. Design goals targeted in traditional networking provide little more than a basis for the design in wireless sensor networks. Clustering sensor nodes and organizing them hierarchically have proven to be an effective method to provide better scalability for the sensor network while conserving limited energy. Clustering through creating a hierarchical WSN facilitates efficient utilization of limited energy of sensor nodes and hence extends network lifetime. However, clusters formation, selecting optimum cluster size, election and reelection of CHs are the main issues to be addressed in designing of clustering algorithms. In this solution, we propose to improve the clustering method of traditional protocols such as LEACH . Traditional clustering techniques uses different algorithms to handle cluster formation and CH selection, some of them have proven to be an effective method to provide better performance. However, the clustering process can still take advantage of AI mechanisms that can provide more accurate and reliable results by taking into account all the contributing parameters such as distances and energy.

3.1 Communication assumptions :

Each node has two ranges as in Figure 14 :

• Sensing range Rs: a node can sense any point in the field that is located within this range. That represents the sensing coverage Rs=20 m.

• Communication Range Rc: A node can communicate with or any node that is located within this range. Neighbors are nodes that are allocated within this communication disk. A node is connected with its neighbors Rc=2Rs, Rc= 40 m.

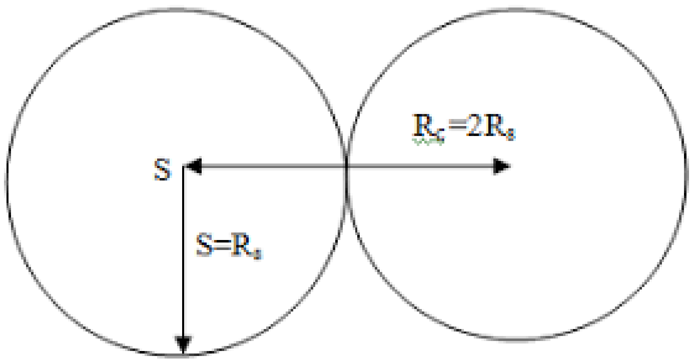

Figure 14 Sensing Range Rs, and Communication Range Rc [67].

3.2 Cluster formation :

Several clustering protocols state that the cluster heads must be chosen before the clusters can be formed, which will mostly produce an unbalanced network, particularly if the CH selection is based on a random technique.

Similar to the Voronoi diagrams [58], To reduce energy consumption and provide a more appropriate coverage, the network was divided into several uniform regions and clusters were formed within each region. The division process will take place in two main stages. The first stage established when a middle point was situated in the center of the deployment zone. From the middle point, the centers of the clusters will be formed precisely after a certain distance till the region's boundaries.

After the nodes are deployed over a sensing field of 100 × 100 m, and the base station was placed in the middle of the sensing field with (50, 50) coordinates. each node calculates the distances with the clusters points to determine which cluster it belongs to. In the end of the cluster formation process, the nodes are ready to the cluster head selection phase.

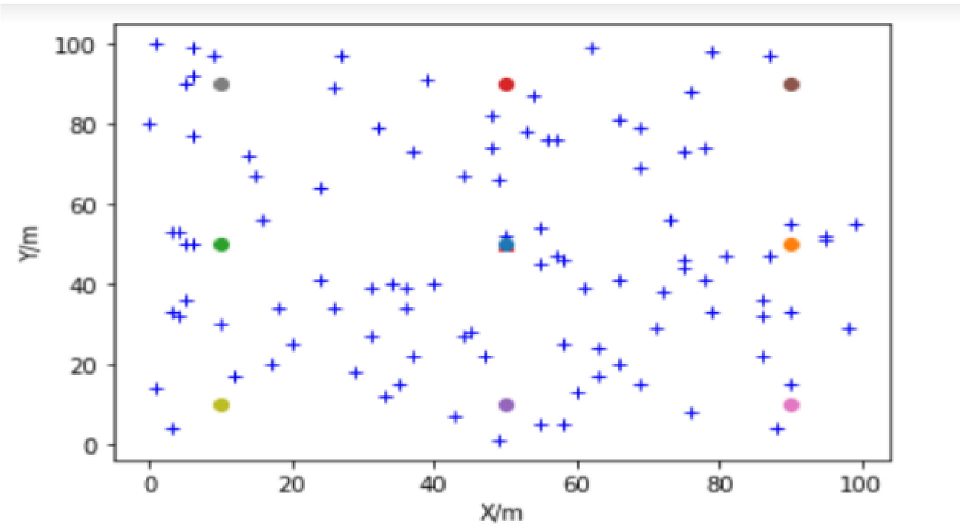

Figure 15 clusters formation in the proposed algorithm

Algorithm 01 : Area dividing :

//xm, ym : area boundaries. r : transmission range*2 , midpoint : the area center.

```
Function divide(xm,ym,r,midpoint) Point[]:
    points = []
    ypoints = []
    xpoints = []
    points.append(midpoint)
    i = 1
    While (i*r<(xm-midpoint.x)) do
        p1 = Point((i*r)+midpoint.x ,midpoint.y)
        xpoints.append(p1)
        points.append(p1)
        i= i+1
    End while
    i = 1
    While (((-r)*i)+midpoint.x>0) do
        p2 = Point(((-r)*i)+midpoint.x ,midpoint.y)
        xpoints.append(p2)
        points.append(p2)
        i= i+1
    End while
```

```
i = 1
While (i*r<(ym-midpoint.y)) do
    p1 = Point(midpoint.x,(i*r) +midpoint.y)
    ypoints.append(p1)
    points.append(p1)
    i= i+1
    End while
i = 1
While (((-r)*i)+midpoint.y>0) do
    p2 = Point(midpoint.x,(i*(-r)) +midpoint.y)
    ypoints.append(p2)
    points.append(p2)
    i= i+1
    End while
For i ⟵ 1 to (size(xpoints)) do
    px = xpoints[i]
    For j ⟵ 1 to (size(ypoints)) do
        py = ypoints[j]
        p = Point(px.x,py.y)
        points.append(p)
        End for
    End for

return points
```

3.3 Cluster head selection :

The cluster head election phase is the most important stage in the clustering process, because it has such a large impact on nodes energy usage. Many works are proposed to reduce the nodes energy depletion, and take into account various parameters such as nodes residual energy and distances between nodes and base station (BS).However, the proposed election algorithm is based on artificial intelligence approach known by reinforcement learning or the Q-learning.

In reinforcement learning mechanism two fundamentals' concepts are considered, known by action and reward. For each cluster, the election algorithm performs an action where it calculates the Q-value for each node to decide which one is the CH. The Q-value calculation based on formulation which takes into consideration the nodes residual energy, the distance between the SNs and BS to respect the inter-cluster from one hand, and also the distance with the cluster center to provide an intra-cluster criterion. This method of electing the CHs ensures that each cluster contains a CH with a sufficient amount of energy and balanced positioning to accomplish its functionalities.

When a CH is selected, it gets a reward where the node in most cases cannot be selected to be a CH in certain number of coming rounds. In the re-election phase the CHs selection algorithm will not take into consideration the previous CHs, this rotation system ensures a balance energy usage between nodes on each cluster. The Q-value formulation used in the algorithm is :

Q-value = ¾ (*node residual energy*) + ¼ (*intercluster distance + intracluster distance).*

The CH reward changes from cluster to another depending on the cluster size. Selected cluster head gets random number of rounds between 0 and the cluster size. Therefore, this technique managed to provide best reward for each cluster depending on its size to guarantee equal nodes battery usage between the different size clusters in the network .

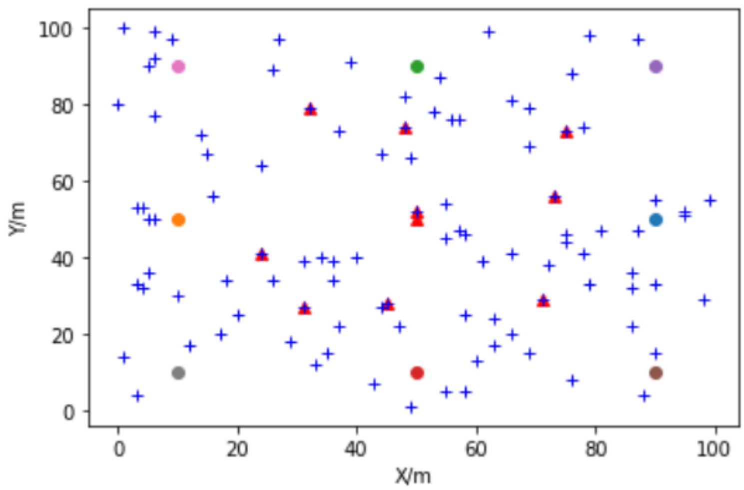

Figure 16 Cluster head selection in the proposed algorithm. CH : with colored triangles

Algorithm 2 : Cluster head selection RL

```
// Q-value initialization :
For i ⟵ 1 to n do
    nodes[i].q = 3/4 * nodes[i].e + 1/4 * 1/(nodes[i].dist+nodes[i].dch)
End for
// CHs selection
indexes = []
For i ⟵ 1 to (size(points)) do
    minQ = -1
    indexQ = -1
    For j ⟵ 1 to n do
        If(nodes[j].rid== i and nodes[j].cond == 1 and nodes[j].rwd == 0) then
            If( minQ == -1) then
                minQ = nodes[j].q
                indexQ = j
            Else
                If minQ < nodes[j].q then
                    minQ = nodes[j].q
                    indexQ = j
                End if
            End if
        End if
    End for
    indexes.append([ indexQ , i ])
End for
```

```
For j ⟵ 1 to n do
    nodes[j].role = 0
End for

CHs =[]
For i ⟵ 1 to (size(indexes)) do
    x = indexes[i][1]
    If x != -1 then
        nodes[x].role = 1
        CHs.append(nodes[x])
End for

For i ⟵ 1 to (size(CHs)) do
    For j ⟵ 1 to n do
        If CHs[i].rid == nodes[j].rid then
            dts= math.sqrt((CHs[i].x-nodes[j].x)**2 + (CHs[i].y-nodes[j].y)**2)
            nodes[j].dts=dts
            nodes[j].chid = CHs[i].id
        End if
    End for
End for
//reward function
For j in range(len(nodes)) do
    If nodes[j].rwd != 0 then
        nodes[j].rwd = nodes[j].rwd-1
    End if
```

```
End for

For i in range(len(CHs)) do
    r = 0
    For j in range(len(nodes)) do
        If CHs[i].rid == nodes[j].rid  and nodes[j].cond == 1 and nodes[j].rwd == 0 then]
            r=r+1
        End if
    rd = 0
    If (r-1) != 0 then
        rd = random.randint(0, r-1)
    End if
    CHs[i].rwd = rd
End for
```

4. Proposed multi-hop routing :

One of the most important aspects of maintaining fault tolerance in energy-constrained wireless sensor networks (WSNs) is efficient multi-hop data routing. A routing technique based on the ant colony algorithm is suggested to discover the optimal path of data transmission in the cluster-based proposed protocol.

A comparison of single-hop and multi-hop transmission methods in [59] revealed that when energy efficiency and SNR gain are the primary concerns, multi-hop should be considered. SNR gain is an abbreviation for Signal Noise Ratio, it is the ratio of the strength of signal carrying information to that of unwanted interference. Efficient SNR is required in fault tolerance network to guarantee reliable communication and fault-free data transmission. This is why multi-hop has an edge over single-hop in an interference limited network.

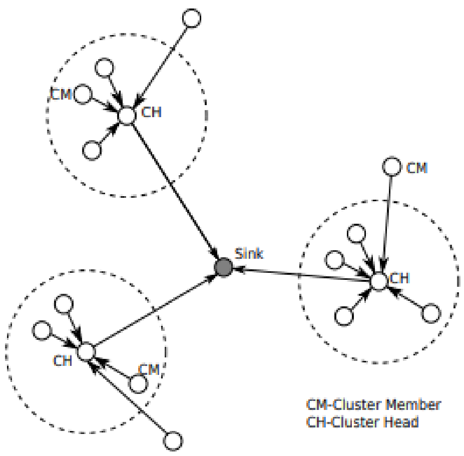

Figure 17 single-hop

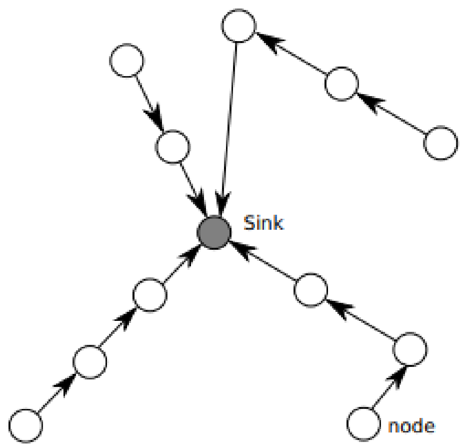

Figure 18 multi-hop

Using the ant colony optimization (ACO), and considering the node communication transmission distance, and residual energy, an optimal path from the CH nodes to the destination node (BS) can be found. Thus, the network energy consumption is reduced and the network lifetime is prolonged and the quality of network communication is improved.

The ant colony algorithm is commonly employed in WSNs for route optimization. However, the suggested work, aims to implement the routing method in a cluster-based network, where the source nodes are the CHs and the destination node is usually the Base Station.

4.1 Ant colony optimization :

One of the most common and typical combinatorial optimization problems in the ant colony approach is the salesman problem. TSP has been presented in several research papers, and implemented for wsn's pathfinding protocols. TSP goal is to find the shortest route the salesman should follow so he only visits each location once before returning to the starting point.

In the proposed routing algorithm, solving the salesman problem using ant colony algorithm is unachievable, simply because the communication in a cluster-based network is between the cluster heads and the destination (BS). This is why the proposed routing technique differ from popular TSP. First, the initial ants start from the same source node (CH). Then, the algorithm should stop when the final destination is found rather than returning to the initial source node.

4.2 Routing process :

Ant colony algorithm is the process of ants searching for best possible routes. Due to the high processing power of the ant colony routing algorithm, the base station acts as the core of the path formation process. On each round, the base station receives the distance parameter from the CHs. CH which has the longest distance from BS is the source node where the ant clan spawns to start the paths formation process.

Starting from the source node, the ants begin its mission to find possible paths to BS. The search method considers both the entire path length and the total energy consumption of the route, which is the remaining energy of all the CHs that build up the path. The energy-distance equation makes sure that the best possible routes from CHs to BS is formed every round.

In the non-initial state, selecting the next-hop node needs to filter the nodes that have been accessed through the accessed nodes table.

In the proposed mechanism, the pheromone equation responsible for the next chosen hop is determined by the "roulette wheel" probabilistic method.

Algorithm 03 : Ant colony optimization

// the main parameters for the ACO algorithm.

Procedure ACO(maxIterations)

setupAnts()   // initialize our ACO code implementation by providing trails and ants matrices.

clearTrails()   // clear the trails. (matrix).

For j ⟵ 1 to maxIterations do

moveAnts() // choose the next node for all ants .

updateTrails() // we should update trails and the left pheromone.

updateBest() // update the best solution in order to keep the reference to it.

ResetAnts() // refresh the ants trails.

End

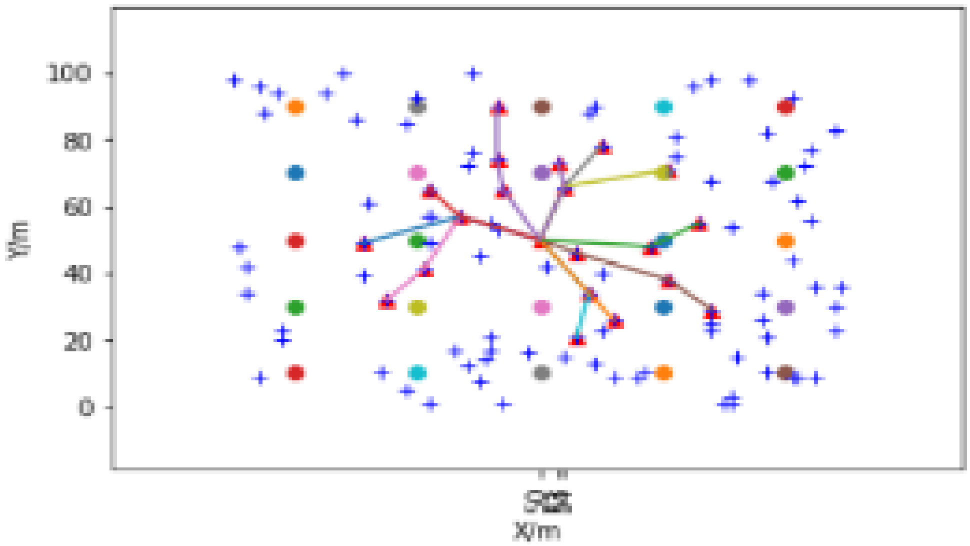

Figure 19 routing process method

4.3 Signal noise ratio gain (SNR):

SNR is the ratio of the strength of signal carrying information to that of unwanted interference. In single-hop routing approaches, the CHs has to transmit the data directly to the BS even if it's far from the base station. Direct transmission over long distances might risk data accuracy and integrity due to environmental interferences, which impact data reliability, which is one of the most essential fault tolerance features.

The multi-hop system in the proposed approach allows the data transmission to be efficient and reliable to prevent sensors from sending faulty data to BS which can affect the network reliability.

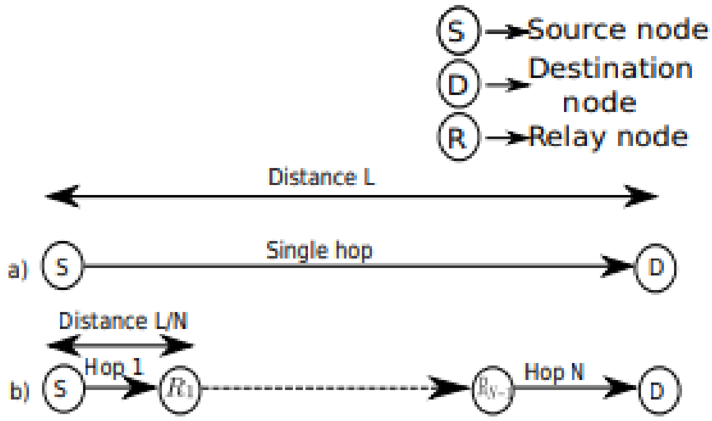

Figure 20 SNR gain in multi-hop routing

The Simulation

II

5. Simulation results and performance analysis :

To evaluate the effectiveness of the proposed approach, a simulation test must be performed, as well as a comparison with another energy-efficient routing protocol, such as the Low Energy Adaptive Clustering Hierarchy protocol (LEACH) in our case.

Since the proposed algorithm besed on artificial intelligence techniques, and Python is the most suitable programming language for this field, all the algorithms were coded, compiled, and executed on the Jupiter notebook web-based interactive computing platform to provide clear results and a valid comparison between LEACH and the suggested algorithms.

Moreover, to provide deployment simulation tests, the algorithms coded to java programing language and executed on simulator application based on JavaFX designed to perform the nodes deployment and routing simulation.

To evaluate the performance of the proposed algorithm, we conducted simulation using Java simulator and deployed 100 devices distributed randomly over a sensing field of 100×100 m . The base station was placed in the middle of the sensing field with (50, 50) coordinates. Furthermore, we assumed the network to be homogeneous, including devices with same energy levels.

The simulation parameters are presented in Table 6.

Table 6 Simulation parameters

Parameter	***Value***
Deployment area	100m x100m
Number of nodes	100 nodes
Base Station location	50m x 50m
Initial energy of nodes	2 J (Joule)
Range of transmission	20 m
Energy (elec)	50*10(-9) J
Energy (amplifier)	100*10(-12) J
Energy (data aggregation)	5*10(-9) J
Packets size	4000 bits

The energy consumption model computes the energy which is dissipated at packet transmission or reception and updates the residual energy. The energy consumption model is presented in the following equation [22]:

$$\{E_{tx}(k,d) = E_{elec} * k + E_{amp} * k * d^{m}\}.$$

$$\{E_{rx}(k) = E_{elec} * k\}.$$

Where E_{tx} and E_{rx} are the energy consumed by the transmitter and receiver, respectively.

At each transmission (or reception), estimated at 50 nJ/bit is the energy consumed to run the transmitter or receiver circuit, whereas amplification energy estimated at 100 $pJ/bit/m2$ is the energy consumed to amplify the signal over the distance, with $m = 2$ or 4 depending upon the distance.

5.1 Simulation guide :

To illustrate clear results about the suggested algorithm performance, the simulation test will be applied on two distinct phases. Through comparison, we highlight the difference between the proposed RL based clustering algorithm and the well known LEACH clustering phases by without including the routing part. The goal is to get unambiguous results about the cluster formation and cluster head process and their real performance.

However, The simulation including the multi-hop routing based on the ant colony optimization technique will be implemented and the following evaluation factors are included in the performance analysis of algorithms :

- Network lifetime.
- Nodes energy usage.
- Cluster heads selected.
- Network energy consumption.

Remark : in this performance analysis, we assume that the network will not be considered dead until the last node dies.

5.2 Clustering process performance evaluation :

Network lifetime :

The figures below show that the lifetime of the network in the proposed protocol exceeds those of LEACH and the operating nodes per transmission or per round in the suggested algorithm reached about average of 4460 rounds. On the contrary on leach protocol, the operating nodes per round reached 3842 rounds, and reached 3554 rounds for the transmission test.

In LEACH protocol there is possibility for no CH selected in the round, in this case the algorithm must redo the selection phase, which will cost extra energy. This problem is not possible to occur in the RL clustering approach because the CHs number is related to the number of clusters formed in the network.

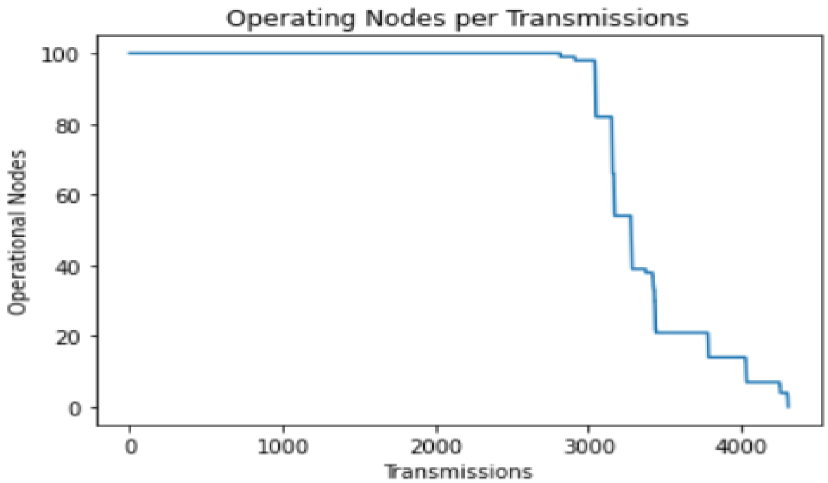

Figure 21 Operating nodes per round (RL)

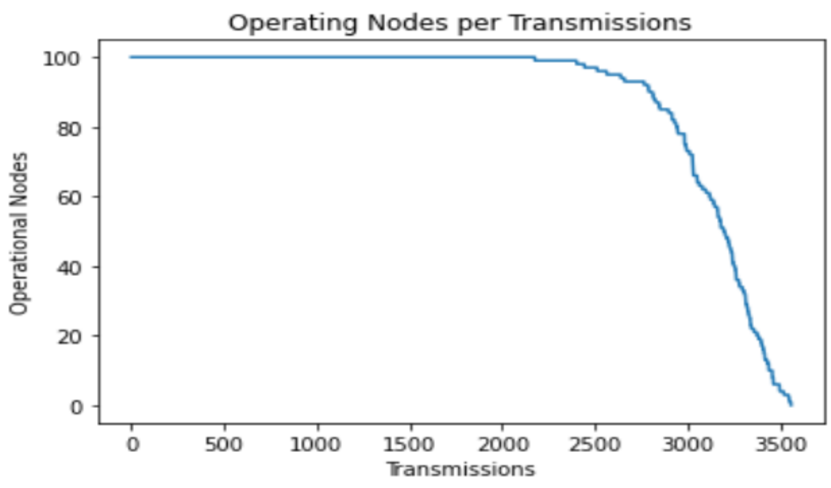

Figure 22 Operating nodes per round (LEACH)

Nodes energy consumption :

In the suggested algorithm, the average energy consumed by a single node is 0.608j per transmission, while the nodes in LEACH protocol consume almost 0.7 j per transmission. The RL-based clustering method outperformed leach due to the effectiveness of cluster head selection process in reducing the nodes energy depletion.

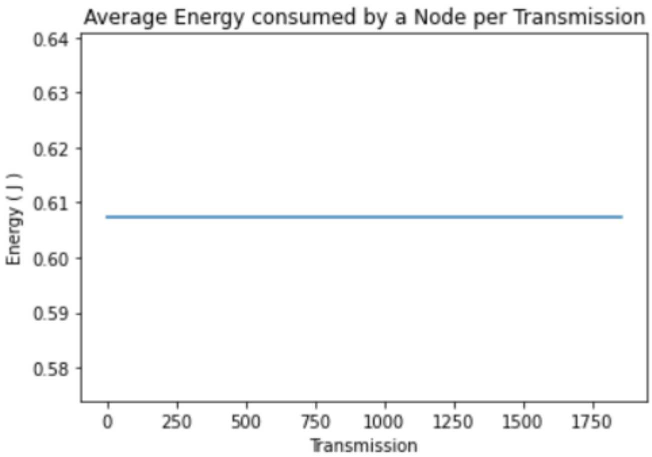

Figure 23 average energy consumed by nodes RL

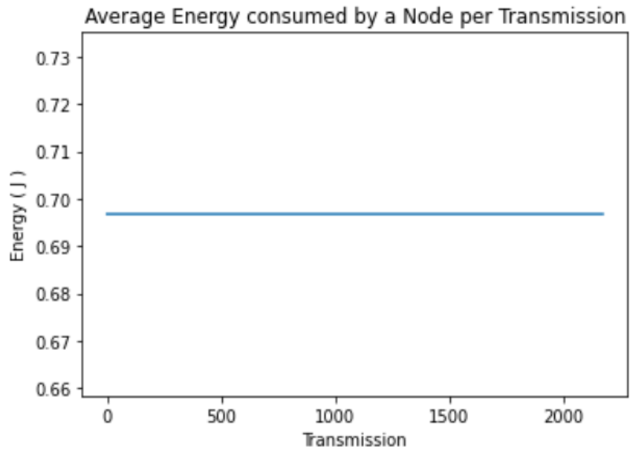

Figure 24 average energy consumed by nodes LEACH

Cluster heads selected :

The number of CHs in clustering process considered as a key element that effect directly the energy usage every round. The figures below illustrates that the number of CHs in LEACH ranges from 5 to 20 (random), which is due to the unaware probabilistic technique, which ignores cluster size and cluster number. In the contrary situation, dividing the deployment region and enabling uniform clustering allowed for excellent management of the CHs amount.

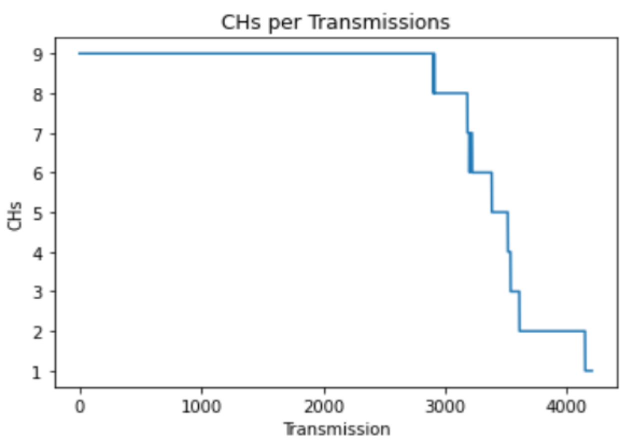

Figure 25 number of CHs per transmission (RL)

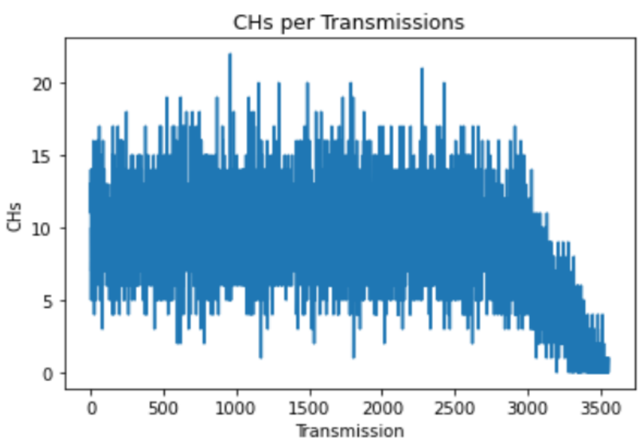

Figure 26 number of CHs per transmission (LEACH)

5.3 Multi-hop routing performance evaluation :

In the suggested approach, to achieve the multi-hop routing a population-based metaheuristic algorithm known by ant colony optimization algorithm is used to find approximate solutions and optimized paths to the BS. The comparison is performed against the single-hop routing in LEACH.

Before representing the routing test results, the simulation parameters for the ant colony algorithm are in the table below :

Table 7 ant colony simulation parameters

Parameter	***Value***
Deployment area	100m x100m
Number of nodes	100 nodes
Base Station location	50m x 50m
Initial energy of nodes	0.5 J (Joule)
Range of transmission	10 m
Energy (elec)	50*10(-9) J
Energy (amplifier)	100*10(-12) J
Energy (data aggregation)	5*10(-9) J
Packets size	4000 bits
Number of trails	1
Evaporation	1
Max Iterations	20
Alpha	1
Beta	5
Q (total amount about pheromone)	500
Ant Factor	2
Random Factor	0.5

5.4 Network lifetime :

The diagram below demonstrates the network remain functional for more then 1200 round. During the ant colony algorithm process, the first dead node happened after 380 rounds.

However, it is evident that the nodes between rounds 400 to 750 are becoming depleted at a slow rate. The large regression in the graph after round 750 and then after round 900 is present because most of the nodes at this period have the same low amount of energy causing the nodes to be exhausted in the same period due.

The ant colony optimization routing process take into consideration the residual energy of the CHs which allow a balance power consumption that guarantee longer lifetime for the network.

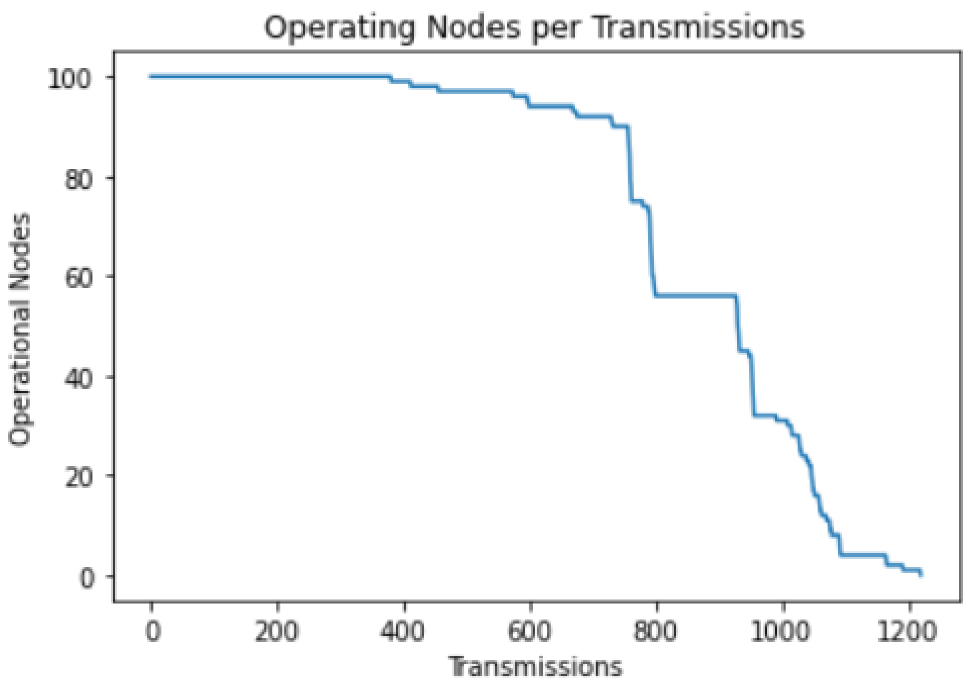

Figure 27 operating nodes per transmission ACO

Nodes energy consumption :

Through comparison, the graphs below illustrate that the ant colony optimization managed to outperform the LEACH protocol considering the nodes energy usage. The consumption of energy in ACO based routing technique reached an average of 0631 j/t, which increased the nodes energy usage in the clustering process simulation just by 0.023 j per transmission. Meanwhile, in the single-hop routing technique which based on direct communication from the cluster heads to the BS, results show that the average energy consumption reached 0.716 j per transmission, which is not quite efficient as the AI proposed routing algorithm.

The reason behind these results is the efficient management of ant colony algorithm in allowing the minimum number of CHs to involve in the transmission process, which lead the CHs to preserve its residual energy. In addition, the common challenge in the classic routing methods which is the fast energy depletion of the nodes close to BS is covered in the proposed algorithm since the path finding process doesn't take only distance in consideration but also the residual energy of CHs.

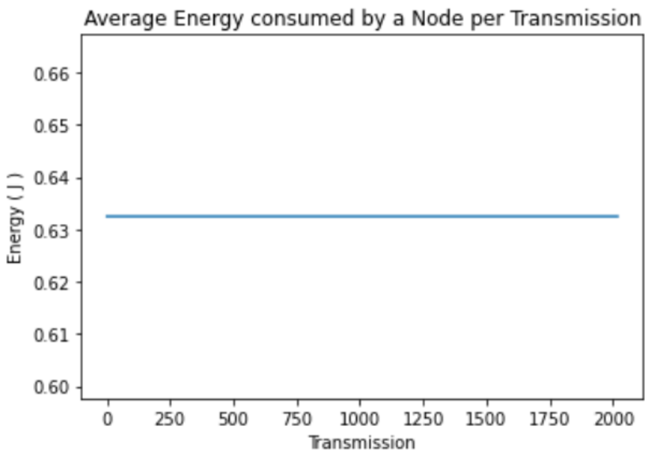

Figure 28 the average energy consumed by a single node in ACO Routing

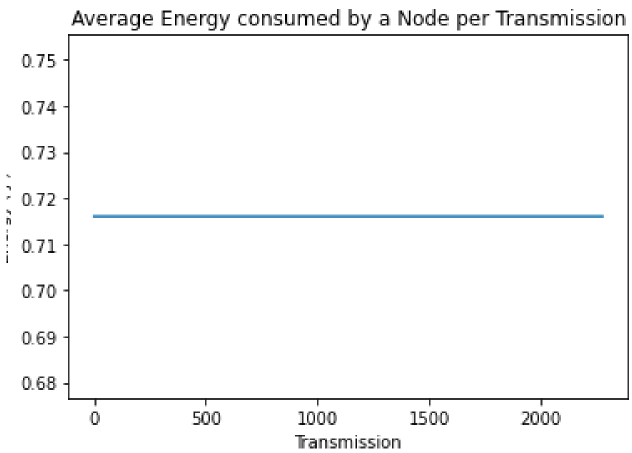

Figure 29 the average energy consumed by a single node in LEACH

Network energy consumption :

The total energy usage is an important factor to understand the energy distribution pattern in the network. This is shown in the graph below, where 1 Joule of energy is consumed every 25 rounds. In the routing method, the energy distribution in the network is balanced through time and presented as the form of a linear graph.

The total amount of energy is 50 joules since each node has 0.5 joule as an initial energy. The reason behind all of these results is essentially due to the fact that the proposed ant colony algorithm adopts an efficient routing mechanism where the ants and pheromone paths finding method allow the minimum number of nodes to interact in the transmission process.

The suggested routing technique is a high computational algorithm that check all paths to the sink node, to ensure that the chosen paths are all respecting the distance and energy factors.

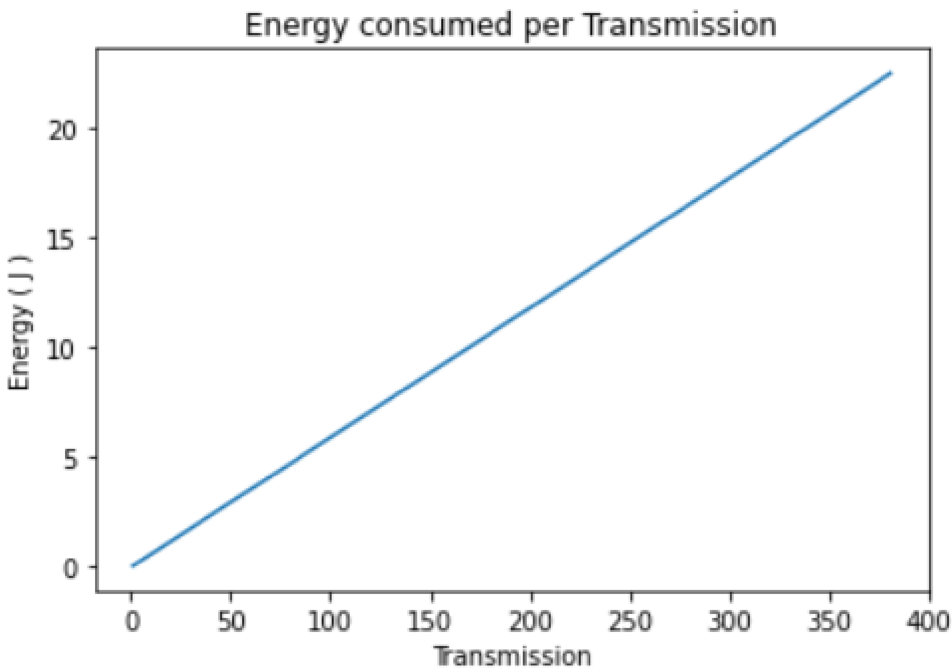

Figure 30 energy consumed per transmission

Conclusion :

In this chapter we went over our project goal, by presenting the proposed fault tolerant routing technique using the reinforcement learning approach to enhance the clustering method, and then providing multi-hop routing technique based on ant colony optimization mechanism.

The suggested algorithms outperformed the classic clustering protocol (LEACH) in many aspects such as the network lifetime, uniform clusters led to better nodes energy usage. The multi-hop routing mechanism ensured reliable transmission between CHs and BS.

Above all, the artificial intelligence approach proved to be an efficient method to deal and improve the fault tolerance preventive aspect in WSNs.

General Conclusion

General conclusion

In this work, we have seen the field of wireless sensor networks and its applications and the issues to be addressed.

Next, the goal of this dissertation project is to implement one of the artificial intelligence approaches to deal with fault tolerance in WSNs and to enhance sensor network routing techniques. For that reason, a brief introduction to artificial intelligence and its various approaches was presented, including reinforcement learning and ant colony algorithm.

Furthermore, we discussed the state of the art and the related work for general fault tolerance strategies as well as artificial intelligence-based approaches.

Moreover, since reducing the nodes energy usage is one of the main goals to achieve longer network lifetime, we were interested in hierarchical routing protocols because they are better in energy efficiency. However, improving the clustering process is necessary to complete a better performance.

To improve the clustering method in WSNs, reinforcement learning technique was proposed, and an ant colony optimization approach implemented to manage the routing mechanism.

The effectiveness of the proposed protocol was evaluated and compared to that of a traditional protocol (using the Clustering technique) LEACH. The experimental results showed that the proposed approach efficiently optimizes power consumption compared to traditional protocols, and improve the fault tolerance preventive aspect for the clustering process in wireless sensor networks.

Finally, as perspectives we plan to improve the performance of our adaptation, we will continue to improve the selection function of CH to obtain better results and compare our protocol with other modern protocols.

Bibliography

Bibliography

[1] M. MAJID, . S. HABIB,, JAVED and Abdul Rehman, "Applications of wireless sensor networks and internet of things frameworks in the industry revolution 4.0: A systematic literature review. Sensors,," *A systematic literature review.,* vol. 22, p. 36, 2022.

[2] W. Yawen, Y. Zhen and G. Yong, "Localization Security in Wireless Sensor networks.," *In Handbook of Research on Wireless Security IGI Global.,* pp. 617-627, 2008.

[3] M. M. a. M. Islam, " Overview of wireless sensor network.," *Wireless sensor networks-technology and protocols,* vol. 1, 2012.

[4] MEENA, T. and S. Ravi Sankar., "Study of Self-Organizing Coordination for Multi-UAV Systems.," *Managing Resources for Futuristic Wireless Networks. IGI Global,* pp. 56-69., 2021.

[5] D. Fu, L. Han, Z. Yang and S. Jhang, "A Greedy Algorithm on constructing the minimum connected," *k. Int. J. Distrib. Sens. Netw,* vol. 12, p. 1703201, 2016.

[6] BENEFIT, " The evolution of wireless sensor networks.," *Silicon Lab.,* vol. 1, pp. 1-5, 2013.

[7] ,. A. ALI, ,. Y. MING and S. CHAKRABORTY, "comprehensive survey on real-time applications of WSN.," *Future internet,* vol. 9, p. 77, 2017.

[8] E. KROTKOV, and . J. BLITCH,, "The defense advanced research projects agency (DARPA) tactical mobile robotics program.," *The International Journal of Robotics Research,* vol. 18, pp. 769-776., 1999.

[9] Q. WANG and . I. BALASINGHAM, "Wireless sensor networks-an introduction.," *Wireless sensor networks: application-centric design,* pp. 1-14, 2010.

[10] G. K. Fedder, "CMOS-based sensors," *SENSORS,* p. 44, 2005.

[11] P. Micha, . K. Jaromir and B. Monika, "Energy harvesting sources, storage devices and system topologies for environmental wireless sensor networks," *A review. Sensors,* vol. 18, p. 2446, 2018.

[12] . J. YICK, M. Biswanath and G. Dipak, "Wireless sensor network survey," *Computer networks,*, vol. 52, pp. 2292-2330, 2008.

[13] A. Ahmad Abed Alhameed and B. Gurvinder Singh, "Wireless sensor network architecture," *International conference on computer networks and communication systems (CNCS 2012),* p. 5, 2012.

[14] K. Kamaldeep, Parneet and . S. Er Sharanjit., "Wireless sensor network: architecture, design issues and applications.," *International Journal of Scientific Engineering and Research (IJSER),* vol. 2, p. 5, 2014.

[15] Q. MAMUN, "A qualitative comparison of different logical topologies for wireless sensor networks," *Sensors,*, vol. 12, pp. 14887-14913., 2012.

[16] R. I. TANDEL, "Leach protocol in wireless sensor network: a survey.," *International Journal of Computer Science and Information Technologies,* vol. 7, pp. 1894-1896, 2016.

[17] I. Sunita Dixit, "Wireless sensor networks: Issues & challenges.," *International Journal of Computer Science and Mobile Computing (IJCSMC,* vol. 3, pp. 681-85, 2014.

[18] M. HILB, "Toward artificial governance? The role of artificial intelligence in shaping the future of corporate governance.," *Journal of Management and Governance,*, vol. 24, pp. 851-870., 2020.

[19] M. Minsky, "Marvin Minsky. age, 1927".

[20] B. LISKOV, "Biography of John McCarthy.," *History of programming languages.* , pp. 197-197., 1987.

[21] I. JAMES, "Claude elwood shannon 30 april 1916—24 february 2001," 2009.

[22] P. Wang, " Non-Axiomatic Reasoning System," *Exploring the Essence of Intelligence.* , 1996.

[23] K. S. J. R. H. R. Colom R, "Dialogues Clin Neurosci," pp. 489-501, 2010.

[24] B. Copeland, ""artificial intelligence"," 24 Aug. 2022. [Online]. Available: https://www.britannica.com/technology/artificial-intelligence. [Accessed 6 September 2022.].

[25] Z. Saleh, "Artificial Intelligence Definition," *Ethics and Standards.* , 2019.

[26] S. &. M. L. C. Haripriya, "A study on artificial intelligence technologies and its applications.," *Int. J. Sci. Res. Comput. Sci. Eng. Inform. Technol,,* vol. 6, no. 4, pp. 1-10., 2020.

[27] "Understanding The Difference Between AI, ML, And DL: Using An Incredibly Simple Example," advancing analytics Company, 15 December 2020. [Online]. Available: https://www.advancinganalytics.co.uk/blog/2021/12/15/understanding-the-difference-between-ai-ml-and-dl-using-an-incredibly-simple-example. [Accessed 30 July 2022].

[28] T. Matiisen, "Demystifying Deep Reinforcement Learning | Computational Neuroscience Lab," 03 September 2022. [Online]. Available: https://neuro.cs.ut.ee/demystifying-deep-reinforcement-learning/. [Accessed 19 December 2015].

[29] M. Dorigo, "Ant colony optimization," *Scholarpedia,* vol. 2, p. 1461, 2007.

[30] B. V. Raghavendra, " Solving traveling salesmen problem using ant colony optimization algorithm," *J. Appl. Comput. Math. JACM,* vol. 4, p. 260, 2015.

[31] H. Dima, " Détection et diagnostic des fautes dans des systèmes à base de réseaux de capteurs sans fils," *Thèse de doctorat. Grenoble.,* 2013.

[32] K. &. L. M. Belkadi, "Energy-efficient fault-tolerant routing for wireless sensor networks.," *2nd International Workshop on Human-Centric Smart Environments for Health and Well-being (IHSH,* 2021.

[33] N. F. H. e. Z. Y. ALRAJEI, "A survey on fault tolerance in wireless sensor networks," *American Society For Engineering Education North Central Section Conference ASEE NCS Conference April,* 2014.

[34] D. A. RENNELS, "Fault-tolerant computing? concepts and examples," *IEEE Transactions on computers,* vol. 33, pp. 1116-1129., 1984.

[35] E. U. e. T. K. WARRIACH, " A comparative analysis of machine learning algorithms for faults detection in wireless sensor networks," *Int. J. Sens. Networks,,* vol. 23, pp. 1-13, 2017.

[36] R. &. P. S. Padmavathi, "An Innovative RTM Providing Test Maintenance in An Automated Scripting New Frameworks.," pp. 344-348, 2017.

[37] Y. L. a. H. Chen, "Energy-efficient fault-tolerant mechanism for clustered wireless sensor networks.," *Int. Conf. Comput. Commun.,* p. 272–277, 2007.

[38] T. S. M. M. R. J. N. Bansal, "FTEP: A Fault Tolerant Election Protocol for Multi-level Clustering in Homogeneous Wireless Sensor Networks," *16th Int. Conf. on Networks, ,* pp. 1-6, 2006.

[39] N. N. a. T. S. L. Karim, "A Fault Tolerant Dynamic Clustering Protocol of Wireless Sensor Networks," *Glob. Telecommun.,* p. 1–6, 2009.

[40] R. K. a. U. Kumar, "A Hierarchal cluster framework for wireless," *Int. Conf. Adv. Comput. Commun, IEEE.,* pp. 46-50, 2012.

[41] D. A. K. A. &. Akbari A., "“Fault Detection and Recovery in Wireless Sensor Network using Clustering," *International in Journal of Wireless,* vol. 3, no. 1, pp. 130-138, 2011.

[42] A. Kaur and T. Sharma, "FTTCP: Fault Tolerant Two-level Clustering," *Int. J. on Networking Security.,* vol. 1, pp. 28-33, 2010.

[43] S. H. C. a. T. S. Huang, "A Fuzzy Knowledge Based Fault Tolerance Algorithm in Wireless Sensor Networks," *26th Int. Conf.Adv. Inf. Netw. Appl.,* pp. 891-896, 2012.

[44] D. T. C. H. C. R. a. M. K. M. R. Brust, "Is the clustering coefficient a measure for fault tolerance in wireless sensor networks?," *IEEE Int. Conf. Commun.,,* pp. 183-187, 2012.

[45] A. C. a. H. B. W. R. Heinzelman, "Energy-efficient communication protocol for wireless microsensor networks,," *IEEE Computer Society. ,* vol. 8, p. 8020, 2000..

[46] M. S. G. V. L. a. R. B. B. M. Tripathi, ""Energy efficient LEACH-C protocol for Wireless Sensor Network,"," *Third International Conference on Computational Intelligence and Information Technology (CIIT 2013), ,* pp. 402-405, 2013.

[47] A. &. L. J. &. N. M. &. S. H. (. Mehmood, "Improvement of the Wireless Sensor Network Lifetime using LEACH with Vice-Cluster Head.," *Ad-Hoc and Sensor Wireless Networks.,* pp. 28. 1-17., 2015.

[48] S. A. a. A. S. M. Abdolkarimi, "A new multi-objective distributed fuzzy clustering algorithm for wireless sensor networks with mobile gateways,," *” AEU - International Journal of Electronics and Communications,* vol. 89, p. 92–104, 2018..

[49] P. K. a. T. Aseri, "“Threshold distance-based cluster routing protocols for static and mobile wireless sensor networks," *Turkish Journal of Electrical Engineering and Computer Sciences,* vol. 25, pp. 1448–1459,, 2017.

[50] A. W. S. J. A. e. a. BARI, "A genetic algorithm based approach for energy efficient routing in two-tiered sensor networks.," *Ad Hoc Networks,* vol. 7, pp. 665-676., 2009.

[51] U. K. D. S. K. e. A. T. E. CHAKRABORTY, "Energy-efficient routing in hierarchical wireless sensor networks using differential-evolution-based memetic algorithm.," *IEEE Congress on Evolutionary Computation,* pp. 1-8, 2012.

[52] N. M. A. e. A. B. OUFERHAT, " Adaptive parametric routing based on dynamic metrics for wireless sensor networks," *IEEE Global Telecommunications Conference GLOBECOM ,* pp. 1-5, 2010.

[53] V. K. S. S. S. P. e. S. V. SHARMA, "A tailored Q-Learning for routing in wireless sensor networks," *2nd IEEE International Conference on Parallel, Distributed and Grid Computing.,* pp. 663-668., 2012.

[54] M. K. R. P. Neeraj Kumar, "Neural Network Based Energy," *First International Conference on Networks & Communications,* pp. 34-39, 2009.

[55] L. S. DE SOUZA, "FT-CoWiseNets: A fault tolerance framework for wireless sensor networks.," *international conference on sensor technologies and applications (SENSORCOMM 2007),* pp. 289-294., 2007.

[56] T.-P. H. a. G.-N. S. C.-W. Tsai, "Metaheuristics for the Lifetime of WSN: A Review," *IEEE Sensors Journal,* vol. 16, p. 2812–2831, May 2016.

[57] G. &. P. G. Đukanović, "The Future of Wireless Sensor Networks and the Applicability of Game Theory,," *ITeO - Proceedings, Apeiron, Banja Luka.,* 2015.

[58] F. e. K. R. AURENHAMMER, "Voronoi Diagrams," *Handbook of computational geometry,* vol. 5, pp. 201-290., 2000.

[59] A. K. R. S. N. S. e. a. SINGH, " Design constraint in single-hop and multi-hop wireless sensor network using different network model architecture," *In : International Conference on Computing, Communication & Automation.,* pp. 436-441., 2015.

[60] X. Lina, O. Gregory MP and C. Rem, " A balanced energy-efficient multihop clustering scheme for wireless sensor networks," *7th IFIP Wireless and Mobile Networking Conference (WMNC). IEEE,,* pp. 1-8, 2014.

[61] A. Lakshmanan, " LITERATURE REVIEW ON ENERGY EFFICIENT ALGORITHM FOR WSN'S.," 2019.

[62] K. K. P. e. S. E. S. KAUR, "Wireless sensor network: architecture, design issues and applications.," *International Journal of Scientific Engineering and Research (IJSER),* vol. 2, no. 11, 2014.

[63] H. Zhang, "Cluster-based routing protocols for wireless sensor networks.," *MATEC Web of Conferences. ,* 2021.

[64] K. NØRVÅG, "An introduction to fault-tolerant systems.," *Department of Computer and Information Science, Norwegian University of Science and Technology, Trondheim,* 2000.

[65] "Reinforcement Learning Tutorial - Javatpoint," www.javatpoint.com, [Online]. Available: https://www.javatpoint.com/reinforcement-learning. [Accessed 3 September 2022].

[66] D. Y. F. Y. Jessica Yu, "View source for Traveling salesman problem - Cornell University Computational Optimization Open Textbook - Optimization Wiki," 2014. [Online]. Available: https://optimization.cbe.cornell.edu/index.php?title=Traveling_salesman_problem&action=edit.

[67] A. D G, "An Energy Efficient Distributed Protocol for Ensuring Coverage and Connectivity (E3C2) of Wireless Sensor Networks.," *International Journal of Ad hoc, Sensor & Ubiquitous Computing.,* pp. 13-10, 2012.