ALGERIENNE REPUBLICAIN DEMOCRATIC AND POPULAIRE

Ministry of High Education and Scientific Research

Setif 1 University - Ferhat ABBAS

Sciences Faculty

Computer Science Department

Efficient Clustering Organization Optimizing Energy in Wireless Sensor Network

Presented by

Mr. BAAZIZ Mohammed Lamine

As a Requirement to aim for the degree of

Doctorate Science in Computer Science

Sustained before a jury composed of:

Abdelaziz	LAKHFIF	MCA. University of Ferhat Abbas Sétif 1	President
Zibouda	ALIOUAT	Prof. University of Ferhat Abbas Sétif 1	Reporter
Chirihane	GHERBI	MCA. University of Ferhat Abbas Sétif 1	Examiner
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Mohamed	BENMOHAMMED	Prof. University of constantine 2	Examiner
Abdelouahab	ATTIA	MCA. University Bordj Bou Arreridj	Examiner
Makhlouf	ALIOUAT	Prof. University of Ferhat Abbas Sétif 1	Invited

2024/2025

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Abstract

Modern wireless communications advancements and miniaturization components in the field of electronics have led to the development of lower-cost, multi-functional micro-sensors. A very new useful type of network, called Wireless Sensor Networks (WSNs), has emerged in recent decades, acting as generators and relay data by controlling interesting physical phenomenon. Although WSNs have conquered almost all areas of everyday life, their development has not yet reached a fully satisfactory level of maturity. Then, some solutions to certain of their problems need to be improved, particularly that of energy conservation. This valuable resource of energy has to be sufficiently available until a WSN reaches its mission. In order to increase WSN lifetime, numerous protocols have been designed to address this problem of power consumption. The pioneer of these protocols was Low Energy Adaptive Clustering Hierarchy (LEACH) protocol and other enhancement variants were subsequently created in this context. In this work, a new protocol named Area Splitting for Clustering (ASC) that reduces energy consumption and increases network lifetime is proposed. The performance evaluation of ASC has been carried out and showed that it outperforms those of Leach and its variant protocols.
Keywords: WSN, energy conservation, Leach, Mod-Leach, Vleach.

Résumé

Les avancées récentes dans les communications sans fil et la miniaturisation des composants dans le domaine de l'électronique ont conduit au développement de micro-capteurs multifonctionnels à moindre coût. Un tout nouveau type de réseau utile, appelé Réseaux de Capteurs Sans Fil (RCSF), a émergé ces dernières décennies, agissant comme générateurs et relais de données en contrôlant des phénomènes physiques intéressants. Bien que les RCSF aient conquis presque tous les domaines de la vie quotidienne, leur développement n'a pas encore atteint un niveau de maturité pleinement satisfaisant. Par conséquent, certaines solutions à certains de leurs problèmes doivent être améliorées, en particulier celle de la conservation de l'énergie. Cette ressource précieuse qu'est l'énergie doit être suffisamment disponible jusqu'à ce qu'un RCSF atteigne sa mission. Afin d'augmenter la durée de vie des RCSF, de nombreux protocoles ont été conçus pour résoudre ce problème de consommation d'énergie. Le pionnier de ces protocoles a été le protocole Low Energy Adaptive Clustering Hierarchy (LEACH), et d'autres variantes d'amélioration ont été créées par la suite dans ce contexte. Dans ce travail, un nouveau protocole nommé Area Splitting for Clustering (ASC) qui réduit la consommation d'énergie et augmente la durée de vie du réseau est proposé. L'évaluation des performances de l'ASC a été réalisée et a montré qu'il surpasse ceux de LEACH et de ses protocoles variants.

Mots-clés: Réseaux de capteurs sans fil, conservation énergétique, Leach, Mod-Leach, Vleach.

الملخص

تُعتبر التطورات الحديثة في الاتصالات اللاسلكية وتقنيات التصغير في مكونات الإلكترونيات من العوامل التي أدت إلى تطوير أجهزة استشعار ميكروية متعددة الوظائف ومنخفضة التكلفة. وقد ظهرت في العقود الأخيرة نوع جديد من الشبكات المفيدة، يسمى الشبكات اللاسلكية الاستشعارية، التي تعمل كمولدات ووسائط لنقل البيانات من خلال مراقبة ظواهر فيزيائية مثيرة للاهتمام. على الرغم من أن الشبكات اللاسلكية الاستشعارية قد غزت تقريباً جميع مجالات الحياة اليومية، إلا أن تطورها لم يصل بعد إلى مستوى النضج الكامل وبالتالي، لا بد من تحسين بعض الحلول لبعض مشاكلها، وخاصة مشكلة الحفاظ على الطاقة. يجب أن تتوفر هذه الموارد القيمة من الطاقة بشكل كافٍ حتى تتمكن الشبكة من إتمام مهمتها. ولزيادة عمر الشبكة اللاسلكية الاستشعارية، تم تصميم العديد من البروتوكولات لمعالجة هذه المشكلة المتعلقة باستهلاك الطاقة. وكان البروتوكول الرائد في هذا السياق هو بروتوكول "الهرمية التكتيلية للطاقة المنخفضة" LEACH، ومن ثم تم إنشاء العديد من النسخ المحسنة لهذا البروتوكول. في هذا العمل، يتم اقتراح بروتوكول جديد يسمى "تقسيم المنطقة للتجميع" ASC الذي يقلل من استهلاك الطاقة ويزيد من عمر الشبكة. تم إجراء تقييم أداء لبروتوكول ASC وأظهرت النتائج أنه يتفوق على بروتوكولات LEACH ونسخها المحسنة.

الكلمات المفتاحية: الشبكات اللاسلكية الاستشعارية، الحفاظ على الطاقة، LEACHو MODLEACH، VLEACH.

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Acronyms

WSN:Wireless Sensor Network

ASC: Area Splitting for Clustering

LEACH: Low Energy Adaptive Clustering Hierarchy

CH:Cluster Head

E-LEACH:Enhanced LEACH

VLEACH:Vice ClusterHeadLEACH

SLeach: Sectored-LEACH

BS: Base Station

NOW:Dot NOW

TDMA: Time Division Multiple Access

ERX: Receiver Energy

Efs: Amplification Energy for short distance

Emp : Amplification Energy for long distance

Eda: Data Aggregation Energy

P: Cluster Head probability,

SA: Simulated Annealing

BCDCP: Base Station Controlled Dynamic Clustering Protocol

General Introduction

Over the past few years, wireless network technology has continually advanced thanks to technological developments in various fields related to microelectronics. Additionally, with the emergence of Wireless Sensor Networks (WSNs), new topics and challenges have arisen to meet the needs of people and the requirements of various application areas (industrial, cultural, environmental, etc.): monitoring rare species, observing infrastructure integrity, optimizing patient treatments, etc. These issues motivate many researchers. Despite remarkable progress in this field, many problems remain to be solved. New protocols have been proposed to address issues such as medium access control, routing, and more in sensor networks. However, managing energy consumption and maximizing the lifespan of sensor networks remain fundamental challenges because sensors are small components with limited storage and processing capacities, and are powered by batteries with very limited capacities, which are usually non-rechargeable. For instance, in applications where sensors are deployed in hostile environments, it is difficult or even impossible to replace the batteries. This is the case for applications designed for climate change monitoring and temperature variation tracking in the Arctic, where it is impractical to deploy a team each time to replace sensor batteries. Therefore, for a sensor network to remain autonomous for an extended period (several months or years) and to achieve maximum longevity, energy consumption must be reduced at all levels of the network architecture (from the physical layer to the application layer).

The specific characteristics of sensor networks alter performance criteria compared to traditional wireless networks. In wired local area networks or cellular networks, the most relevant criteria are throughput, latency, and quality of service, as new activities such as image transfer, video transfer, and Internet browsing require high throughput, low latency, and good quality of service. In contrast, in sensor networks designed for continuous monitoring of an area of interest, the goal is to maximize network longevity. Therefore, energy conservation has become a primary performance criterion, while other criteria like throughput or bandwidth usage have become secondary. Moreover, in event-oriented sensor networks where information needs to be relayed to the control centre in a timely manner, it is necessary to jointly optimize latency and energy conservation, as low latency can negatively impact the number of communications and, consequently, energy consumption in the networks. Sensor nodes in a Wireless Sensor Network (WSN) are interconnected without relying on dedicated infrastructure or centralized control for communication. Typically stationary, they utilize wireless channels characterized by limited range, unreliability, and susceptibility to environmental factors like noise, signal reflections, interference, and physical obstacles. WSNs are primarily established to facilitate low-cost ambient data collection. The nodes themselves are small, inexpensive, and possess constrained energy, computing, communication, and storage capabilities, limiting them to basic computational and communication tasks. They detect and measure environmental events, transmitting results via direct or multi-hop paths to a central access point (sink) with fewer resource constraints. WSN architectures generally fall into two categories: distributed, where sensor nodes are randomly dispersed without a specific topology; and hierarchical where nodes are organized into distinct clusters or groups [1,2].

The main contributions of our work are:

- formation of a virtual grid, or a split area into equal cells,
- An inclusion algorithm is proposed to perform the number of nodes included in the communication radius of the candidate's node to be a CH.
- Selection of CHs taking into account both residual energy and the density of neighboring nodes calculated from precedent step.
- Monitor the energy levels of CHs to detect CHs out of energy and replaces them by selecting new CHs.

This Thesis introduces a new method of uniform distribution of nodes and a new protocol called Area Splitting for Clustering (ASC), designed to reduce energy consumption and extend network lifetime. Performance evaluations of ASC showed that it surpasses

LEACH and its variants in effectiveness. This novel approach for selecting Cluster Heads introduces two new routing protocols.

The new approach incorporates both the residual energy of nodes and the number of neighboring nodes into the Cluster Head selection process. The proposed protocol employs geometric methods, such as dividing the network area into equal squares, each treated as a separate cluster. During the initial round, only the residual energy is used to classify nodes, while from the second round onwards, the number of neighboring nodes for each cluster member is taken into account until the network's energy is depleted.

Organization of the thesis :

Chapter one gives introduction on WSN, its definition, components, architecture, structure, design, services and applications.

Some examples of operating systems used in WSN were introduced. The different routing protocols used in WSN were also introduced in the first chapter.

Chapter two introduces Clustering protocols including the most known Low Energy Adaptive clustering for hierarchy (Leach), its principle that is based on choosing the cluster head in every round randomly where some clusters can have big size while others can be very small and this will increase the number of messages sent considerably.of its derivatives like Modified Leach, Sectored Leach, VLeach, AE-Leach and other types of protocols where introduced .

Chapter three introduces a new method of Uniform distribution of nodes, its principle, and give comparison with other protocols in terms of energy consumption, number of Alive nodes and the throughput.

Chapter four introduces the proposed protocol, its Network model, architecture and it's Evaluation with Leach and its derivatives.

Chapter five analyses the results got after comparison between my protocol called ASC and Leach and its derivatives like Mod-Leach and how my proposed protocol surpasses the others in terms of Energy consumption, throughput and network lifetime.

The thesis will be concluded by a General Conclusion.

Chapter 1 : Introduction to Wireless Sensor Networks

1.1 Introduction

Wireless Sensor Networks (WSNs) exhibit promising potential due to their ability to support various applications, including fire detection and monitoring vehicle traffic[3]. WSNs rely on compact sensor nodes to collect data and send it to a designated node known as a "Sink." This chapter details the network's architecture and key features, the diverse applications and services enabled by Wireless Sensor Networks, and concludes with an exploration of the operating systems and routing protocols employed in these networks.

The development of Wireless Sensor Networks (WSNs) has created a recent research community that is committed to addressing challenges and opportunities presented by these networks in different domains. As technology advances, WSNs will likely continue to evolve and contribute to solving real-world problems, further motivating researchers to explore new avenues and innovations in the field.

Despite the efforts and remarkable progress that have been made, there are still some obstacles that need to be overcome to reach full maturity. In order to ensure the proper functioning of a WSN until its successful final mission, the energy consumption of sensors remains a crucial factor to consider among these obstacles. Energy efficiency must be considered at every stage of WSN design and operation. From the hardware design of sensor nodes to the development of communication protocols and routing algorithms, energy awareness should be integrated to minimize unnecessary energy expenditure [4]. The question of energy conservation has been extensively studied through multiple protocols, but no definitive result has been achieved. Even if the problem is solved, it will still be a challenge to overcome the excessive miniaturization of sensors, such as nano sensors. The optimization of energy consumption may be believed to be relevant for a long time [5].

Studies aimed at optimizing this scarce resource focus on communication (via routing protocols) in WSNs, as energy dissipation is primarily caused by message transmission. Therefore, knowing that clustering is commonly accepted as a hierarchical approach to efficiently manage the control and regulation of communications of cluster members, the optimization of sensor energy consumption is often addressed through this context.

Depletion of a sensor node power not only puts that sensor out of service (no more ensuring data collection) but can also end its role as relaying data collected by its neighbouring nodes to the sink. If the number of these relay nodes exceeds a certain threshold, the data collected by a WSN would no longer arrive (Through the sink) to the end user, which would compromise the mission of this WSN. Node energy is regarded as the primary resource that a WSN is dependent on.

Clustering in Wireless Sensor Networks (WSNs) is a key technique used to reduce energy consumption and extend network lifetime. By grouping sensor nodes into clusters, each with a designated cluster head, data can be aggregated locally before being transmitted to the base station.

This minimizes redundant communication and reduces the number of long-distance transmissions, which are the most energy-intensive. Cluster heads are often rotated periodically to balance energy usage across nodes. But rotating based on neighbouring nodes is more efficient than rotating based randomly.

To select cluster heads based on the number of neighbor nodes, we first proved the efficiency of a uniform distribution of nodes, and secondly we suggest a new clustering approach that divides any deployment areas into equal sections. The proposed approach has an added value, as the CH, which is chosen according to proven equations, is always closest to most of the sensor nodes and has the highest energy. This reduces energy consumption by a large percentage and increases the network lifetime. This protocol performed better than well-known referenced protocols in simulation scenarios carried out.

1.2 State of The Art

Technological advances in microelectronics, micro mechanics, and wireless communications have given rise to a new generation of networks called Wireless Sensor Networks (WSNs).

1.2.1 Wireless Sensor Networks

A WSN contains Sensors in the area of focus to sense sound, temperature, movements . Sensing units typically have data processing and transmission features. The sensing unit sensed data, typically via a radio transmitter, to an operation post, both directly and via a Sink as shown in figure 1.1. To reduce power consumption, sensed data are normally sent via other sensors in a multi-hop_approach. Retransmitting sensors and the Sink can perform fusion of the sensed data in order to filter out erroneous data and anomalies.

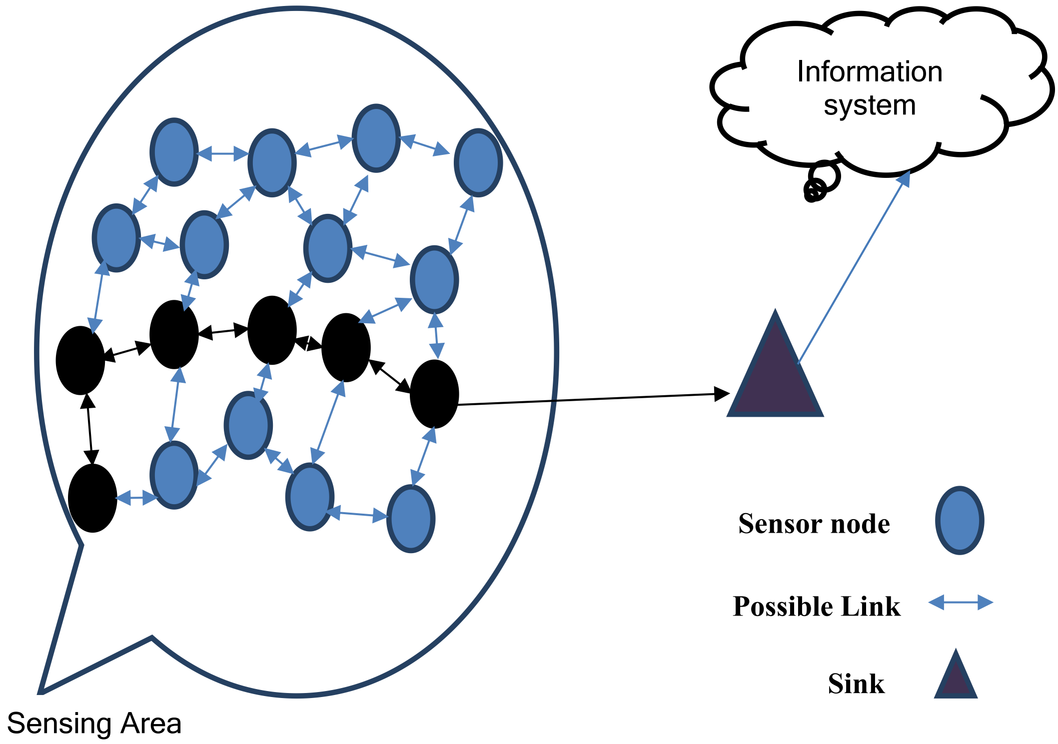

Figure 1.1:An Example of a WSN

Components of a WSN:

- Sensing area: A sensing area is the region in which the nodes are located.
- Sensor Nodes*:* Sensor nodes are the central components of the network, tasked with collecting data and sending it to the sink.
- Sink*:* A sink is a base station responsible for receiving, processing, and storing data sent by other sensor nodes. Its function is to reduce the total number of transmitted messages, thereby decreasing the network's overall energy consumption.
- Information system: It includes the user who is connected to the Internet.

1.2.2 WSN node

Figure 1.2 shows the components of a sensor node, which generally consist of a sensor module, a transmission module, a micro-controller or a processor and GPS modules, a memory, and an energy supply module.

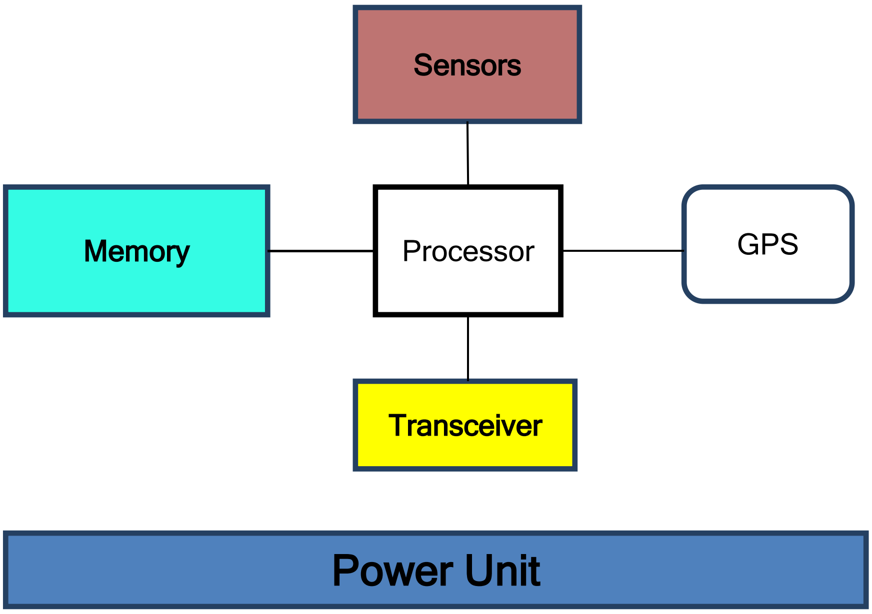

Figure 1.2: Sensor node structure

Several node models are currently on the market, including some of the most well-known ones shown in figure 1.3 such as the MicaZ by Crossbow, the Mica2, the Imote, and the TelosB.

Figure 1.3:Examples of sensor nodes

Characteristics of a sensor node:

Wireless sensors exhibit a range of characteristics (table1.1) that make them versatile and suitable for various applications. Below, are some of these key characteristics.

Small size	The sensors are compact in size, which makes them discreet and easy to install.
Processing capacity	Equipped with processing capabilities to process the collected data locally.
Wireless communication capability	Sensor nodes can wirelessly communicate with other devices or systems via various protocols.
Limited energy capacity	Designed to operate with minimal energy consumption for extended battery life.

Table 1.1:sensor node characteristics

1.2.3 WSNs architecture

Generally, in WSNs architecture, we need five layers (OSI Model):application layer, transport layer, network layer, data link layer, and physical layer as shown in Figure1.4. In addition to these five layers, we have three cross-layers, which are power management cross-layer, mobility management cross-layer, and task management cross-layer. These cross-layers are used to manage the network [6].

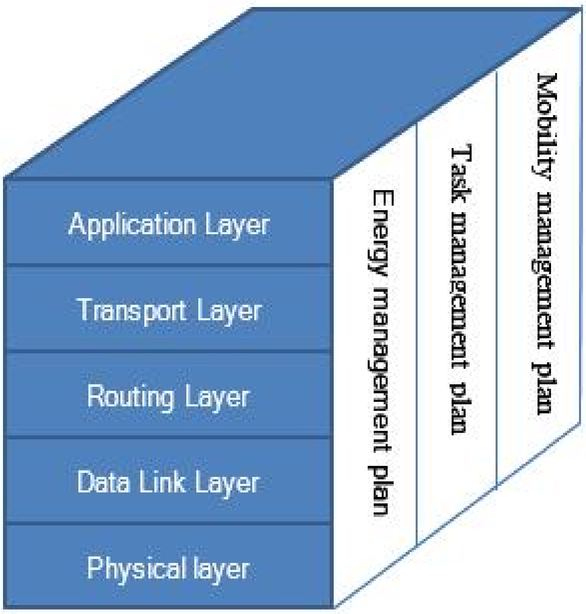

Figure 1.4: OSI Model of WSN

1.2.4 WSNs structures

WSNs include different topologies for radio communications. Network structures applied to WSNs are shortly discussed below:

- ***Mesh network***

This type of network (figure 1.5) allows data transmission from one node to another within the radio transmission range. If a node needs to send a message to another node that is out of direct radio range, it can use intermediate nodes to relay the message to the intended destination.

The primary advantage of a mesh network is its scalability and redundancy. If a node fails, other nodes can still communicate with each other and forward messages through alternative routes. Furthermore, the network's range is not solely dependent on the distance between individual nodes; it can expand simply by adding more nodes to the system.

However, a significant drawback of this network type is the increased power consumption for nodes that participate in multi-hop communication. This higher power usage can reduce battery life more quickly compared to nodes that do not relay messages. Additionally, as the number of communication hops increases towards a destination, the transmission time of messages also increases, especially if nodes need to conserve power.

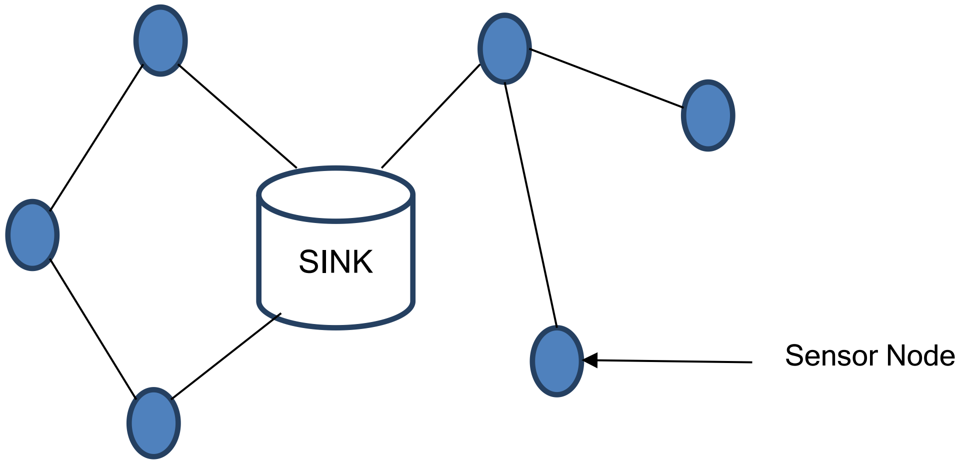

Figure 1.5: A Mesh Network structure

- ***Star network***

The star network communication structure as shown in Figure 1.7 is employed when only the Sink (base station) can transmit or receive messages to and from remote nodes. In this setup, nodes are restricted from communicating directly with each other. The advantages of this network include simplicity and efficient power management for remote nodes.

Additionally, it enables low-latency communication between the Sink and remote nodes. However, a significant drawback is that the Sink must be within radio range of all individual nodes. This network is less robust compared to others because it relies on a single node to manage the entire network.

- ***Ring structure***

In a ring structure (Shown in Figure 1.6), each node is linked to precisely two neighbors for communication. Messages flow around the ring in a uniform direction (either clockwise or counterclockwise). If a node fails, it can cause a network-wide disruption due to the break in the ring. However, ring structures may encounter challenges such as traffic congestion and complexities with redundant communication paths.

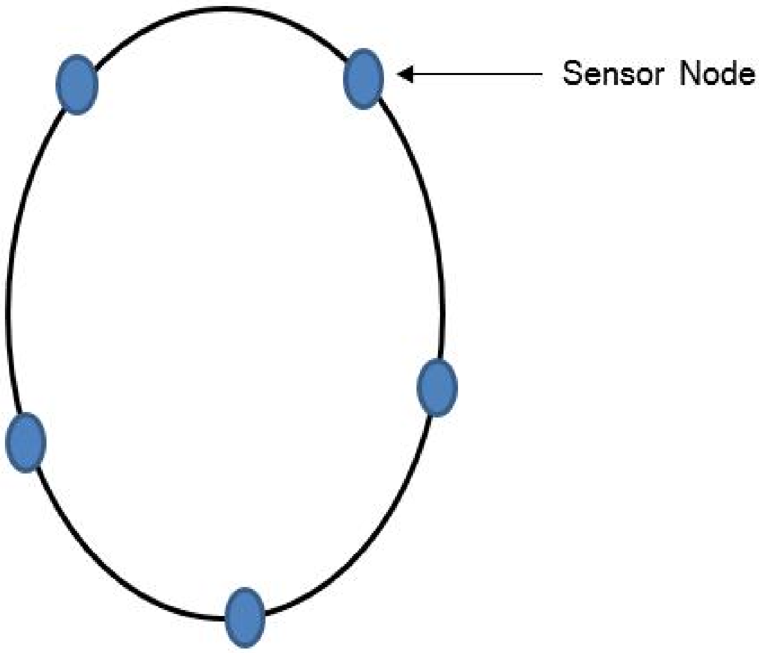

Figure 1.6:Ring Network structure

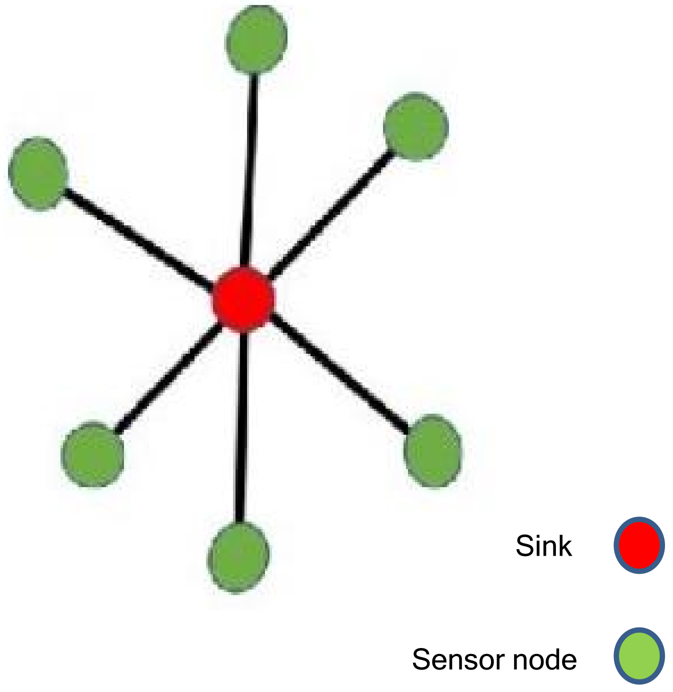

Figure 1.7. A Star Network structure

- ***Peer to peer***

In this structure, sensor nodes interact with one another both in a peer-to-peer and multi-hop fashion (figure 1.8), and also communicate directly with the sink node. There is no base station (BS) infrastructure in this setup. Consequently, spectrum sensing, resource provisioning, and sharing are managed either individually by each node or through cooperative communication. When deployed on a large scale, this structure can evolve into a mesh network with numerous multi-hops. While this structure avoids high computational complexity and overhead, it may experience significant latency due to the extensive number of hops within the mesh network.

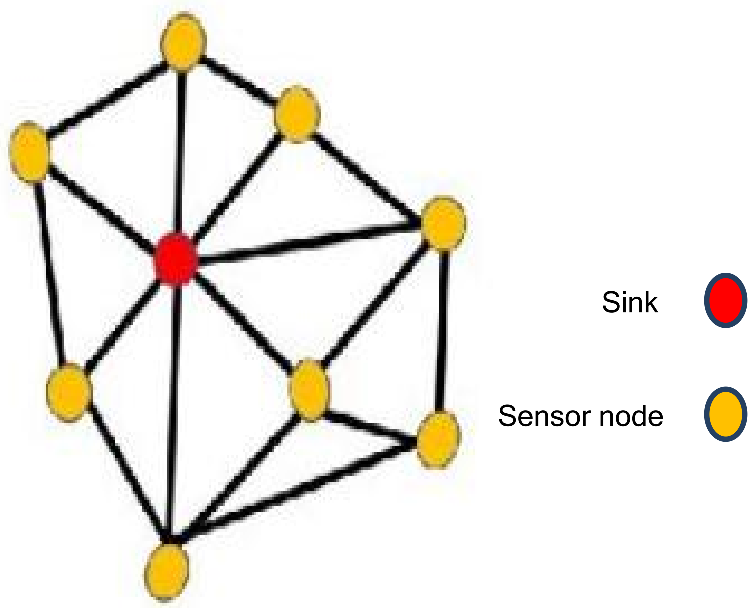

Figure 1.8: A Peer-to-Peer Mesh Network structure

1.2.5 WSN Applications

Wireless sensor networks (WSNs) find application in various fields such as area monitoring, environmental surveillance, industrial monitoring, and more. Below, different applications of WSNs are elaborated upon.

- ***Habitat monitoring***

Deploying data collection unit offers a non-intrusive method for monitoring environments that are highly sensitive to human presence [7], [8]. For instance, sensors are utilized to collect environmental data (such as air warmth, brightness, breeze speed, moisture content, and precipitation) in the South-West Rift Zone of Volcanoes National Park on the Big Island of Hawaii as part of the Pods project at the University of Hawaii at Manoa [9]. Another illustration is the PermaSense Project [10], which focuses on gathering accurate data on physical parameters in various natural slope areas in the Swiss Alps (see Figure 1.9). This data is used to develop theoretical models for temperature simulation and hazard assessment purposes.

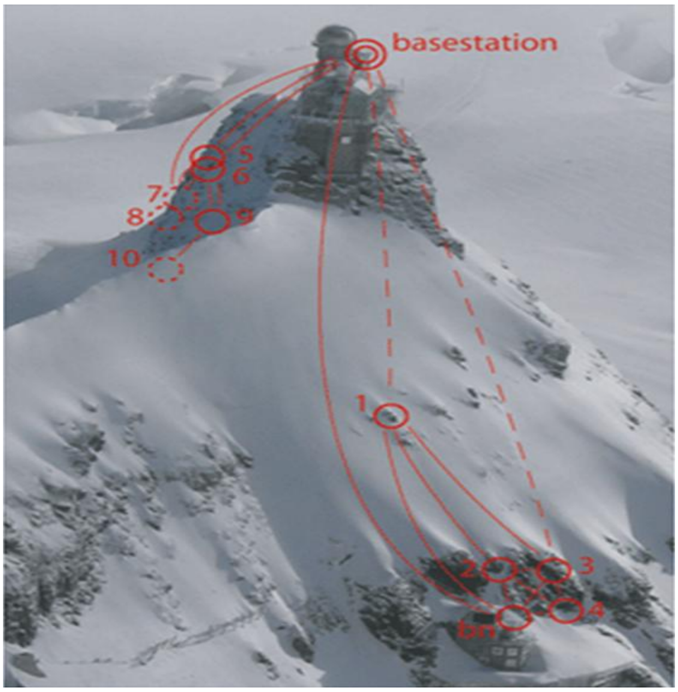

Figure 1.9: WSN PermaSense project [10]

In Princeton's Zebranet Project [11], sensor nodes are deployed to track the patterns and actions of zebras. It is essential to minimize individual activity for accurate animal tracking, ensuring the data reflects natural animal behavior. Due to the expansive size of these areas, data collection often involves mobile units positioned on the perimeter outside the WSN coverage. In another application [12], a plane deploys 30 airborne sensors in the Arctic to analyze and assess climate change. Assembled data can be transmitted to a boat or low-flying plane that traverses the monitored area.

- ***Industrial applications:***

Industrial uses of wireless sensor networks (WSNs) span both indoor and outdoor settings, focusing on monitoring and managing industrial equipment, processes, and personnel. Banner Engineering [13] illustrates several instances:

- Wireless perimeter security: Utilizing solar-powered wireless alert systems to detect breaches and notify personnel (refer to Figure 1.12).

- Monitoring in bottling plants: Sensors oversee levels, pressure, and temperature in rotary fillers, optimizing tank filling timing without requiring wired connections on moving parts (refer to Figure 1.13).
- Day tank level monitoring: WSNs collect data from tanks without wired power or data links, transmitting it for continuous analysis and logging at a central control hub. Ultrasonic sensors guarantee precise level readings despite gradual filling or depletion

Additional specifics on WSN specifications and constraints are provided to outline the challenges associated with these applications.

- ***Military applications:***

Military applications of wireless sensor networks focus primarily on remote sensing [14]. It Provides a detailed survey of WSN military applications. In battlefield scenarios, depicted in Figure 1.10, WSNs play a critical role in monitoring enemy intrusions. Initial deployment involves strategically placing wireless sensor nodes across the battlefield using methods such as aerial deployment via airplanes or ground deployment using specialized robots [15], [16]. These sensors form a network covering the entire area, capable of monitoring various parameters including heat, pressure, sound, light, electromagnetic fields, vibrations, and more.

The American defence Plan (discussed in [17]) exemplifies this approach with nodes equipped with seismic, auditory, radio wave, magnetic, chemical, biological, and infrared detectors. These sensors gather comprehensive environmental data crucial for military operations, designed to be both disposable and cost-effective.

City combat is an additional critical usage where WSNs are deployed. Nodes placed in urban environments serve to detect enemy intrusions, movements, and potential chemical attacks [18]. Data gathered out of the Sensing region is capable of being transmitted to either a stationary base or a mobile military unit that operates around the perimeter of the WSN. This information plays a critical role in potentially saving lives or minimizing material losses, underscoring the need for swift delivery to its destination.

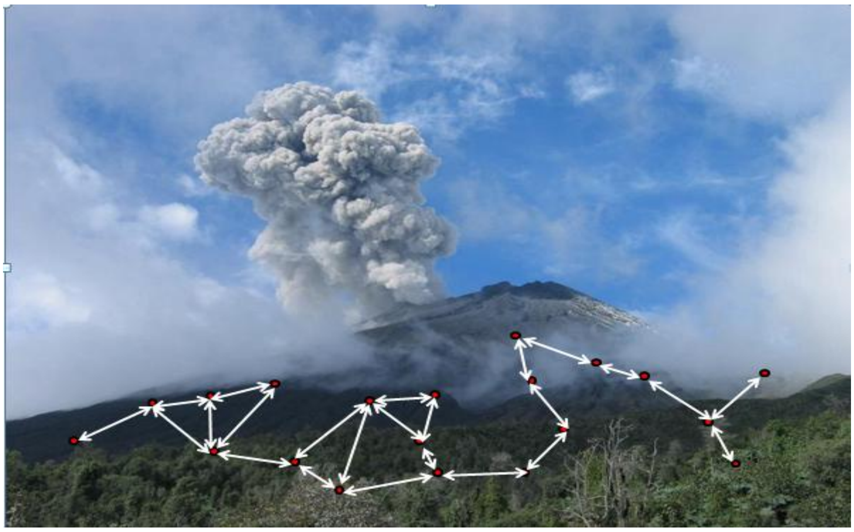

Figure 1.10: WSN military application scenario [19]

- ***Health Applications***

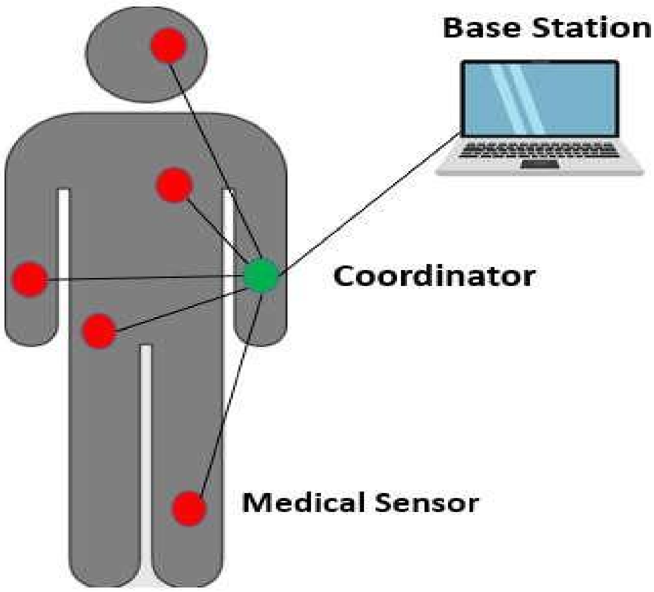

Figure 1- 11: Sensing for Human Body [19]

Wireless Body Area Networks (WBANs) possess a crucial feature in enabling communication for medical procedures, particularly those involving WBANs implanted inside the human body. WBANs are equipped with small, lightweight, and cost-effective sensors that can be applied to the body like smart patches, integrated into clothing (smart clothing), implanted under the skin, or deeply embedded in body tissue [20, 21]. These technologies support healthcare professionals and physicians in continuous monitoring and accurate diagnosis of patients' health conditions. Patient data collected from WBANs are securely stored in a centralized healthcare system, ensuring stable and reliable records. This information is readily accessible to doctors for assessing patient health status and can be used to notify patients through alarms, Short Message Service (SMS), or email alerts [21].

Figure 1.11 shows an example of the healthcare application, formed by a number of medical sensors; these sensors are connected to a coordinator. The coordinator collects data and forwards them to the Sink. The Sink is a medical server that receives all the medical data gathered by the coordinator.

- ***Home applications***

Technological advancements now allow sensors to be embedded in common household appliances [22] like respirators, refrigerators, and washing machines. These sensors can communicate with each other or via the Internet, enabling users to monitor these appliances from anywhere. The integration of these technologies, known as "Smart Home" [23,24], aims to automate building management and improve user lifestyles with eco-friendly features and enhanced comfort. The rise of the Internet of Things (IoT) has led to a proliferation of connected devices, expanding possibilities for home automation.

1.2.6 Benefits of Wireless Sensor Networks

Several advantages exist for using Wireless Sensor Network [25]:

- Achieving a higher level of fault tolerance is possible, because of the dense deployment of a larger number of nodes.
- Coverage of a large area is possible through several sensors.
- Additional sensor nodes can be incorporated into the area of concern.

An improvement in sensing quality is achieved by merging multiple independent sensor measurements.

1.2.7 The obstacles and difficulties

Wireless Sensor Networks differ from ad-hoc Wireless Networks due to their distinct characteristics [26].

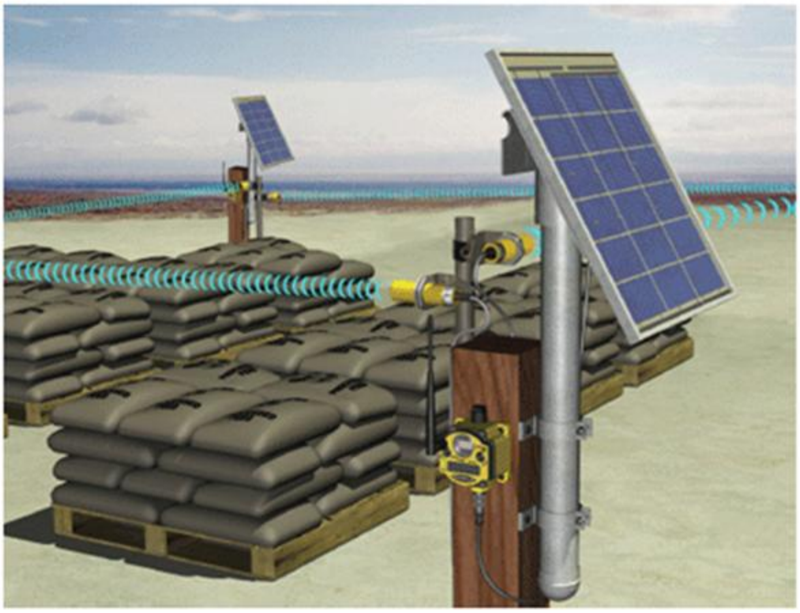

Figure 1.12: Wireless perimeter guard [27]

Sensor networks differ significantly from ad-hoc networks in several key aspects:

- The topology of a sensor network is highly dynamic, unlike the relatively stable topology of ad-hoc networks.
- Sensor networks can accommodate significantly more nodes than ad-hoc networks, often by several orders of magnitude.
- Nodes in sensor networks are densely deployed to ensure comprehensive coverage.
- Sensor nodes within these networks operate under constraints such as limited power, memory, and computational capabilities.
- Sensor nodes are prone to failures due to their deployment in challenging environments.
- Due to their scale, sensor networks may lack globally unique identification numbers for individual nodes.

Figure 1.13: Instance of an observation in a Packaging plant [13]

WSNs identify multiple uses across different fields, as demonstrated in earlier sections. Each application typically involves Joint detection, messaging, and processing among numerous Detectors tasked with monitoring Shifting entities, physical phenomena, or environmental events. These applications are structured into specific operational tasks, including deployment, application functionality, and information exchange [28].

These tasks significantly impact network properties. For instance, the implementation assignment influences node density and topology, thereby influencing Information acquisition and directing methods based on linkage and detection Range. Range ensures that each point in the detection sector is observed by at least one detecting device. The Grid achieves a Range level k if each point is within the detection area of at least k detectors. Connectivity ensures that any node can communicate with others through intermediary nodes when direct communication is not feasible. Sensing and communication ranges play a crucial role in maintaining coverage and connectivity.

In WSN deployment, choosing a deterministic sensor placement can enhance network properties. However, certain applications such as military operations, remote areas, and hazardous environments may necessitate a random sensor distribution approach where deterministic placement is impractical.

1.2.8 WSN Design

Network's structure varies according to the use and is affected by elements such as error resilience, Expandability, Hardware constraints, Shape, and energy usage [29]. Following elements are illustrated below:

- ***Error resilience***

Node failures in WSNs are much higher than other networks, because of hardware issues or physical damage or by depleting their power supply. Protocols deployed in a sensor network must ensure that alternative paths are available for forwarding packets.

- ***Expandability***

Based on the purpose for which the sensing network is aimed, the count of sensing units can fluctuate from several to millions. The exchange among sensing units shouldn't be affected by variations in node concentration across distinct zones of the structure.

As developing a sensing system application, it is crucial to minimize production costs. This involves ensuring that the price of each sensor node is kept as low as possible, necessitating low complexity for each node. Furthermore, both initial investment and ongoing maintenance costs should be minimized.

- ***Hardware Constraints***

A sensor node comprises four essential components: a sensing unit, a processing unit, a transceiver unit, and a power unit plus a Memory. Depending on the specific application, additional components like a Global Positioning System (GPS) may be included.

Energy source is crucial for assessing sensor node's longevity because it directly affects the battery life. Sensor nodes are designed to be compact and must adhere to stringent requirements such as minimal power consumption, affordability, autonomy, and the ability to adapt to diverse environmental conditions.

- ***Shape***

In sensor network applications, nodes are often deployed in close proximity using various methods tailored to specific applications. For example, in military scenarios, nodes may be deployed via airdrops or individually by robots. After deployment, the network topology can change due to several factors:

- **Energy level:** Each sensor has limited battery life, may causing nodes to become unavailable over time and leading to unexpected changes in network topology.

- **Messaging range:** Energy constraints affect each sensor's communication range, which can diminish over time and be further affected by obstacles or interferences, altering the network topology.
- **Faulty sensors:** Changes in network topology can occur due to malfunctioning sensors.
- **Mobility:** Some sensors may be mobile, resulting in dynamic changes to the network topology.
- **Addition of new nodes:** Introducing new nodes after initial deployment can also modify the network's structure.

<u>Transmission's items can be:</u>

- **Radio:** It is suggested to utilize the Manufacturing, Research, and Healthcare (MRH) bands for radio links. These bands allow flexibility in choosing power-saving communication protocols, but interference from existing applications can be a significant issue.
- **Infrared:** This method is robust against interference from existing applications but requires line-of-sight for effective transmission.
- **Photonic:** Advantages include smaller device size, lower power consumption, and freedom from interference and eavesdropping within opaque enclosures. However, challenges include maintaining line-of-sight between transmitter and receiver due to random sensor deployment, reduced bandwidth in non-line-of-sight scenarios, and increased complexity with larger field-of-view transceiver systems.

For military applications, communication faces greater interference, necessitating robust coding and modulation schemes to support the chosen transmission medium effectively.

- ***Energy usage***

The operational lifespan of sensor nodes is heavily influenced by their battery capacity. Typically, these nodes rely on limited power sources, such as <500 mAh at 1.2 V, with little or no possibility for recharging. Commercially deployed sensors commonly use two AA alkaline cells or a single Li-AA cell. Given these constraints, effective power management and conservation strategies are crucial for sensor networks, necessitating the development of power-aware protocols and algorithms.

In a sensor field, the primary functions of a sensor node include event detection, local data processing, and transmission of raw or processed data. Power consumption is thus distributed across three main domains: sensing, communication, and data processing, each requiring optimization. In multi-hop sensor networks, nodes often serve dual roles as both data collectors and relays. Excessive rerouting or retransmission significantly increases power consumption, highlighting the importance of efficient communication strategies.

In essence, ensuring prolonged operation of sensor networks relies heavily on optimizing power usage across all operational aspects, from sensing and data processing to efficient communication strategies in multi-hop environments [30].

1.2.9 Services of WSNs

Numerous applications within Wireless Sensor Networks rely on standard services such as time synchronization, data aggregation, location detection, topology management, data storage, and message routing.

a. Time Synchronization

Time synchronization is pivotal within Wireless Sensor Networks (WSNs) [31]. In order to coordinate their activities effectively for intricate sensing tasks, sensor nodes need to be synchronized. Time synchronization guarantees precise time stamping of sensed events. Errors in timestamps, often due to factors like hardware clock drift, can result in sensed data being transmitted to the sink in an incorrect chronological sequence.

Accurate period alignment is vital, especially for low-duty power cycles. Synchronized sensing devices may send signals to sink and then enter an energy-saving mode to preserve power.

Precise time alignment is essential, especially for low-duty power cycles. Coordinated sensor nodes can transmit signals to the sink.

b. Data Aggregation

Data aggregation is of utmost importance in WSNs due to the constrained power resources of sensor nodes. Hence, it is essential to minimize the number of messages transmitted. Given that sensor nodes in close proximity frequently detect the same phenomena, some sensors may produce identical readings. By collaborating locally, adjacent sensing units can sift or consolidate their measurements preceding forwarding those toward a central Sink. That strategy significantly decreases the total number of messages sent [32].

c. Location detection

Location detection of a sensor node can be expressed as global coordinates or inside an application-defined local coordinate system. It serves as additional WSN services where location awareness is required; for example, message routing. Besides that, in applications like fire detection, it is usually not sufficient to determine if a fire is happening, but more importantly,where.

d. Message Routing

In WSNs, routing protocols must minimize energy consumption and achieve an acceptable degree of fault tolerance if some of the sensor nodes died.

e. Data Storage

Data gathered by separated sensors has to be stored alternatively internally or externally. In cases where offline storage isn't an option, the data must be stored within the WSN infrastructure itself [33].

1.2.10 Examples of Operating Systems used in WSNs

The design of operating system for WSNs diverges from the traditional operating system design due to their particular features like limited resources and inaccessible deployment environments. Some of the WSN operating systems are described in what follows.

1) TinyOS

TinyOS is a compact operating system designed with a micro threaded architecture, aiming to address two primary challenges: enabling concurrent data flows among hardware devices and supporting modular components with minimal processing and storage overhead. These challenges are crucial, as TinyOS must effectively manage hardware resources while ensuring efficient concurrent operation.

TinyOS adopts an event-based programming model, which is optimized for executing multiple tasks concurrently using minimal memory. In contrast to a stack-based threaded approach, where each execution context requires dedicated stack space and context switching can be slower, TinyOS achieves higher throughput. It achieves this by rapidly creating tasks associated with events without resorting to blocking or continuous polling.

Furthermore, TinyOS emphasizes energy efficiency by placing the CPU in a sleep state when idle, thereby conserving power. This approach is particularly advantageous in resource-constrained environments where energy preservation is critical.

In summary, TinyOS distinguishes itself with its event-driven architecture, efficient memory usage, and energy-saving strategies, making it suitable for managing hardware capabilities and resources in embedded systems effectively [34][36].

2) *Mate*

Mate [35] integrates with TinyOS as a component designed to enhance accessibility and streamline programming for sensor networks. It functions as a byte-code interpreter, catering to no expert programmers by facilitating quick and efficient network programming. Mate provides an execution environment crucial for systems like the UC-Berkeley mote, which lacks hardware protection mechanisms.

In Mate, programs are structured into capsules, each comprising 24 one-byte instructions along with type and version information, facilitating straightforward code injection. Capsules autonomously deploy themselves across the network. Mate supports the beaconless (BLESS) ad hoc routing protocol and allows for the implementation of custom routing protocols. Sensor nodes receiving updated capsule versions automatically install them, enabling network-wide programming through hop-by-hop code injection.

Capsules in Mate are categorized into message senders, message receivers, timers, and subroutines. Events trigger Mate execution, serving not only as a virtual machine platform for application development but also as a comprehensive tool for managing and controlling sensor networks.

3) MANTIS

MANTIS [37] is an embedded operating system designed for multi-threaded environments, leveraging its single-board hardware to facilitate rapid and adaptable application deployment. Prioritizing programmer convenience, MANTIS adopts a traditional layered multi-threaded architecture and employs standard programming languages.

Its layered structure encompasses multi-threading, pre-emptive scheduling with time slicing, mutual exclusion for I/O synchronization, a comprehensive network protocol stack, and efficient device drivers. Remarkably, the current MANTIS kernel implements these functionalities using less than 500 bytes of RAM.

The implementation of MANTIS relies on standard C language for both the kernel and its API, ensuring compatibility and ease of development across supported platforms.

4) EYE OS

As previously mentioned the operating system designed for Wireless Sensor Networks must be highly efficient in terms of memory usage and coding simplicity, prioritize power efficiency, and support distribution and reconfiguration capabilities. EYES OS [38,39] achieves these goals by employing an event-driven model and a task mechanism.

The operation of EYES OS follows a straightforward sequence: it executes a computation, returns a result, and then enters sleep mode to conserve power. Tasks within EYES OS can be scheduled using various approaches such as FIFO, priority-based scheduling, or deadline-based scheduling (e.g., Earliest Deadline First, EDF). These tasks are triggered by events in a no blocking manner.

EYES OS provides a comprehensive Application Programming Interface (API) both locally and for network components. The local API offers functions for accessing sensor node data, checking resource availability and status, and configuring parameters or variables within sensor nodes. The network API facilitates data transmission and reception, as well as retrieving network-related information.

In essence, EYES OS supports two main sets of functionalities: those executed during boot time to upload software modules, and those providing localization information for nodes within the network. This design ensures that EYES OS meets the stringent requirements of WSNs by optimizing resource utilization, energy efficiency, and facilitating dynamic network management.

5) SenOS

SenOS [40] operates on a finite state machine (FSM) architecture and comprises three main components:

1. **Kernel:** This component includes a status arranger and an Occurrence Line. The status arranger awaits Entry from the occurrence line, which operates on a First-In-First-Out (FIFO) basis.
2. **State Transition Table:** This table stores information about state transitions and their corresponding call back functions. Each state transition table defines a specific application. It accommodates various uses concurrently by utilizing multiple state transition tables and switching among them.
3. **Call back Library:** This library consists of callable functions. When an event is received, it is installed in the Task list. The first Task in the List triggers a Phase change, which then invokes the associated call back functions.

The kernel and call back library are constructed statically and reside in the flash ROM of a sensor node. In contrast, the state transition table can be dynamically reloaded or modified at runtime because it is specific to the application.

SenOS's FSM-based design enables straightforward implementation of concurrency and reconfiguration. Moreover, it can be extended to include functionalities such as network management, leveraging its modular and flexible architecture.

6) MagnetOS

MagnetOS [41] is an innovative decentralized dynamic OS explicitly designed to prioritize application adaptation and energy conservation. Unlike other operating systems, MagnetOS integrates a network-wide adaptation mechanism and policies to efficiently utilize node resources, alleviating the burden typically placed on applications to create their adaptation mechanisms, which often leads to inefficiencies in energy usage.

The primary objectives of MagnetOS include:

1. Stable adaptation to underlying resource changes.
2. Energy conservation efficiency.
3. Providing a generalized abstraction layer for applications.
4. Scalability for large networks.

MagnetOS functions as a Single System Image (SSI) or unified Java virtual machine, incorporating both static and dynamic components. Static components rewrite applications at the bytecode level, enhancing them with necessary instructions for original semantics. Dynamic components handle application monitoring, object management, invocation, and migration. The SSI abstraction enhances flexibility in object placement and simplifies application development.

Programmers interact with MagnetOS through an interface that allows explicit object placement and overrides decisions made by the automatic placement mechanism.

Moreover, MagnetOS introduces two online power-aware algorithms:

- **NetPull:** Operates hop-by-hop at the physical layer to relocate application components, aiming to reduce energy consumption and extend network lifespan.
- **NetCenter:** Performs multi-hop operations at the network level for energy-efficient application component movement.

Unlike traditional ad hoc routing, where communication endpoints are fixed, NetPull (and NetCenter) dynamically adjust communication endpoints to conserve energy effectively.

In summary, MagnetOS stands out for its advanced capabilities in application adaptation, energy efficiency, and network scalability, offering a robust framework for managing and optimizing resources in distributed environments [41].

1.2.11 Routing in WSNs

1. With Fixed Base Station

This is liable to be categorized into hierarchical, multi-path, location-based, and hybrid routing. In hierarchical structures, network nodes are split into two categories: one set gathers and transmits data to the Sink (base station), while the other monitors the environment. Multi-path routing aims to enhance network reliability by utilizing multiple paths between sensors and the sink. In location-based routing, the sink possesses knowledge of the source node's location and sends queries to specific locations of interest to retrieve data. Hybrid routing protocols combine two or more of the a fore mentioned routing approaches.

- **Hierarchical-based Routing**

In hierarchical architecture, higher-energy nodes are designated to process and transmit information to the Sink, while lower-energy nodes handle sensing tasks within specific areas. This approach partitions the network into multiple clusters, where each cluster consists of a cluster head and several cluster members. This forms a two-tier hierarchy: cluster heads occupy the upper tier, and cluster members the lower tier. Cluster members gather data from the physical environment and forward it to their respective cluster heads. The cluster heads then process this data and relay it to the sink, either directly or through a multi-hop route.

Heinzelman et al [9] have proposed Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol. It represents the initial hierarchical clustering approach in WSN. It runs in multiple rounds, each consisting of two phases. During the first one, clusters are formed, while in the second, data is sent to the BS. CHs are elected based on a predefined percentage of CHs and their history of serving as cluster heads in previous rounds. LEACH helps distribute the workload among CHs to a certain extent. Time slots allocated to individual cluster heads prevent unnecessary collisions and reduce energy consumption. However, LEACH is less suitable for large-area networks due to the uneven distribution of cluster heads, which introduces additional overhead.

PEGASIS [42] is a protocol that builds upon the LEACH protocol, introducing a sequential chain formation achieved through two main steps: chain construction and data aggregation. The core principle involves nodes communicating exclusively with their closest neighbors, taking turns to deliver details to BS. By utilizing this chain method, the protocol reduces the overhead associated with dynamic cluster formation and minimizes data transmission requirements. It ensures an even distribution of energy load throughout the network. However, a downside is increased latency experienced by distant nodes due to the single-chain structure, potentially impacting overall performance.

W. Naruephiphat et al. introduced Grouping method known as restricting associate element grouping[43].This algorithm introduces a constraint on the maximum number of participant elements that every CH can accommodate. It organizes sensor nodes into groups based on their nearness to BS: nodes within the station's transmission range are categorized in level 1, while those further away are assigned higher levels depending on their distance.
By limiting the number of member nodes per cluster head to below a specified threshold, the protocol aims to evenly distribute the workload. This strategy enhances the network's longevity and reduces the latency in forwarding data packets.

LEACH-C [44] is an adapted version of LEACH that incorporates unified group coordination. In its first step, BS gathers location data and residual energy levels from all nodes across the network. Using this information, the base station then selects cluster heads and organizes the remaining nodes into clusters. Communication within and between these clusters is facilitated through single-hop communication. By leveraging comprehensive network knowledge and detailed node information, LEACH-C can establish optimized clusters that minimize energy expenditure during data transmission. However, this centralized approach introduces additional overhead due to the necessity of transmitting node messages to BS and may not be suitable to deployment in larger-scale networks.

- **Multipath-based Routing**

Presents an alternative approach to routing by selecting multiple paths for transmitting data from a source to a destination. This method enables several routes between the source and destination, thereby enhancing reliability and balancing the network load. Numerous multi-path routing protocols have been developed specifically Aimed at WSNs. They aim to manage the Task allocation challenges moreover asset constraints typical of lesser capacity sensing element nodes by simultaneously forwarding details across numerous channels.

In Ganesan et al [45], a novel braided multi-path routing protocol has been developed to create several partially separate paths, enhancing fault tolerance within sensor networks. This protocol employs two types of path reinforcement messages: the primary path message and the alternate path reinforcement message. Path construction begins with the sink node initiating the process by sending a primary path reinforcement message to its optimal next-hop neighbour towards the source node. This message propagation continues until it reaches the source node. Simultaneously, the source node dispatches an alternate path reinforcement message to its second-best neighbour towards the sink node, thereby reinforcing an alternative route.

- **Location-based Routing**

Based on their geographical positions; nodes determine distances to neighbours using reception intensity. Relative coordinate information can be derived through exchange of control packets among neighbouring nodes. Alternatively, nodes may utilize the Global Positioning System (GPS) for accurate location data Nodes whose positions are unknown can estimate their approximate locations by referencing the positions of nodes whose locations are known [46].

Alasem et al [47] have suggested a position situated, power-sensitive, and reliable routing protocol that leverages sensor positions. The protocol utilizes location information obtained from GPS. Each node communicates its location to neighbouring nodes and constructs a routing table. This table includes neighbour node IDs and their respective distances from the destination node. The source node makes routing decisions based on these distances, selecting the node closest to the destination as the candidate relay to transmit information.

- **Hybrid Routing :**

Hybrid routing combines elements of various routing protocols to take advantage of their respective benefits and improve network performance. Many studies have explored it in the development of routing protocols for WSNs.

Bagheri et al [42] have introduced a clustering-based multi-path routing protocol designed for reliability and energy efficiency, leveraging nodes equipped with GPS. Cluster heads are chosen Depending on the available power of each node. Path finding process begins with the sink initiating a request packet sent to close CH, which propagates until it Extent to the destination CH that may receive multiple requests. Multi-path routes are then established through these cluster heads, enabling each cluster head to select an alternative path in case of primary path failure.Wang et al [48] have introduced a hierarchical multi-path routing protocol where each node maintains a hop count indicating its distance from the sink. Nodes use this hop count to choose a primary parent node and an alternate parent node for establishing multi-path routes. This results in a network structure resembling a tree, with the sink node at the root. The hierarchical organization helps in reducing data traffic and conserving energy within the network.

2. ***With movable BS***

In routing protocols where the sink remains static, sensor nodes near the sink often handle heavy data traffic, leading to their premature depletion and eventual network partitioning, rendering the sink unable to receive data. Introducing a movable BS renders the structure adaptive but complicates routing. This section examines existing routing protocols involving mobile sinks, categorizing and explaining them. These protocols typically fall within three classifications.

- **Hierarchical-based Routing** divides the structure into layers. Up-layer nodes handle workloads alike treating or transmitting information, while down-layer nodes perform sensing near the target. Data moves upwards from lower layers to higher layers, while queries move downwards from higher layers to lower layers. This hierarchical structure imposes dynamic roles on sensors, creating a virtual hierarchy within the network typically spanning two or more tiers. Successful implementation of a hierarchical approach requires a well-defined structure that is easily navigable and mitigates the energy depletion issue, especially in higher tier nodes [49].

- **Tree-based Routing** Managing BS movement is crucial in its environments, and tree-based routing presents an economical key for this challenge. The interconnected tree structure simplifies sink mobility management significantly. Within this framework, whatever initiator element can transmit its output to BS at lowest expenditure.
- **Virtual-structure-based Routing**

This is an effective method for data dissemination with mobile sinks, serving as a rendezvous point for sensor nodes to store measurements when the sink is unavailable. As the mobile sink moves through the network, these nodes report sensory data. It is also permitted to be established using either a backbone-based or a rendezvous-based approach. The chapter provides an overview of Wireless Sensor Networks, highlighting how their routing protocols differ from those in other networks. In chapter 2, we shall show an improvement on one of the most known routing protocols for WSNs.

1.3 Conclusion

In this chapter, we initially discussed the basics of wireless sensor networks, including an overview of what constitutes a wireless sensor network, its unique features related to sensor nodes and the network itself, and the various specialized applications it supports. We also covered the different operating systems used in these networks. This chapter provided insight into the overall operation of a wireless sensor node, which comprises several hardware components (such as the processing unit, sensing unit, transmission unit, and power source) and the software that controls these components. A wireless sensor node can also be described in terms of its protocol layers. In sensor network applications, these sensors are often deployed in challenging and inaccessible environments. When their energy runs out, battery replacement is not an option. Moreover, sensors need to be capable of self-organization to relay collected data to a base station and must be resilient to failures to ensure continuous operations.

Chapter 2 : Clustering Based Protocols

2.1 Introduction

Network lifetime is arguably the most crucial metric for assessing sensor network performance. In environments with limited resources, managing every constraint is essential. Network lifetime stands out because it signifies the maximum potential utility of the network, given its role in tracking energy consumption. It is also a key factor in ensuring availability and security within wireless sensor networks.

To extend the network's lifetime, it's necessary to minimize the nodes' energy usage. Although advancements have been made, extending the battery life of these devices remains a significant challenge, underscoring the need for further research into improving the energy efficiency of both platforms and communication protocols.

Due to the problem of Energy consumption in WSN, many types of protocols were designed to increase the network lifetime and overcome many changes in network topology. The Low Energy Adaptive Clustering Hierarchy (LEACH) protocol was the pioneer in this field, leading to the development of several enhanced variants. Most of protocols were developed based on this protocol like E-Leach, S-Leach, A-Leach, etc. In this section, we will discuss key protocols that have effectively enhanced the lifespan of various sensor networks.

2.2 WSN topologies:

A network topology is generally defined as the physical or logical architecture of such a network. The physical arrangement, that is, the spatial configuration of the network, is referred to as physical topology. In contrast, logical topology is represented by how data is transmitted through the communication links. In wireless sensor networks, a topology is used to provide information about a set of nodes and the connectivity links between each pair of nodes. A key role is played by it in the functioning of any protocol, as well as in the capacity and overall performance of the network. A topology is often represented by a graph, in which the nodes are modeled by the vertices and the communication links are modeled by the edges.

2.2.1 Flat Topology:

Flat topology, or unstructured topology, lacks a defined logical structure, with all sensor nodes performing identical roles in the network. Multi-hop communication may be required, and scalability is crucial with a large number of nodes. This architecture is marked by low maintenance costs, high fault tolerance, and the ability to create new paths when topology changes occur. However, nodes near the base station tend to take on more routing tasks, risking energy depletion in those areas. Furthermore, the uniformity of node functions leads to low sociability and necessitates a high volume of control messages. A figure typically depicts this topology, showing sensor nodes as vertices and radio communication links as edges.

2.2.2 Chain-based topology

In this topology, sensor nodes are connected in a transmission chain to conserve energy, with a leader node, often a base station, facilitating communication. Each node sends packets to its successor, leading to the leader, which helps in data aggregation. figure 2.1 shows the structure of this topology.

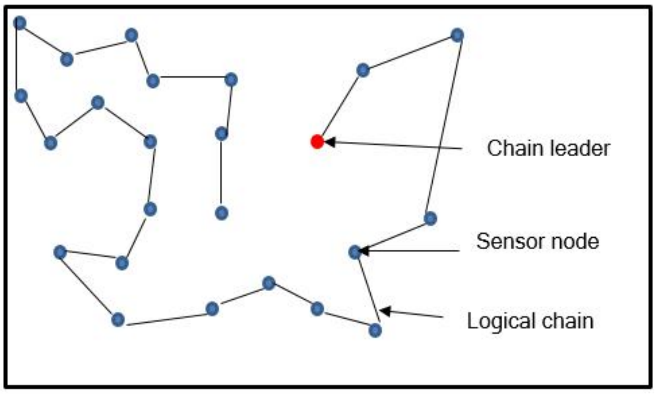

Figure 2.1: Chain based Topology

PEGASIS is a protocol that exemplifies this approach, where nodes receive data from their predecessor and transmit it to the next, merging packets to reduce transmissions. Transmissions occur in rounds, starting a new at the sink. PEGASIS aims to extend node lifespan through collaboration and enhance local coordination among nearby nodes to minimize bandwidth usage [53].

2.2.3 Tree-based topology

In a tree-based topology (or hierarchical topology), all deployed sensors form a logical tree, with each node knowing its parent. A child node transmits data to its parent node, which then aggregates the received data with its own and sends it onward until it reaches the sink. The main goal of constructing a tree is to avoid flooding, unlike in flat topology.

2.2.4 Cluster-based topology

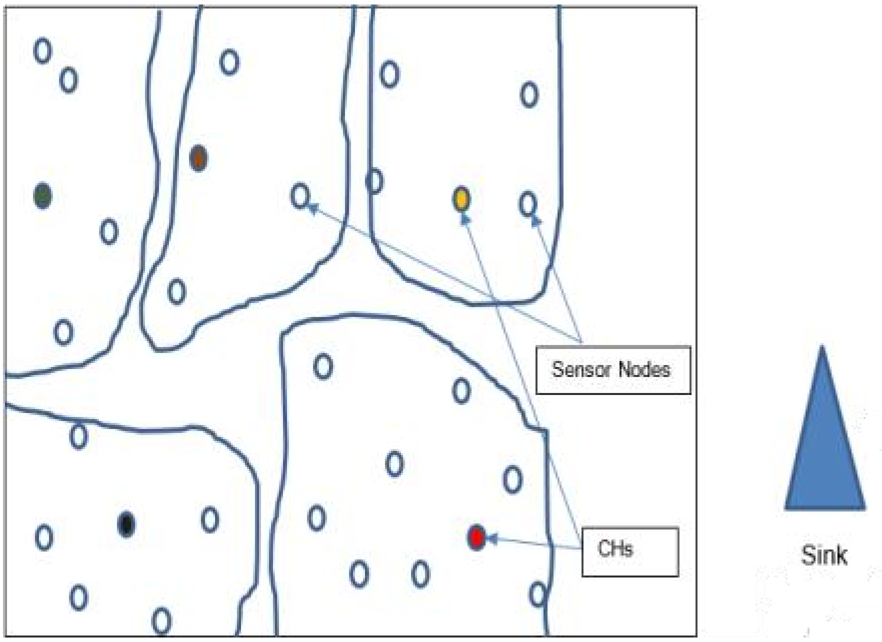

Figure 2.2:Clustering Topology

The clustering approach involves partitioning the network into a number of groups known as clusters. These clusters are organized to be more homogeneous based on a well-defined principle, thereby forming a virtual topology. Each cluster is typically identified by a specific node, referred to as the cluster-head (figure 2.2). The cluster-head is responsible for coordinating between the members of its cluster, aggregating their collected data, and transmitting it to the Sink (base station). This node is selected for the role based on a particular metric or a combination of metrics. Before discussing some algorithms that are based on clustering, it is important to present the main concepts associated with this technique**.**

2.2.4.1 Definition

Consider a wireless network represented by a connected, undirected graph:

$G = (V,E)$, where Vdenotes the nodes and E signifies the communication links. In the $\{V_1, V_2,\ldots, V_k\}$ such that:

$$V = \bigcup_{i=1}^{k} V$$

Each subset V_i induces a connected sub-graph or a connected component of the graph G. The set of these components forms a reduced graph or a component graph

$G'=(V',E')$ derived from G, where:

- The vertices $v'_i \in V'$ represent the connected components V_i of the graph G,
- E' includes the edge (v_i, v_j) if and only if an edge exists in the graph G connecting a vertex $u_i \in V_i$ to a vertex $u_j \in V_j$.

We refer to these groups as "Clusters," and they do not necessarily remain disjoint. We identify each cluster by a specific node called the cluster-head "CH." The system selects the cluster-head through an election process, known as the Set-up phase, based on a specific metric or a combination of metrics such as identifier, degree or weight, energy, k-connectivity, mobility, and more.

We evaluate the effectiveness of a clustering algorithm by examining the number of clusters formed and the stability of these clusters in relation to node mobility. The clustering process aims to optimize the maintenance of network topology information and to reduce the overhead associated with broadcasting for path discovery.

2.2.4.2 Intra-cluster and Inter-cluster Communication

Communications within each cluster are managed by the cluster-head, and routing information is maintained to enable connections with other cluster-heads. Additionally, since direct connections between cluster-heads are not established, gateway nodes are also elected and utilized for communications between cluster-heads.

2.2.4.3 Maintenance of clusters:

To adapt to changes in the network topology, dynamic updates of the clusters are carried out whenever a cluster-head or a member is migrated from one cluster C_i to another C_j . On the other hand, if the status of a cluster-head is maintained for as long as possible, even if the maximum weight is not held within its own cluster, the role will be lost once depletion occurs (for example, when the battery is exhausted). Therefore, a mechanism for maintaining the topology through re-election is required.

2.3 Some Clustering Algorithms for WSN

Wireless sensor networks are characterized as a special type of ad hoc network with unique features in terms of infrastructure, architecture, energy autonomy, and the use of radio waves for communication. However, differences in their specificities, objectives, and needs are observed. The minimization of energy consumption within a cluster is achieved through clustering in sensor networks by performing data aggregation and fusion functions to reduce the number of messages transmitted to the base station.

Recently, several clustering techniques have been proposed to address the main challenges encountered in sensor networks. The maintenance of network topology information, reduction of the overhead generated by route discovery, and minimization of energy consumption are aimed at by these techniques, considering the specific nature of these networks. Most of these techniques are designed with an energy-oriented approach, aiming to extend the network's lifespan, while some are oriented towards quality of service. Two well-known clustering protocols, VGA [50] and LEACH [51] are presented here, and further discussion on other algorithms will be provided.

2.3.1 Virtual Grid Architecture routing: VGA

VGA [50] uses a clustering method to maximize the lifespan of sensor networks where nodes either remain stationary or move at low speeds. The approach constructs fixed, disjoint, and uniformly sized clusters with symmetrical shapes without relying on GPS. The network performs data aggregation at two levels: local and global. All the cluster-heads, known as Local Aggregators (LAs), handle local aggregation. A subset of these LAs, called Master Aggregators (MAs), manages global aggregation. Researchers identify determining the set of MAs as an NP-hard problem. Heuristics aim to form the set of MAs from the set of LAs to maximize the lifespan of sensor networks. For example, the CBAH [52] (Cluster-Based Aggregation Heuristic) selects the set of MAs based on the capacities of the LAs. Members of the same cluster monitor the same phenomenon, and their LA correlates the collected data. This LA then transmits the correlated data to its corresponding MA.

2.3.2 LEACH protocol

It is a decentralized method which facilitates one-step transmission between clusters and

BS. The ClusterHead (CH) node consumes additional energy compared to ordinary nodes since it receives data from all member nodes, and then transfers them to the Sink. In LEACH, the CH selection process does not take into consideration the residual energy of the nodes, which may lead to the death of some CHs and reduces the network performances.

Numerous hierarchical protocols derived from LEACH have been employed to enhance network lifetime and performance. Due to the drawbacks of LEACH, several derived protocols have been developed, such as V-Leach, Mod-Leach, Improved LEACH, and S-Leach.

To select CHs effectively, common techniques include centralized approaches, where a central entity orchestrates CH selection, and distributed methods, where nodes collaboratively elect CHs based on local information [73].

LEACH [54] has served as the basis for many variations and improvements in cluster-based routing protocols for WSNs, addressing some of its limitations and tailoring the protocol to specific application requirements. It remains a fundamental protocol in the field of WSNs and energy-efficient routing [55]. Information is collected by nodes from their surroundings and transmitted to their corresponding CH. CH groups, compresses, and delivers the aggregated data from cluster participants to the sink. The lifespan of WSNs is enhanced in LEACH protocol by reducing the number of transmitted packets through cluster structuring. choosing the cluster head did not take into account the distance or current node energy, which is considered as one of the various downsides. When communicating with the sink, the CH only uses a single hop, which is another disadvantage that makes LEACH irrelevant for large networks.

The two phases of LEACH are cluster setup and steady phase. In the initial phase, the node is in charge of choosing a CH at random from 0 to 1. In the following round, that sensor will become a CH if it is less than T (n), which is determined by equation (1).

The threshold is given as:

$$T(n) = \frac{P}{1 - p \times (r \bmod p^{-1})}, \forall n \in G.$$

$$T(n) = 0, \forall n \in G$$

P: indicates the CH's percentage in the network.

r: represents the current round

G: indicates the group of sensor nodes that have not been CH in the last 1/p rounds.

T(n): the threshold calculated for a node n and it is calculated in every round

LEACH protocol architecture is shown in figure 2.3. Normal nodes in such type of protocol consume less energy than the CH node because the last one gathers and merges collected information before sending it to the SINK. Leach protocol is based on one hop process between CHs and the SINK whatever the distance between them and the energy level of these CHs [62]. When a node is selected as CH, it must inform other sensor nodes of its new ranking in this round. To prevent conflicts between CHs, an 'ADV' alert with the CH identifier is sent to all other nodes using the CSMA/CA-MAC protocol.

The message is ensured to be received by all nodes through dissemination. Furthermore, it ensures that the nodes belonging to the CH require a minimum amount of energy to communicate. The decision of a node to join a CH is therefore based on the amplitude of the signal received by that node. So, the CH with the most robust signal, or the nearest, will be chosen. In the case of signal amplitude equality, ordinary nodes randomly select their CH. Each node member communicates its choice to its CH. Upon receipt of a request, the CH responds with a message "Join-REQ."

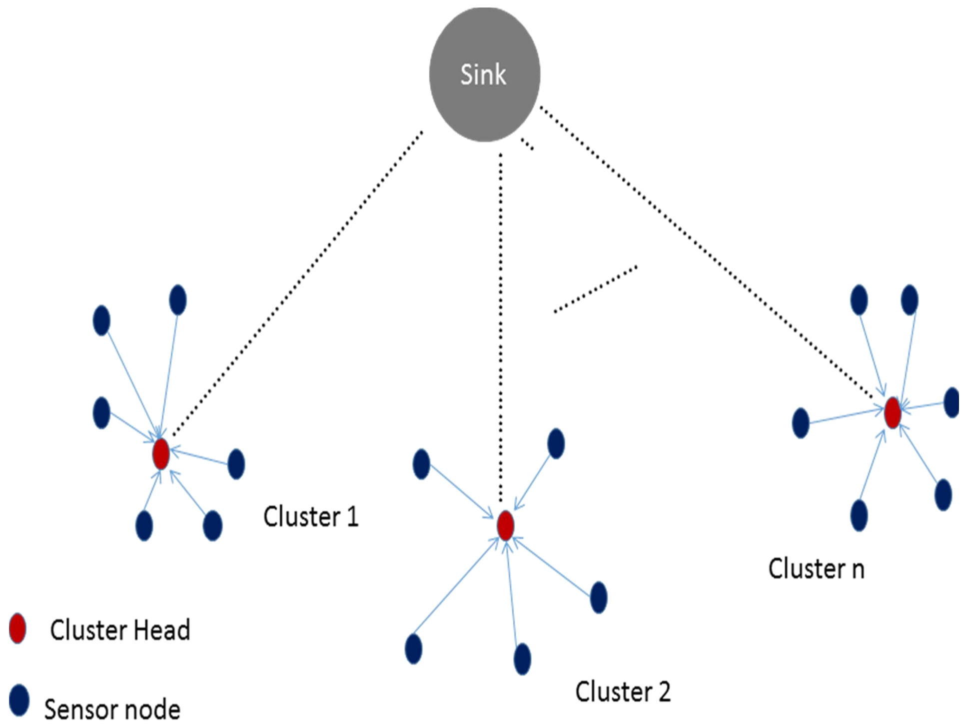

Figure 2.3:LEACH protocol Clusters Formation

Each CH serves as a local manager to oversee data communication inside its cluster after cluster formation. Each member node is given a time slot to transmit data during the creation of a TDMA scheduler. A frame is the collection of slots allowed to cluster nodes. The time of each frame varies with the number of sensor nodes in the cluster. In order to less interference between broadcasts in neighbouring groups, each CH also chooses a random code from a set of CDMA propagation codes. In order, for its subscribers, to use it for communication, it is then sent to them. During the steady-state phase, data will be transferred to the sink. Using the TDMA scheduler, members transmit their sensed data during their own slots. This enables them to conserve energy by turning off their communication connections outside of their slots. The CHs aggregate these data after which they combine, compress, and transfer the complete message to the sink.

The network will advance to the next round after a certain amount of time. Up until all network nodes have elected the CH once through the preceding rounds, this process is repeated. The round is restarted at zero in this instance.

Although LEACH has the merit of being the first to apply the clustering approach in WSNs to organize communications according to the sensor cluster heads and sink hierarchy to optimize energy consumption in a WSN, it suffers from several weaknesses:

1. After the protocol is executed, some clusters may have more member nodes and others fewer; some CHs may be located at the centre and others at the edge of the cluster, which implies an increase of energy consumption.
2. The ideal number and distribution of CHs cannot be guaranteed because CHs are selected randomly.
3. Sensors with minimal residual energy have the same chance of being elected CHs as nodes with high residual energy, which poses the problem of premature energy failure for the former. In such a case, if energy failure recovery capabilities have not been planned for, the WSN mission may be compromised due to the loss of data collected by members of a CH with a depleted battery.
4. CHs communicate directly in single hops with the Sink, which means that the Sink is within their range. In large WSNs, the communication must be multi-hop through CHs to the Sink and even multi-hop within the same cluster.
5. The random selection algorithm of CHs causes an imbalance problem in the energy load. The distance factor is not taken into consideration when forming clusters, due to which sometimes very large clusters and very small ones exist at the same time in the network [54].

2.3.3 Leach Derivatives

Due to LEACH protocol limitations, much research was done to overcome these limitations, and many protocols were developed to decrease energy consumption and increase the network lifetime. In this section, we will introduce some of the new protocols derived from LEACH. Cluster-based algorithms play a vital role in Wireless Sensor Networks (WSN), offering advantages such as scalability and energy efficiency. These algorithms organize sensor nodes into clusters, with cluster heads (CHs) responsible for transmitting data from cluster nodes to the sink. The election of CHs is a critical aspect, impacting energy consumption and network lifespan [63]. Various CH election algorithms exist, each designed to address specific challenges and requirements of WSNs. These algorithms consider factors like node proximity, residual energy levels, and communication overhead.

1) VLEACH Protocol

If a Cluster Head does not have sufficient energy to transmit the aggregated data to the Sink, it can lead to data loss and may affect the overall performance of the network. This scenario can occur due to various reasons, such as energy depletion or failure of the Cluster Head. [59]

In the VLEACH protocol, each cluster has a CH that communicates data collected from the cluster nodes to the sink, a vice-CH that takes over the CH's role if CH dies, and cluster nodes that gather data from their surroundings and communicate it to the CH. Due to its constant data collection from cluster nodes, aggregation, and transmission to a potential distant Sink, the CH in the original LEACH dies earlier [60].

In VLEACH protocol, we have CH and vice-CH that take on the responsibilities of CH when CH dies. It is not necessary to vote for a new CH every time and the current CH dies if the above work is completed. This will increase the lifespan of the network as a whole and network-wide communication.

2) MOD-LEACH

Compared to LEACH, the MODLEACH protocol represents advancement. It featured two unique approaches to cut down on energy consumption: a reliable cluster head replacement mechanism, and dual transmission power levels [61].

According to the simulation findings, MODLEACH is superior to LEACH when factors like throughput, cluster head formation, and network longevity are taken into account [72].

3) LEACH-C

LEACH-C (Centralized LEACH) is indeed a centralized protocol designed to improve the efficiency of cluster formation and CH selection in Wireless Sensor Networks. In LEACH-C, the sink node, which typically serves as the central coordinating entity in WSNs, takes on the responsibility of making all decisions related to CH selection and cluster formation [56].

In LEACH-C, there is a guarantee or discussion about the placement of cluster head nodes. Since the cluster is adaptive, obtaining bad clustering while using the central control system to form a cluster may produce better clusters; at begin of each iteration, the position and residual energy of sensor nodes will be transmitted to the Sink. After acknowledging this information, all nodes must be given an equal part of the energy burden, according to the Sink. For this, the Sink calculates the average energy value of all nodes and determines that the residual energy of the nodes is more than the average. Once it forms the clusters with their CHs, it sends out a message containing the CH identifiers (IDs). For each node, if the node ID matches the same ID that it received, that node will be elected as the CH; otherwise, the node will make contact with the relative CH and transfer data to the latter at its slot.

However, it dramatically increases network overhead since all sensors will have to transmit their position to the Sink at the moment during each CH election phase. As the author discussed, the steady-state phase of LEACH-C is the same as the steady-state phase of LEACH [56].

4) I-LEACH

The rounds of this protocol are split between set-up and steady state durations, similar to classic LEACH. If a node's energy level is higher than the average energy value during setup, the sink elects that node as the cluster head. The data signals sent to the cluster heads and then relayed to the sink during the steady-state period are scheduled using the TDMA protocol [70].

I-LEACH's combination of energy-aware CH selection and TDMA based scheduling contributes to improved energy efficiency and network performance, extending the operational lifespan of WSNs. This protocol is particularly suitable for applications where energy conservation and prolonged network operation are critical, such as environmental monitoring and surveillance systems [57].

5) SLEACH

Sectored Leach or SLeach is a technique that reduces the transmission distance between nodes by segmenting the communication space into sectors that are centred around the sink. Reduced distance causes the node energy to live longer because the energy needed for transmission is inversely correlated with distance [58].

6) RED-LEACH

This protocol is an advanced leach protocol. This protocol works in rounds, each separated into a setup phase and a steady state phase. Each node's leftover energy and distance from the Sink are taken into account by RED-LEACH, which are important for energy efficiency [70].

7) E-LEACH

An approach for choosing a CH to save energy has been introduced by earlier research on E-LEACH. The remaining energy is a factor that E-LEACH takes into account while choosing the following CH. According to simulations, E-LEACH has a longer network lifetime compared to LEACH. Data transfer from a CH to the Sink has been altered by the suggested method. If a CH has a lower distance to the Sink, it will look for another CH as a next hop rather than delivering data directly to the Sink [64].

8) AE-LEACH

There are four significant parts in AE-LEACH. The sensor nodes' mobility is calculated in the first part. The second one uses the AE-LEACH protocol to conduct clustering based on descriptors. The goal trajectory is calculated using the Particle Filter (PF) algorithm in the third part, and energy efficiency is calculated using the Gini index in the fourth part [66].

2.3.4. Other Routing protocols

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

In [67], Lindsey and Raghavendra introduced PEGASIS, an advanced version of LEACH. PEGASIS organizes nodes into a chain where each node communicates with its neighbors, aggregating data until it reaches a designated node that sends it to the Sink. Unlike LEACH, PEGASIS avoids cluster formation and uses a round-robin method for selecting nodes to transmit data to reduce energy consumption. Simulations show that PEGASIS can extend the network's lifespan by two to three times compared to LEACH by eliminating clustering overhead and reducing transmission frequencies. However, PEGASIS still needs dynamic topology adjustments, which can add overhead, and it assumes direct communication with the Sink and knowledge of all nodes' locations, which may not be practical in real-world scenarios. Consequently, PEGASIS is best suited for stationary sensors and may perform poorly in mobile environments.

2) TEEN (Threshold-sensitive Energy Efficient sensor Network protocol)

Manjeshwar and Agrawal [68] developed a clustering method known as TEEN, tailored for scenarios where parameters might change suddenly. The network employs a hierarchical, multi-tier structure where neighbouring nodes form clusters, and this clustering extends up to the base station. Once clusters are established, each cluster-head sets two thresholds for its members: a Hard Threshold (HT) for significant changes and a Soft Threshold (ST) for minor fluctuations. Nodes that detect changes meeting or exceeding the Soft Threshold send alert messages to the Sink, reducing unnecessary transmissions and conserving energy.

Nodes continuously monitor the medium, and data is transmitted only when a parameter surpasses the Hard Threshold or deviates from a stored value (SV) by at least the Soft Threshold. This method conserves energy compared to periodic protocols like LEACH because message transmission is more energy-intensive than data detection. However, if the HT and ST thresholds are not received, nodes might not communicate, leading to no data transmission and a lack of information about nodes' energy status. Therefore, TEEN is not ideal for applications needing regular data updates.

3) APTEEN

To overcome these limitations, the authors introduced an enhanced version of TEEN called APTEEN (Adaptive Threshold-sensitive Energy Efficient sensor Network protocol). APTEEN is a hybrid protocol designed to adapt the periodicity and threshold values used in TEEN based on user requirements and application needs. In APTEEN, cluster-heads provide their members with the following parameters:

- The set of physical parameters of interest to the user (A).
- The thresholds: Hard Threshold (HT) and Soft Threshold (ST).
- A TDMA schedule that allocates specific time slots to each node.
- A Time Counter (CT), which defines the maximum allowed time between two successive transmissions by a node.

In APTEEN, nodes continuously monitor their environment. If a node detects that a parameter value exceeds the HT, it will transmit data only if the parameter value changes by at least the ST amount. If a node fails to transmit data within the CT time period, it must capture new data and resend it.

APTEEN offers substantial flexibility by allowing users to set the CT interval and the HT and ST thresholds to manage energy consumption according to these parameters. However, it adds complexity due to the need for implementing threshold functions and managing time periods. Consequently, the overhead and complexity associated with the multi-level cluster formation in both TEEN and APTEEN are relatively high.

4) Geographic Adaptive Fidelity (GAF)

GAF [69] is a location-based routing protocol designed for ad hoc and sensor networks, using GPS or other positioning systems for location information. It partitions the network area into virtual grids, ensuring communication between adjacent grids and maintaining routing fidelity. Each grid elects one active node, while others enter sleep mode to conserve energy. Nodes start in the Discovery state to find others in the grid, and then move to Active or Sleeping states depending on the conditions.

GAF helps reduce energy consumption while ensuring routing fidelity. However, in highly mobile environments, active nodes may leave their grids, which can reduce routing fidelity and increase packet loss. The protocol assumes uniform node distribution and fixed transmission ranges, leading to high complexity and overhead, especially with frequent topology changes.

5) *Base Station Controlled Dynamic Clustering Protocol: BCDCP*

BCDCP depends on the Sink to choose CHs from a collection of sensors, considering their remaining power and a set power boundary that reflects mean power status of all nodes. The protocol employs an iterative algorithm for cluster division, starting with the network being split into two sub-clusters. This process continues, further dividing the clusters until the required number of clusters is achieved [70].

BCDCP employs transmission among sensing groups to relay the information toward BS. Once groups are established, the BS selects the most efficient routing path by implementing a Least Hierarchical Extending (LHE)[71] to link the cluster heads, which is then conveyed to the sensor nodes. A TDMA schedule is implemented so that each node can send its sensed data to its respective CH. After every sensing device has transmitted its data, the CH conducts data aggregation and forwards the information to the Sink via the inter-CH routing path established by the Sink.

6) *Dynamic Least Hierarchical Extending Routing Protocol: DLHERP*

It seeks to enhance the performance of BCDCP by preserving numerous other traits. It utilizes Least Hierarchical Extending (LHE) to optimize choices in both inter-cluster and intra-cluster communications [72].

2.4. Issue of resource optimization

Sensing elements typically possess energy reserves, making power consumption crucial. By embedding energy awareness in design and operations, the network's longevity can be enhanced. The primary objective of Energy-Efficient Routing protocols is to extend the network's lifespan by minimizing energy usage [71].

2.5. Conclusion

In this chapter, we have provided an in-depth examination of key hierarchical protocols in sensor networks and the underlying concepts that these protocols are based on.

we began by exploring various clustering protocols specifically designed for sensor networks. We observed that clustering emulates a centralized structure and leverages its benefits effectively in small to medium-sized networks. This approach is particularly well suited for sensor networks due to their limited memory capacity for storing the entire network topology. We also found that selecting the right metric(s) for designating cluster-heads is essential for forming stable clusters. These metrics should take into account the nodes' ability to function as cluster-heads and the network's topology. Nonetheless, energy constraints are a major consideration in sensor networks. Furthermore, to achieve load balancing among nodes, clusters should be uniform in size, meaning that all clusters should have roughly the same number of nodes, and in radius, meaning that all nodes within a cluster should be no more than k hops from their cluster-head to minimize control traffic related to routing, service discovery, and so on. Additionally, the role of the cluster-head should be rotated periodically, and the clustering process should be distributed.

Chapter 3 : A uniform distribution of nodes based on Leach Protocol

3.1 Introduction

The advent of Wireless Sensor Networks has introduced new themes and challenges across various fields such as industry, agriculture, environment, healthcare, military, and intelligent transportation. This has spurred continued interest and research in the development of WSNs. Despite significant progress, several challenges remain, particularly in achieving full system maturity. Among these challenges, managing sensor energy consumption is crucial.

Energy conservation has been a major focus of research through various protocols, yet no definitive solution has been found. Even if energy issues are addressed, the challenge of miniaturizing sensors, like nanosensors, persists. Consequently, energy optimization will remain a significant concern for the foreseeable future.

Research on optimizing this limited resource often targets communication aspects, particularly through routing protocols, since energy dissipation largely results from message transmission. Clustering is a widely accepted hierarchical method for managing communication within WSNs, and optimizing energy consumption is frequently approached within this framework.

When a sensor node depletes its power, it not only ceases data collection but also fails to relay data from neighbouring nodes to the base station. If the number of such relay nodes falls below a critical threshold, data may not reach the end user, jeopardizing the WSN's mission. Thus, energy management is fundamental to the functionality and effectiveness of a WSN.

Selecting cluster heads (CHs) using a uniform distribution of nodes significantly reduces energy consumption. This is due to the shorter distances between each CH and the nodes within its cluster, unlike in LEACH and its derivatives, where clusters can be uneven.

In such non-uniform clusters, some nodes are located far from their CHs, leading to increased transmission energy for these nodes.

3.2 The proposed protocol

In the clustering approach, various factors, such as the number of nodes within each cluster and the position of the cluster head (CH), can influence the overall energy consumption of the network. Additionally, the process of selecting a cluster member to replace an energy-depleted CH and forwarding data to the sink, whether through a single-hop or multi-hop path, also affects node energy usage. These factors can significantly impact the network's lifespan and the success or failure of the Wireless Sensor Network mission [71,43]

The proposed protocol named UDLEACH addresses these issues by focusing on manually deploying sensors in a matrix arrangement, which offers several advantages:

1. **Uniform Distribution**: Sensors are evenly distributed across the area.
2. **Energy Consideration**: Nodes with low residual energy are avoided as CHs to prevent premature failure.
3. **Inter-Cluster Communication**: Multi-hop communication is used to transmit packets between isolated nodes.
4. **Cluster Formation**: Clusters are formed based on distance, with consistent cluster widths determined by the CH's transmission range.
5. **Fixed CH Count**: A predetermined number of CHs is maintained for each round.

Compared to traditional LEACH protocols, UDLEACH significantly reduces energy consumption, enhancing network efficiency and longevity.

3.2.1 Sensor Deployment in UDLEACH

The LEACH (Low-Energy Adaptive Clustering Hierarchy) protocol is indeed a ground-breaking approach in wireless sensor networks, focusing on energy-efficient communication by organizing nodes into clusters and rotating the role of cluster heads. Its impact has been profound, inspiring numerous enhancements and variations to address different challenges and improve performance. The Uniform Distribution based LEACH (UDLeach) protocol builds on the principles of LEACH but introduces a new dimension: uniform distribution of nodes. This approach is designed to tackle issues related to energy consumption and network lifetime more effectively. The purpose of the LEACH algorithm is to reduce the energy consumption needed to create and maintain clusters to increase the lifetime of WSN [74].

UDLEACH proposes a manual deployment of sensors, where the installer strategically places the sensors in a matrix. This allows for optimizing coverage and minimizing energy consumption.

3.2.1.1 *Deployment Structure*

The sensors are arranged in a regular matrix, which facilitates network management and communication between sensors. Each sensor can be identified by its coordinates in the matrix, simplifying routing and data aggregation.

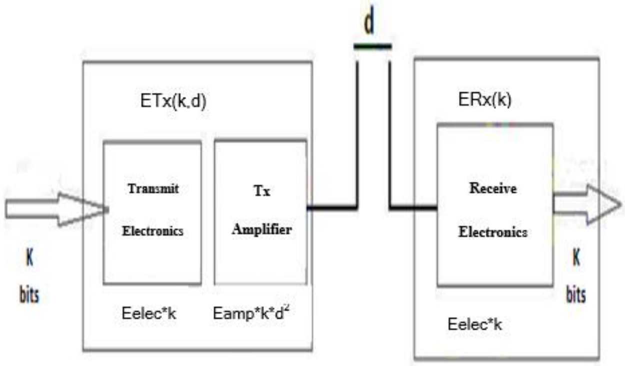

Figure 3.1 : Wireless sensor radio model [4]

3.2.1.2 *Advantages of Manual Deployment*

- **Control over Topology:** Allows the installer to position sensors while considering obstacles and areas of interest.
- **Resource Optimization:** Strategic deployment reduces redundancies and optimizes coverage.
- **Ease of Implementation:** A matrix simplifies the configuration and maintenance of the network.

3.2.2 ENERGY CONSUMPTION MODEL

Before diving deeper, it's essential to understand the commonly used energy model in Wireless Sensor Network routing protocols. This model is crucial for clustering approaches because it addresses radio characteristics and energy dissipation, which are key factors affecting protocol performance. The radio model from Yick et al [4] will be used to evaluate various recent protocol modifications. Figure 3.1 illustrates the system model for data transmission between two nodes.

E_{elec}: is an electronic circuit energy

$\boldsymbol{do}\sqrt{\frac{Efs}{Eamp}}$: is the threshold distance

$Eamp$: is the energy consumed in the amplifier

Efs: is transmitting amplifier constant for free space and multi-path fading modes.

E_{Rx}, E_{Tx}: are the energy amount received and sent respectively.

To send a k-bit message to a receiver far from it by a distance d, the ETx radio transmitter consumes:

$ET_x(k,d)=Eelec*k+Eamp*k*d^p$

So the system has two cases for transmission energy:

$ET_x(k,d)$=k*Eelec+$E_{fs}*k*d2$, if d<d0

Or

$ET_x(k,d)$=k*Eelec+k*Eamp*d^4 m, if d>=d0

To receive a k-bit message, the ERx radio receiver consumes:

d: the distance to the SINK

$ER_x(k)=ER_{xelec}(k)$

$ER_x(k)=E_{elec}*k$

Eelec and Eamp denote the energy consumed by the electronic circuit and amplifier, respectively. When a cluster head (CH) consolidates data from other sensor nodes into a single signal for transmission to the sink, the energy used in this aggregation process is referred to as Eagg.

The energy consumed by CH is computed as follows:

if distance_to_SINK < do

E_{CH}(i,k,d)=k*Eelec*mi+k*E_{agg}*(mi+1)+k*Eelec+$E_{fs}*k*(d)^2$.

if distance_to_SINK >= do

E_{CH}(i,k,d)=k*Eelec*mi+k*EDA*(mi+1)+k*Eelec+k*Eelec+Eamp*k*$(d)^4$.

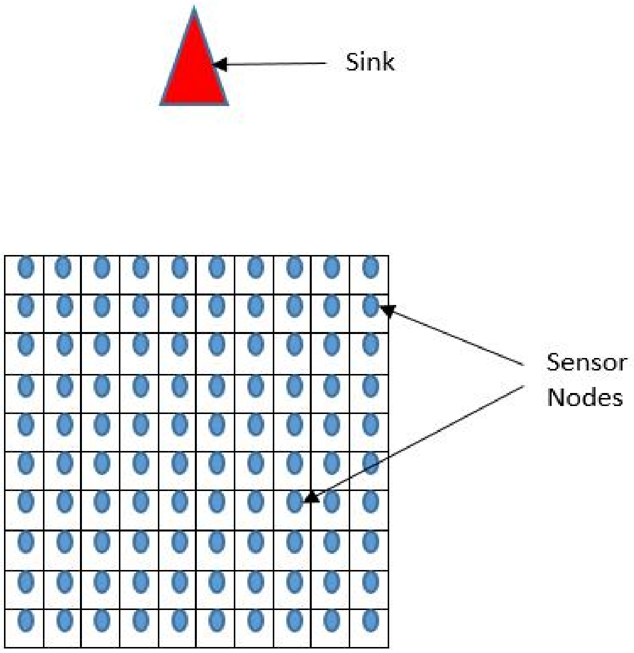

Figure 3.2: An Example of A Sensor Deployment

- ***Equations of Uniform distribution of nodes***

In Wireless Sensor Networks (WSNs), a **uniform distribution of nodes** refers to an arrangement where sensor nodes are spread evenly or consistently across a given area. This distribution aims to ensure that each node is approximately equidistant from its neighboring nodes.

Whether using a grid, hexagonal pattern, random placement, or circular distribution. The choice of method depends on the specific requirements of the WSN application, such as coverage, connectivity, and deployment constraints. In a grid-based uniform distribution, nodes are placed in a regular grid pattern within a square or rectangular area.

The grid has $\sqrt{n} * \sqrt{n}$ cells (for a square grid), so the spacing between adjacent nodes in both x and y directions is:

$$d_x = \frac{W}{\sqrt{n} - 1}$$

$$d_y = \frac{H}{\sqrt{n} - 1}$$

For node (i,j), where i and j range from 0 to $\sqrt{n}$ -1.

$x_i = i * d_x$ (1)

$y_j = j * d_y$ (2)

Where x, y are the coordinates of a sensor node n
i,j: are the counter in x and y axis respectively.

The figure 3.2 shows an example of a uniform distribution of 100 nodes in an area of 100 meter per 100 meter.

We replaced the for loop in the LEACH protocol with two while loops. The first loop calls the predefined function rand for the random deployment of sensors, while the second loop, as shown in the code described below, deploys the sensors according to a matrix equation where the sensors are distributed as shown in the Algorithm 3.1.

```
J ←— 1 ; k ←— 1;

while j<=H/y

I ←— 1;
while i<=W/x

                S(k).xd ←—  i*x;

                  S(k).yd ←—  j*y;

            K   ←—    k+1;
I ←— i+1;

end
        j ←— j+1;

end
```

Algorithm 3.1. iterations for implantation of sensor nodes

Where:

H, W represent the distance between two nodes in the same column and in the same line respectively.

I, J: represent the counter in the abscissa and Y-axis respectively.

K: the ranking of a node; xd, yd: its coordinates.

3.2.3 Implementation and results analysis

We selected a MATLAB development environment where the nodes are homogeneous and randomly deployed within the operational area. The network is composed of 100 nodes scattered over a square region measuring 100 x 100 meters. Each node begins the simulation with an initial energy of E0 = 0.1 J and has an unlimited data capacity for transmission to the Sink. Additionally, the base station's energy is assumed to be unlimited. The table 3.1 outlines all the parameters utilized in the simulation scenarios.

Parameters	**Values**
Network surface	100*100 m²
Position of the sink.	X=0.5xm, Y=0.5ym
Number of nodes	100
Initial energy of node	0.1 J
Energy threshold	0.00001 J
ET_x (Energy Transmission)	50* 10^{-9} J/bit
ER_x(EnergyReception)	50* 10^{-9} J/bit
Efs (signal amplification coefficient in free space)	10*0.000000000001
Eamp (Amplification Energy when d> d_0)	0.0013*0.000000000001
E_{agg} (aggregation energy)	5*0.000000001
P(probability of being a CH)	0.1
Rmax (number of rounds)	1000

Table 3.1: Network Parameters

3.2.3.1 Energy consumption

To evaluate the performance of the UDLEACH, LEACH and its derivatives, we focus primarily on power utilization of the sensing elements, as it is a key variable in determining the lifespan of a Wireless Sensor Network. In this subsection, we present the results of our simulation of the proposed protocol in order to show the influence of the heuristic implemented for easily select the cluster head and the security solution. Therefore, we assess our simulations based on these metrics: energy consumption, sensor node lifespan, and the data rate sent to both CHs and to the base station, also Known as throughput. The proposed protocol significantly reduces energy consumption compared to LEACH, VLEACH,SLeach and MOD-LEACH, as illustrated in Figure 3.3. Although SLeach also offers a long network lifetime, our protocol maintains operational capability for over 40 additional rounds compared to SLeach.

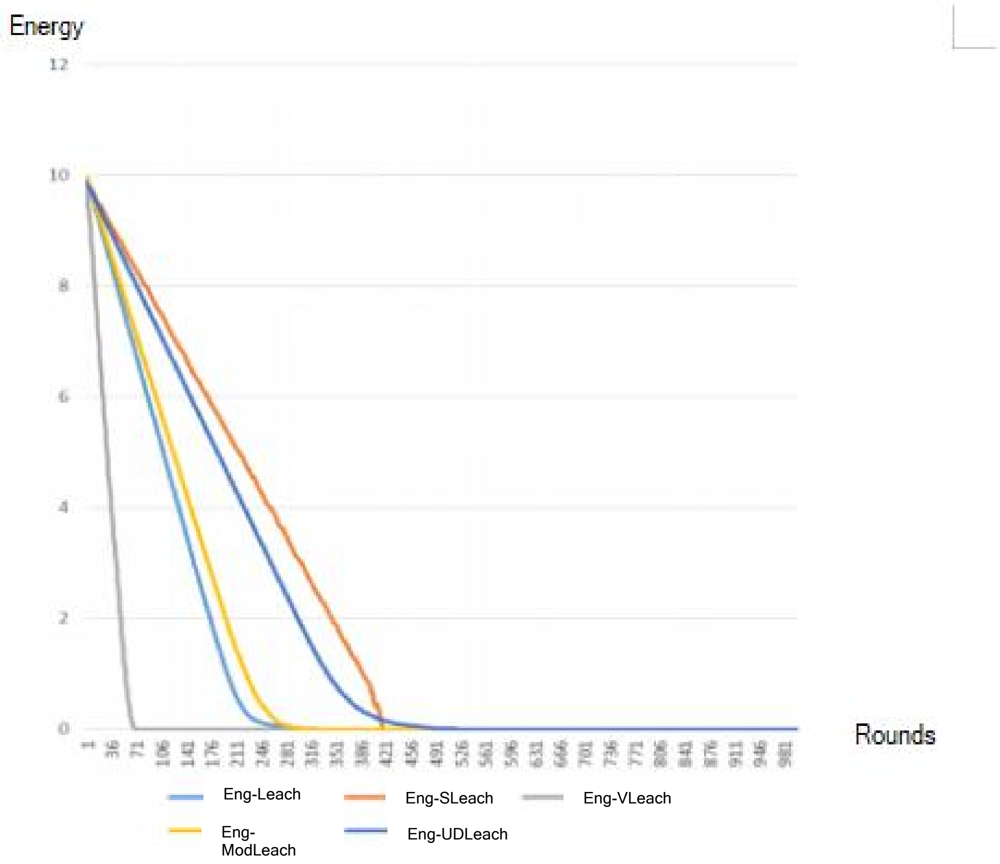

Figure 3.3: Average residual energy for the 5 protocols

As we can't define a protocol better than all others in All parameters, but UDLeach proposed protocol can overcome the precedent clustering protocols except with the SLeach that defeat our protocol in energy consumption in the first 300 rounds shown in simulation. In the beginning, SLeach is better because of the distance reduced as the communication area is divided into sectors. Initially CHs in UDLeadh protocol consume more energy than SLeach but in the last 40 rounds as illustrated in table II, lifetime is extended more than in SLeach as Clusters become smaller.

3.2.3.2 Network Lifetime

To assess the Wireless Sensor Network lifetime, 1000 iterations are performed, with the results depicted in Figure 3.4. Various simulations examine different network densities, deployment areas, and communication ranges to evaluate the UDLeach protocol's performance across different scenarios. Table 3.2 offers a comprehensive comparison of UDLeach with other protocols under equivalent conditions.

The network using MOD-LEACH, LEACH, VLEACH, S-Leach, and UDLeach protocols depletes after an average of 283, 343, 72, 441, and 484 rounds of simulation, respectively. The UDLeach protocol demonstrates the longest network lifespan compared to LEACH, MOD-LEACH, and S-Leach due to its superior cluster head distribution and lower energy consumption. UDLeach extends network lifetime by approximately 10% over S-Leach, 40% over LEACH, and 71% over MOD-LEACH. This improved performance is achieved by eliminating overhead associated with dynamic cluster formation seen in LEACH, VLEACH, and MOD-LEACH protocols.

Simulations	UDLeach	Mod-Leach	Leach	VLeach	SLeach
Simulation1	473	288	353	73	437
Simulation2	486	278	338	65	400
Simulation3	481	290	337	72	436
Simulation4	497	275	345	80	492
Average	484,25	282,75	343,25	72,5	441.25

Table 3.2: Simulations for the 5 protocols

The results obtained from a second simulation further exhibit the superiority of the UDLEACH protocol compared to LEACH and others. The results are illustrated in the graph below; the network using the LEACH, VLeach, Mod Leach, SLeach protocols depletes after 340, 72, 282, 441 rounds respectively while the UDLEACH protocol maintains the network lifetime for almost 485 Rounds.

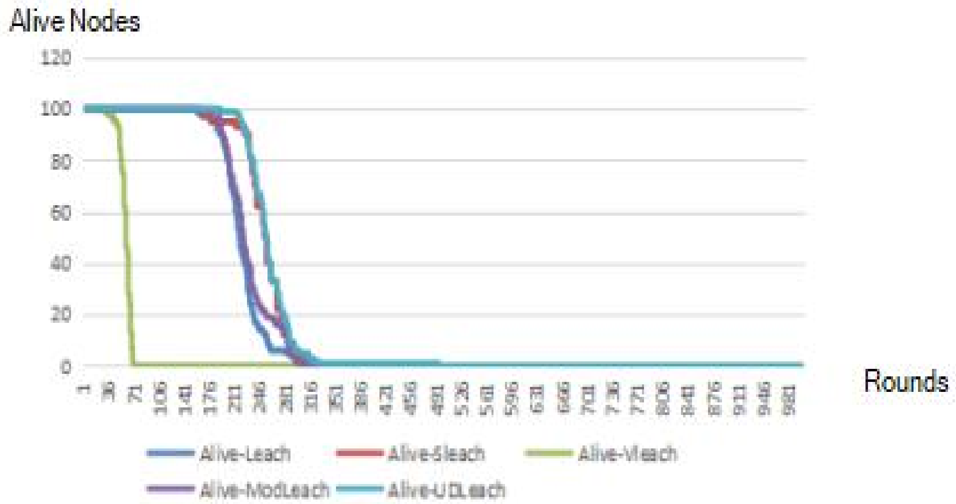

Figure 3.4:Network Lifetime

3.2.3.3 The Throughput

Reliable data transport is a fundamental requirement for the majority of multimedia applications in wireless sensor networks. An appropriate transport protocol for these applications must not only consider reliability and energy consumption factors but also memory usage and data delivery delay. The proposed transport solution in this work improves throughput without degrading other performance factors by utilizing several mechanisms; all of this is illustrated in the following figures of number of packets sent to BS and number of Packets sent to the CH for the 5 protocols. The throughput represents the combination of the two metrics.

The proposed protocol achieves a higher throughput compared to LEACH and its derivatives, without increasing energy consumption. This is due to the equal spacing of nodes, which reduces transmission energy compared to LEACH, SLeach and VLEACH as illustrated in Figure 3.5, the latter three protocols exhibit lower throughput and reduced network lifetime.

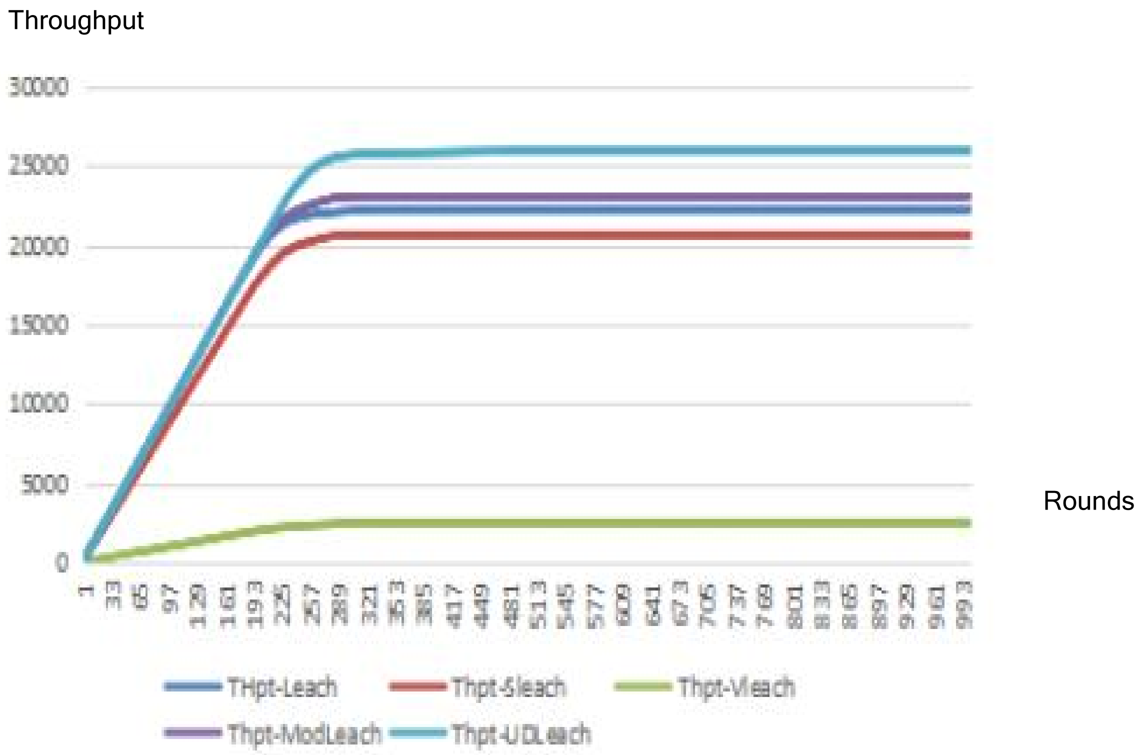

Figure 3.5: The Throughput

3.3 Conclusion

The UDLEACH protocol, with its manual matrix deployment approach, represents an effective solution for managing sensor networks by balancing energy consumption and network performance. The comparison of the LEACH, UDLEACH, Mod-Leach, VLeach and S-LEACH protocols reveals that UDLeach is superior regarding power expenditure and outperforms most of precedent methods regarding throughput and network longevity. In future research, we plan to apply the UDLEACH protocol in a larger capture area with dimensions exceeding those utilized in this study. Our protocol has various applications, including agriculture, where uniformly placed sensors monitor soil conditions to optimize irrigation and fertilization, enhancing crop yield and resource conservation. In smart cities, uniform node distribution optimizes streetlight control based on real-time traffic data, reducing energy consumption. In healthcare, evenly distributed sensors in hospitals monitor patients' vital signs, ensuring timely interventions. Additionally, in smart factories, these sensors enhance operational efficiency and predictive maintenance by monitoring equipment performance and environmental conditions. In future research, we plan to apply the UDLEACH protocol in one of the precedent application with a larger capture area exceeding those utilized in this study.

Chapter 4: The proposed ASC protocol

4.1 Introduction

A sensor network is a collection of sensors working together to monitor and control the environment. Depending on the application, the number of sensors can range from hundreds to thousands and more. Two critical factors in such networks are energy consumption and the number of neighbouring nodes for each sensor. In networks with thousands of sensors, efforts are focused on reducing energy use by partitioning the network into groups to facilitate more efficient data transmission to the base station.

Methods for sensor networks that use clustering techniques involve cluster members sending their data not directly to the base station but to their cluster head. Thus, cluster heads are tasked with coordinating the cluster members, aggregating their data, and forwarding it to the base station, either directly or through multi-hop communication. Since cluster heads handle a larger volume of data and have to transmit over longer distances, they tend to deplete their energy faster if they are assigned this role for extended periods. Therefore, it is important to avoid selecting cluster heads with low energy levels, as their batteries can quickly run out due to their high workload.

In this chapter, we introduce a novel technique for partitioning a sensor network into equally sized zones. This zonal structure forms the basis of a new protocol called ASC (Area Splitting for Clustering). Each zone will be treated as a cluster, with the number of neighbouring nodes for each node being calculated. The node with the highest number of neighbours and the most energy will be selected as the cluster head. A table with information on each node will be updated every round. The following chapter will explain how to choose a cluster head using precise geometric calculations rather than probabilistic methods, highlighting the benefits of our protocol in comparison to previous ones.

4.2. The proposed protocol

In the clustering approach, clusters have some characteristics, like the number of nodes included and the position of the cluster head inside the cluster, and this may impact the amount of energy consumed by the whole network. Similarly, choosing a cluster member node to replace the current CH that is running out of energy and forwarding the captured data to the sink in a single-hop or multi-hop path also plays an important role in dissipating the energy of nodes. All of this can impact, positively or negatively, the network lifetime and inevitably, the success or failure of the WSN mission [71,43].

To this end, the new Area Splitting Clustering protocol (ASC) was designed to mitigate or remedy the drawbacks encountered in previous LEACH-based protocols. The ASC protocol provides the following advantages:

1. Divide the clusters that have more nodes (more than the average) into two equal groups with one CH each. The problem of the position of the CHs is solved by choosing as CH the node closest to the majority of the cluster members.
2. The distribution is close to the optimum because we do not choose CH randomly, and each zone will have its CH close to the majority of the nodes in its cluster.
3. In the proposed protocol, residual energy is considered as a very important factor, so a node with insufficient energy is not chosen as a CH to avoid its rapid death.
4. Inter-cluster multi-hop communication is used to send packets of isolated nodes.
5. The formation of clusters takes into account the distance factor. The clusters will have the same width depending on the transmission range of the CH of each cluster, which is considered the same in our protocol.
6. There is a fixed number of CHs in the network for every round.

Due to the limited number of LEACH advantages compared to our ASC, this new protocol decreases energy consumption significantly compared to the other LEACH-based clustering protocols.

4.2.1 Network model

At sensor deployment and after area splitting, the following assumptions hold:

- All nodes have the same length of communication range CR and reception range RR.
- All nodes have fully charged batteries, static and are equipped with a GPS system.
- The sink is stationary with no resource limitations. It has the location information of all nodes in the network.

The total energy consumed by a sensor is divided in three types according to the equation number 1:

$$E_{cons} = E_{tr} + E_{rec} + E_{agg} \qquad (1)$$

Where, E_{conc}, E_{tr}, E_{rec}, andE_{agg} are consumed, transmission, reception, and aggregation energies for a sensor node in the general case.

The organizational chart

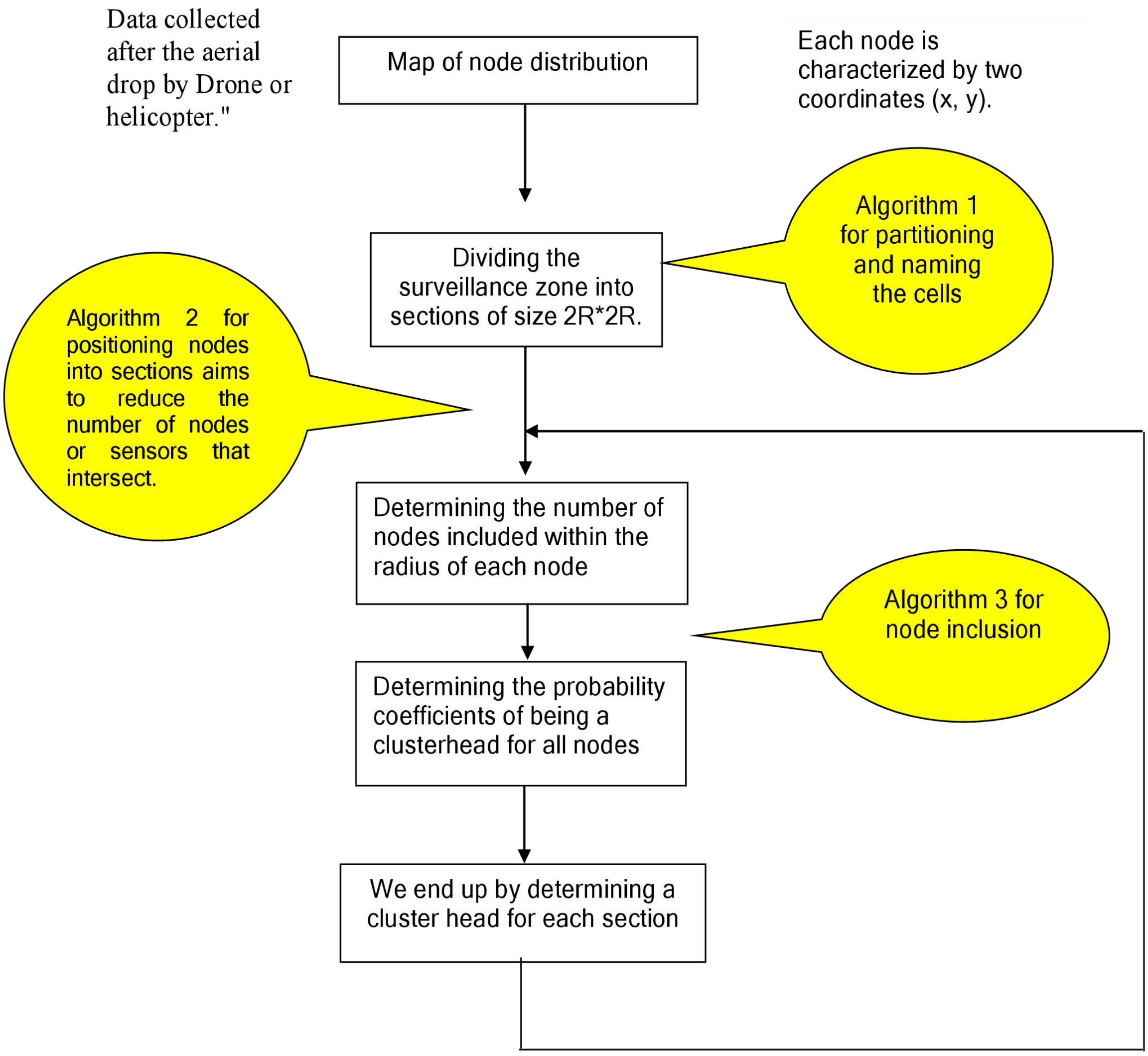

Figure 4.1: flowchart of the proposed protocol

After calculating the number of nodes included in each sensor radius as demonstrated in the flowchart in figure 4.1 ; that number will have the highest probability pr=1, and the other nodes are assigned a probability P = number of nodes included / maximum number of nodes included. We need to find the appropriate border node. We can assess connectivity between coverage radius as follows:

1- Included, hence good connectivity.
2- Not included, hence no connection.
3- Above the radius line, hence a connection that risks losing transmitted data.

Note: If we encounter 2 or more nodes with the same number of included nodes (same probability), then this issue will be resolved by determining the distance between these nodes and the centre of mass (gravity) of the section. Therefore, the node closest to the centre of mass will be more qualified than others, which will be qualified with a probability pb = pr (calculated) - 0.05 * order of distance, which will be calculated later. Example: Section 1 The neighboring sectors are: 6, 2, 7. Section 8: neighboring sections (2, 3, 4, 7, 9, 12, 13, 14)

GPS Location using satellite

There are two types of sensor locations in a wireless sensor network. Distributed localization is done for each sensor node in a local way, i.e., each node evaluates its location using inter-sensor measurements, and the information is collected from its neighbors, whereas in our protocol all sensor nodes are thought to be GPS located, in a centralized way, i.e., their locations are transmitted straight to the SINK. The SINK gets the nodes' latitude and longitude also from satellite.

- **Radius calculation**

The problem is whether the radius used to split the area will be the sensation range or the communication range.

Because the sensation range is the smallest and the connection between the sensors to be effective, or the sensors are said to be fully connected, the communication range, will be considered as The Radius R to base all the calculations.

Figure 4.2 shows an example of an area split based on R.

4.2.2 Splitting algorithm and cell naming

Our work aims to implement a protocol that is based primarily on the formation of a virtual grid, or a split area into equal cells covered by sensor nodes deployed by a flying device. Each sensor node uses its GPS-indicating position to associate with a point on a given cell. Nodes located geographically in one cell in the area are considered equivalent in terms of cell number and will have the same Cluster Head (CH) that will be chosen in each round, as will be shown in the following phases of the protocol. This equivalence is based on keeping nodes located in a particular cell of the area.

The division of the zone N * M on equal cells of size L * L such that L = 2 * R, where R is the communication range as explained before (It is assumed that all sensors have an equal radius because they are of the same type).

In each cell, a sensor leader is chosen to collect the data from the different sensors and transmit the aggregated information to the Sink, which has a database that contains the coordinates of each sensor. This sensor, called the Cluster Head, will be replaced by another one as its energy will be reduced at the end of the round. At each round, another sensor will be chosen as a CH. The variables are calculated as shown in figure 4.2 where the area is divided into 36 cells containing 75 nodes randomly deployed.

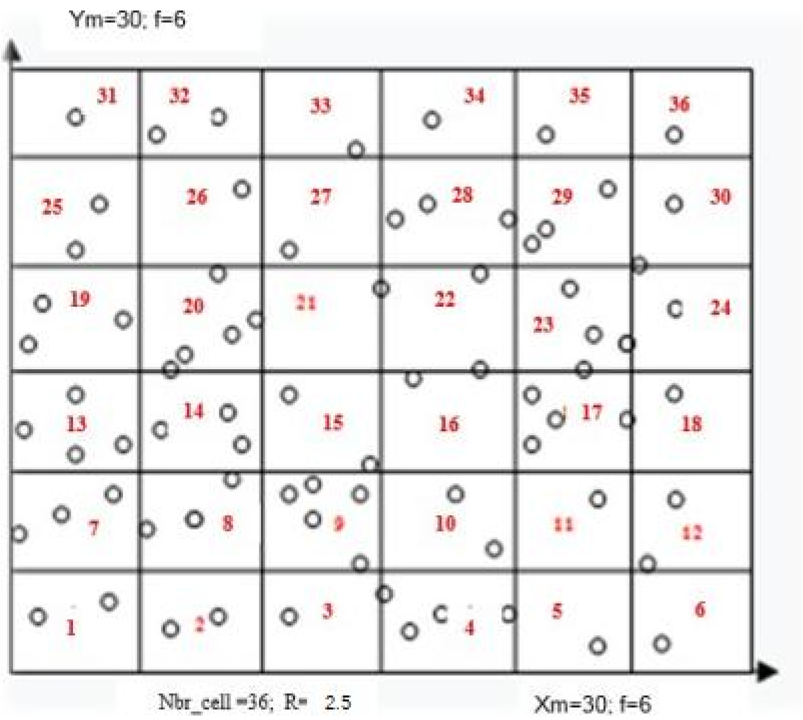

Figure 4.2:Division Area

Let the following variables be true:

Nbr_cell: number of cells in the total area.

Z_n: number of the cell to search for the sensor n.

R: the diameter or half the cell length. (R is assumed to be the same for all sensors)

F: number of cells in the x and y axis

c1, c2: order of the cell where the node i is located for the X and Y axis respectively.

xm, ym: length and width of the total area respectively.

The formula to localize nodes is as follows**:**

$$Z_n = c2 \times F + c1 + 1 \qquad (2)$$

The cell, where a sensor node is located, is calculated by equation 2; c1 and c2 are the locations of the sensor node in x and y-axis respectively. They are calculated in the following Localization algorithm.

- **Node localization**

Let x and y be the beginning of each section in the X axis and Y axis respectively; xm and ym are the length and width of the total area, respectively, and F is the number of cells in the width. The number of the cell where the sensor node belongs will be named zn in the structure of node i, which will be calculated in the algorithm below:

```
For   x = 0 to (xm/2*r) -1   do
  if S(i).xd >2*r* x then
   if S(i).xd<2*r*(x+1) then
       s1=x
For y= 0 to (ym/2*r)-1 do
   if S(i).yd>2*r*y   then
   if   S(i).yd<2*r*(y+1)  then
              s2=y
    S (i).zn=s2*f+s1+1
```

Algorithm 4.1. Localization algorithm

4.2.3 Inclusion method

Each sensor node has in its memory a table that contains the number of its cell, the total number of nodes in its cell, and the total number of nodes in its Radius.

Let a node n0 that we would calculate its neighbours with the coordinates (x0, y0) and let n (x, y) be the coordinates of a sensor node n included in the communication radius of the node n0. So for testing the inclusion of any node in the circle, substitute its coordinates in x and y, respectively, in the following inequality:

$$(x-x_0)^2+(y-y_0)^2 \leq R^2 \qquad (3)$$

To determine if the sensor is included, we must substitute its coordinates x and y in equation 3. The points to be solved will be removed from the resolution of this equation. The following inclusion algorithm calculates the number of nodes included in the communication radius of the candidate's node to be a CH.

Let **(x, y), (x0, y0):** are the coordinates of the included node and the coordinates of the node having the radius R, respectively, in the map.

***z*:** total number of cells in the area.

Nbn: number of nodes in a cell j.

```
For j=1 to z do
For   i = 1 to cell (j).nbn   do
For k =1 to cell(j).nbn   do
if   k<>i  then
If (sqrt((S(i).xd-S(k).xd)^2+(S(i).yd-
S(i).yd)^2))<R  then
S (i).ic=S(i).ic+1
```

Algorithm 4.2. Inclusion algorithm

Although the coordinates of the nodes of each cell are known by the GPS system, the calculation is done by each sensor node and information resulted will be stored as shown in the Table 4.1, that contains node's cell number; the total number of nodes in that cell and the number of neighbours or nodes included in its communication range.

After detecting the death of a node by a CH at a given round, an update message will be transmitted to all nodes in its cell.

Cell number	Number of nodes	Nodes included

Table 4.1: Sensor node parameters

4.2.4 Cluster Head Selection

The choice of the CH will be based on a single criterion called Inclusion Number (IN), which must be the maximum in its cell. The calculation of this number will be shown after from the second round until the end of network's life, the residual energy amount is the second-used factor.

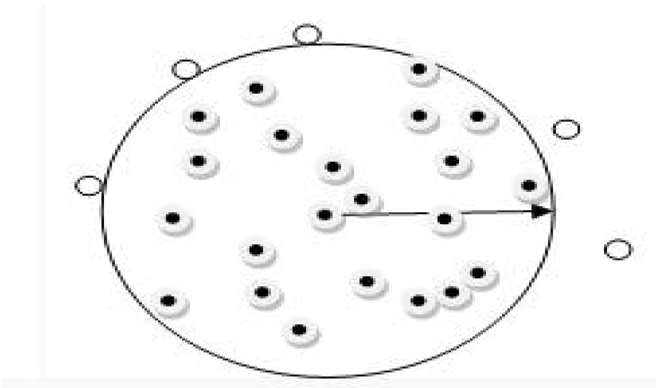

Figure 4.3:Nodes Inclusion

As shown in figure 4.3 nodes are included inside the communication range of the node situated in the center of the shown circle. That number allowed the node to be a cluster head for the current round. According to our proposed protocol, selecting cluster heads among several nodes has been made by an inclusion method, and we choose the node that has the maximum degree. That is, the node that has the most sensors in its circle.

4.2.4.1 Selection criteria for CH in the first round

Any CH elected in the first round, as described in the membership criterion, is a node with the largest number of sensors in its communication radius. No other factors will be taken into consideration. As it is supposed that all batteries of the sensors are fully charged, then the residual energy factor is not taken into account as a parameter for the CH choice in this first round.

4.2.4.2 Selection criteria for CH from the second round

After network operation for the first round, a CH is chosen in each cluster. Since all nodes have the same amount of energy, the inclusion number that ranks the nodes in each cluster and the node with the largest number of inclusions referenced by ***ic*** is chosen as CH. After which, a rotation mechanism based on this number and on the residual energy, is applied to select the next CH. The cluster members send their collected data to the corresponding CH, which forwards the aggregated data directly to the remote sink [5].

The charge rate of batteries for all sensor nodes will not be the same, and this will generate a preference between nodes that have already used less energy compared to those that have used up more. Therefore, the residual energy factor should be a second interesting parameter for selecting CH in the second round.

4.2.5 Energy consumption model

Before going into further detail, it is necessary to remember the commonly accepted energy model for routing protocols in WSNs. Clustering approaches also use this valued model because of its assumptions inherent to radio characteristics, notably energy dissipation. The latter is essential because of its direct impact on routing protocol performance. The radio model in [4] will be used to compare all contemporary protocol adjustments. The system model for transmitting data between two nodes is shown in figure 3.1.

E_{elec}: is an electronic circuit energy

$\boldsymbol{do}\sqrt{\frac{Efs}{Eamp}}$: is the threshold distance

$Eamp$: is the energy consumed in the amplifier

Efs: is transmitting amplifier constant for free space and multi-path fading modes.
E_{Rx}, E_{Tx}: are the energy amount received and sent respectively.

To send a k-bit message to a receiver far from it by a distance d, the ETx radio transmitter consumes:

$ET_x(k,d) = E_{elec} * k + E_{amp} * k * d^p$

So the system has two cases for transmission energy:

$ET_x(k,d) = k * Eelec + E_{fs} * k * d^2$, if $d < d0$

Or

$ET_x(k,d) = k * Eelec + k * Eamp * d^4$ m, if $d >= d0$

To receive a k-bit message, the ERx radio receiver consumes:

d: the distance to the SINK

$ER_x(k) = ER_{xelec}(k)$

$ER_x(k) = E_{elec} * k$

E_{elec} and E_{amp} present the energy dissipated in the electronic circuit and the amplifier, respectively.

When a cluster head CH receives data from other sensor nodes, the CH proceeds to aggregate the received data to produce a single signal to be sent to the sink. During this operation, the amount of energy consumed is equivalent to Eagg (aggregation energy).

The energy consumed by CH is computed as follows:

if distance_to_SINK <do

$E_{CH}(i,k,d) = k * Eelec * mi + k * E_{agg} * (mi+1) + k * Eelec + E_{fs} * k * (d)^2$.

if distance_to_SINK >= do

$E_{CH}(i,k,d) = k * Eelec * mi + k * EDA * (mi+1) + k * Eelec + k * Eelec + Eamp * k * (d)^4$.

4.2.5.1 Residual Energy calculation

The energy of each sensor node counts as an important parameter along with the number of its neighbouring sensors. The residual energy factor affects the choice of CHs in each round, starting with the second round. Thus, the probability of choosing a cluster head will depend on two factors:

1. Residual energy ***E***
2. Number of included nodes ***ic***.

The value of the production of the two factors for every sensor node is calculated as in the Equation below:

$$V(i) = S(i).E \times S(i).ic \quad (4)$$

Where

S(i).E **and** ***S(i).ic*** are the residual energy and number of neighbouring nodes, respectively for the sensor node i.

V(i) is the value of the production of E and ic.

So for each cluster, the value of each sensor node will be calculated as in equation 5, and the sensor that has the greatest value will be elected as a cluster head.

4.2.5.2 Network stability

When a CH becomes out of energy, it is essential to select a suitable replacement node to take over its responsibilities to maintain connectivity and ensuring the availability of CHs in the cluster. The replacement process for dead Cluster Heads plays a crucial role in mitigating the impact on the overall network performance and ensuring network stability. By promptly replacing dead CHs with suitable nodes, we can maintain connectivity, preserve the desired network structure, and sustain the functionality of the protocol. By promptly replacing dead CHs, we ensure that the network remains operational and that data can be efficiently routed to the sink. As shown in figure 4.4, every dead CH inside a round will be directly replaced by a node that has the succeeding value of V(i) illustrated in the equation 4.

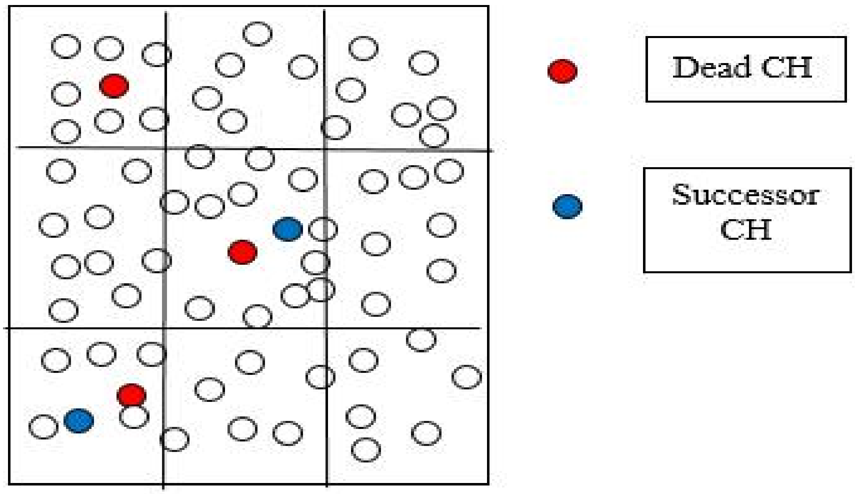

Figure 4.4: Successor CH inside the round

4.2.5.3 Distance between nodes

As our protocol deals with separated clusters with one CH for each, the important distance is between nodes in the same cluster where the distance factor is more important. If some cells are very dense with sensor nodes and others are not. The densely cells will be divided into two separated ones and they will be considered as two different cells.

4.3 Conclusion

In this chapter, we introduced a distributed protocol designed for sensor networks. This protocol utilizes a hierarchical topology achieved by dividing the network into virtual zones. Our proposed algorithm for partitioning the network into these zones does not require any prior information about the network, such as node energy, link statuses, or geographic locations. The zones created are adjacent to each other. Once the network is segmented into virtual zones, each node is assigned to a specific zone. Clustering is then performed based on these virtual zones, and a Cluster Head (CH) is selected for each zone based on the number of neighbouring nodes and the node's residual energy.

Unlike probability-based protocols for selecting the Cluster Head, which can result in clusters of varying sizes (such as the LEACH protocol and its variations), our protocol ensures more consistent cluster sizes.

Packet transmission within clusters in our protocol follows the same process as other clustering protocols, where nodes send their packets to the Cluster Head, which then forwards them to the base station. Each node maintains a table that tracks its zone number and the number of nodes within its transmission range. Additionally, this chapter details algorithms for partitioning the capture zone, numbering the resulting virtual zones, locating various nodes, and calculating the neighbours of each node.

Our routing protocol stands out from most other hierarchical protocols in the following ways:

- It relies entirely on computational methods.
- The network-partitioning algorithm operates without any network-specific information (such as node locations or energy levels).
- The protocol uses a straightforward and cost-effective algorithm for calculating neighbours and creating data tables for each sensor node.
- It is well suited for large sensor networks.

Chapter 5: Simulations and Results

5.1 Introduction

In this chapter, we examine several protocols aimed at optimizing energy consumption in sensor networks. These protocols have been assessed using the Matlab simulator, with various simulations carried out to compare the performance of our ASC protocol against LEACH and its derivatives.

To show the effectiveness of the proposed protocol, we performed a series of simulations. This section presents the preliminary results. The simulations are designed to evaluate the protocol across four key metrics: energy consumption, network lifetime, network stability, and throughput.

5.2 SIMULATION AND RESULTS

5.2.1 Simulation parameters

We have chosen a Matlab development environment in which the nodes are homogeneous and randomly deployed in the operational environment. We considered a network with a density of 100 nodes deployed on a square surface of 200 x 200 m^2.
The simulation starts with an initial energy for every node equal to E0 = 0.1 J and no limited data amount to be sent to the sink. In addition, that sink has no resource limitations (energy, memory, calculation, etc.).
We specify all the parameters used for the scenario simulation, such as energy thresholds, communication ranges, and update intervals, in the Table 5.1.

Parameters	Values
Network surface	200*200 m²
Position of the sink.	X=0.5xm , Y=0.5ym
Number of nodes	100
Initial energy of node	0.1 J
Energy threshold	0.00001 J
ET_x (Energy Transmission)	50* 10^{-9} J/bit
ER_x(Energy Reception)	50* 10^{-9} J/bit
Efs (signal amplification coefficient in free space)	10*0.000000000001
Eamp (Amplification Energy when d> d_0)	0.0013*0.000000000001
E_{agg} (aggregation energy)	5*0.000000001
P(probability of being a CH)	0.1
Rmax (number of rounds)	1000
Communication range	5m

Table 5.1: Simulation Parameters for the 5 protocols

To evaluate the performance of LEACH, Mod-LEACH, V-LEACH, S-Leach, and ASC protocols, we are mainly interested in the power usage of sensing units since it constitutes a paramount factor for determination of the WSN lifetime duration. We therefore carry out our simulation according to two metrics: the energy consumption and the lifespan of the sensor nodes.

The comparison of the energy consumption of LEACH, Mod-LEACH, V-leach, S-Leach, and our ASC is the first part of our simulations. The figure 5.1 shows the amount of energy used:

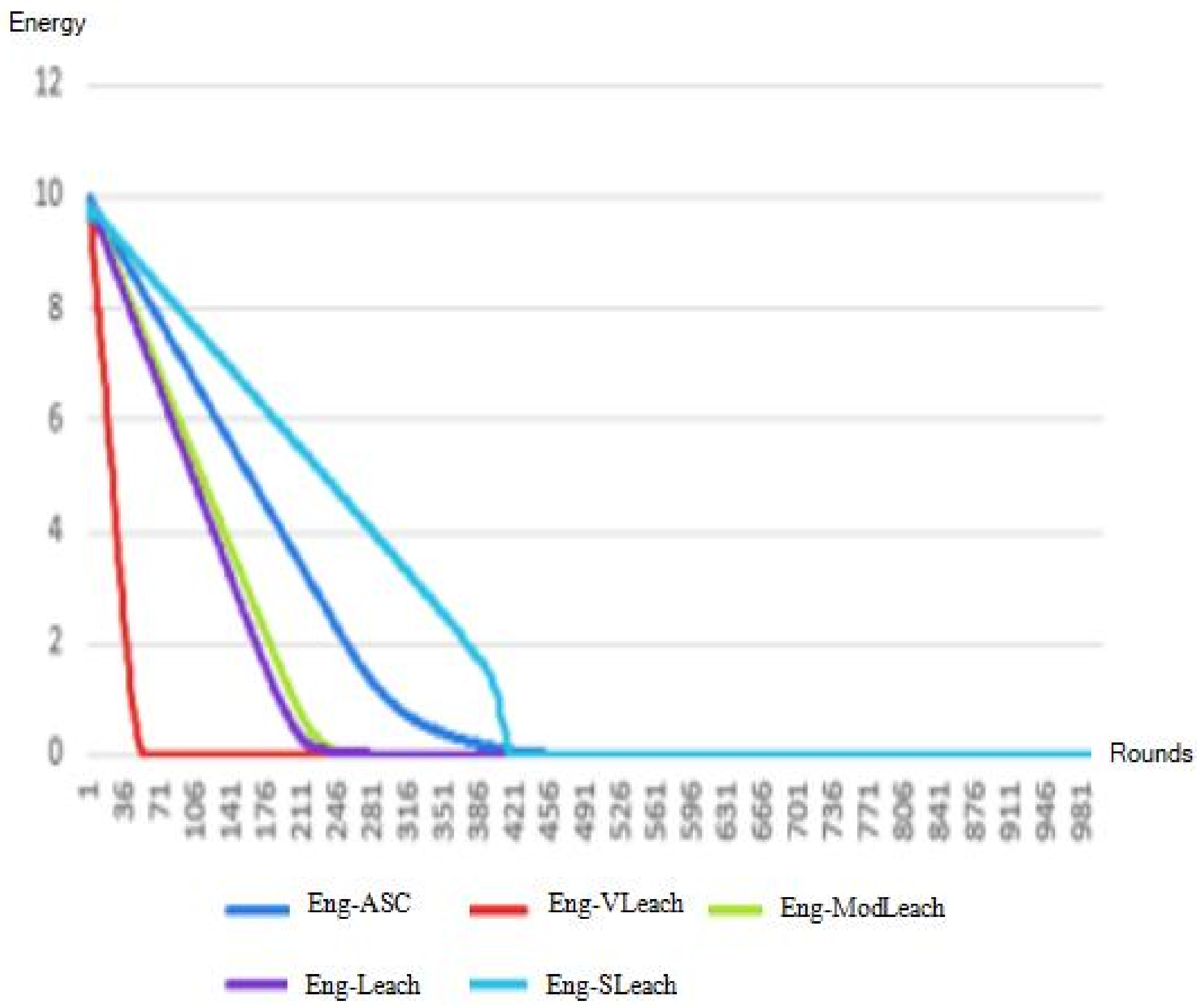

Figure 5- 1:Average residual energy for the 5 protocols

All nodes in the wireless sensor network die in rounds 494,437, 334, 279, and 65 for the ASC, SLeach, Leach, Mod-Leach, and V-Leach protocols, respectively. Compared to reference protocols, this favours our ASC protocol in terms of minimizing energy consumption and thus maximizing the lifetime of the WSN. The energy consumption in our protocol is reduced significantly compared to SLeach and Leach protocols. This is especially important for WSNs, where sensor nodes are put in wide areas where energy is consumed more than small ones.

5.2.2 Network lifetime

In order to assess the WSN lifetime, 1000 iterations (rounds) are performed. The results obtained are illustrated by the graph in figure 6.

Exploring different network densities, deployment areas, and communication range patterns, various simulations have been done to provide deeper insights into the ASC protocol's performance under various conditions. Table 5.2 presents detailed simulation results that compare the performance of the ASC protocol with other protocols under similar conditions.

Simulations	ASC	Mod-Leach	Leach	VLeach	SLeach
Simulation1	473	278	353	64	437
Simulation2	486	268	338	67	350
Simulation3	481	280	337	66	436
Simulation4	494	278	278	66	420
Average	483,5	276	326.5	65.75	410.75

Table 5.2: Protocols simulations

The network using MOD-LEACH, LEACH, VLEACH, SLeach, and ASC protocols is exhausted after 276, 327, 66, 411, and 484 rounds of the simulation on average, respectively. The ASC proposed protocol exhibits the highest lifetime compared to the LEACH, Mod-Leach, and SLeach protocols because the first has a better distribution of CHs and fewer energy consumptions compared to other protocols. The increase of network lifetime is about 20 % compares to S-Leach and around 30 % compared to Leach and 80 % compared to ModLeach.

The performance provided by the ASC protocol is achieved through overhead elimination caused by the formation of dynamic clusters in LEACH, V-leach, and Mod-leach.

5.2.3 Dead nodes in all protocols

After 1000 iterations for all precedent protocols, it is clear that our proposed protocol outperforms others and it has the last dead nodes as given in the Table 5.3:

Protocol	round
LEACH	334
MOD-LEACH	279
V-LEACH	65
S-LEACH	437
ASC PROTOCOL	494

Table 5.3: Last dead node in the 5 protocols

The next diagram shows the curve of the protocols until the last dead node. Figure 5.2 shows that our proposed protocol has the last dead node compared to Leach, VLeach, Mod-Leach, and S-Leach protocols

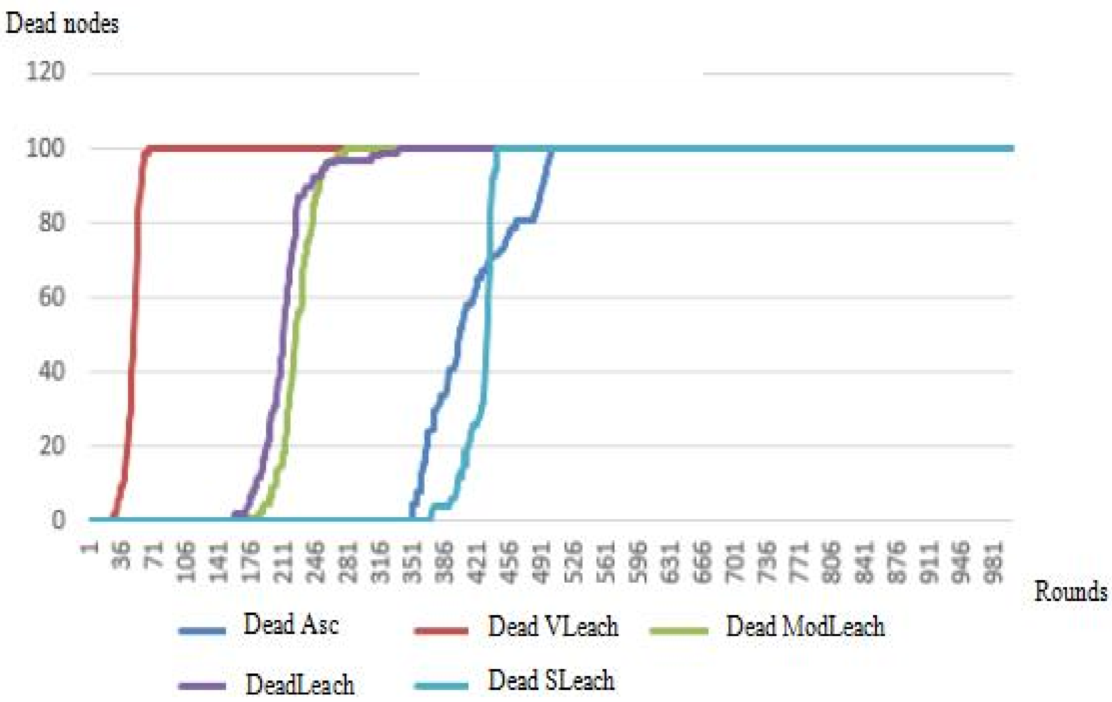

Figure 5.2:Last dead nodes for the 5 protocols

In the critical round of 450 in the life of the network, a histogram in figure 5.3 illustrates the advantage of our protocol because most of networks were dead except ASC where our protocol that takes a big advantage over all others.

5.2.4 Energy consumption

The energy consumption in the 5 protocols shows that our protocol has drastically decreased the energy consumption Because of best Choice of CH for each round, using

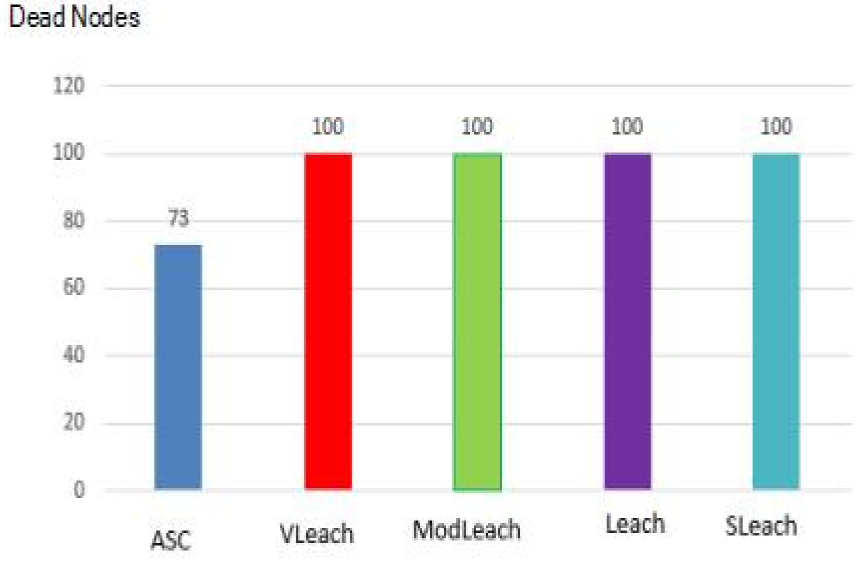

Figure 5.3: Critical round 450 for Dead nodes

Simple processing that minimizes energy consumption and the CH chosen is always the closer to other sensor nodes. Figure 5.4 shows all networks are out of energy except the network that uses our protocol where energy still enough for more than 50 rounds.

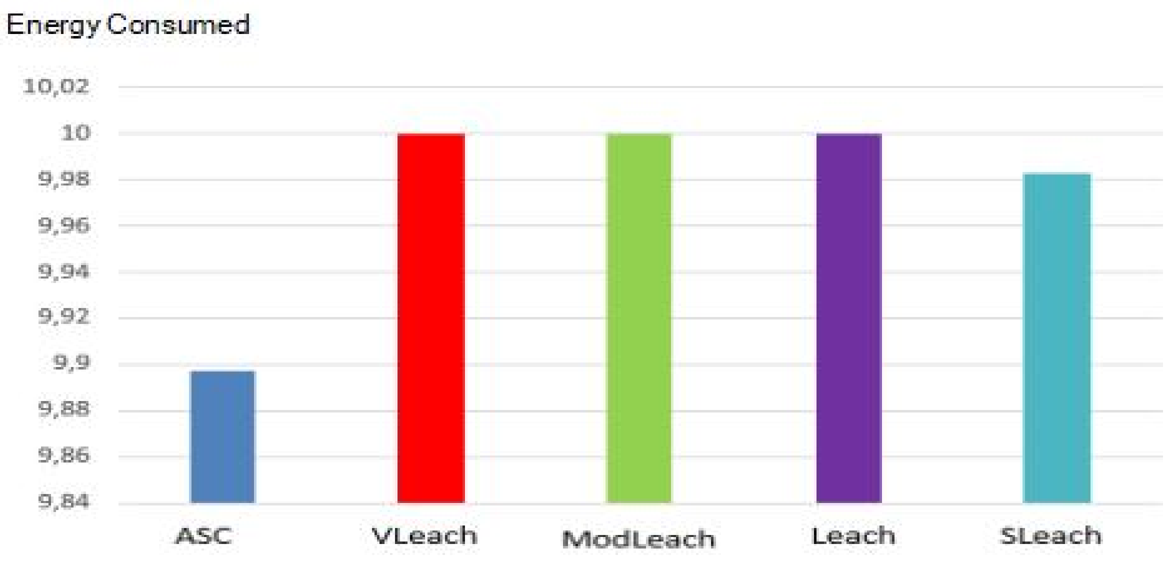

Figure 5.4: Energy consumed in the round 440

5.2.5 Throughput

After simulations for Leach, Mod-Leach, V-Leach, S-Leach, and ASC protocols, we

obtained the following graph, illustrated in figure 10. where the throughput in our protocol is decreased because of less packets sent to the Sink compared to Leach and its derivative.
From Table 5.4**,** we can see that the ASC protocol has significantly decreased the number of messages sent to Sink and CHs and has 16186 packets sent on average compared to Leach which has an average of 21947 messages and over 22773 for the Mod-LEACH protocol.
For V-Leach and S-Leach, we have a very low throughput that doesn't reach 4000 for both, and S-Leach is slightly under 2000. This is due to the fact that our protocol has the best method for choosing the cluster head for every cluster of nodes, which has decreased the redundancy of the messages sent compared with the two left protocols.

	ASC	**MODLeach**	**LEACH**	**VLEACH**	**SLEACH**
Simulation 1	16373	23121	21851	2048	90
Simulation 2	15583	22702	21994	2046	2000
Simulation 3	17573	22478	21152	2048	3700
Simulation 4	15215	22791	22791	2050	2300
average	16186	22773	21947	2048	2000

Table 5.4: Throughput results for the 5 protocols

The throughput of our protocol as shown in figure 5.5 is lower than that of Leach and Mod-Leach because our protocol has significantly and positively reduced the number of messages sent to Sink and CHs, since sending and receiving messages is the most costly activity in terms of node energy dissipation. This also contributes favorably to reducing node energy consumption, which enhances the ability of a WSN to successfully reach its mission.

The proposed ASC protocol adopts a new method for cluster formation and cluster head designation. The performance of our proposed ASC and reference protocols (LEACH, VLEACH, and ModLEACH) has been evaluated according to different relevant metrics, and the results obtained showed that ASC performs better than these well-known competitors, particularly for long-lived WSN applications.

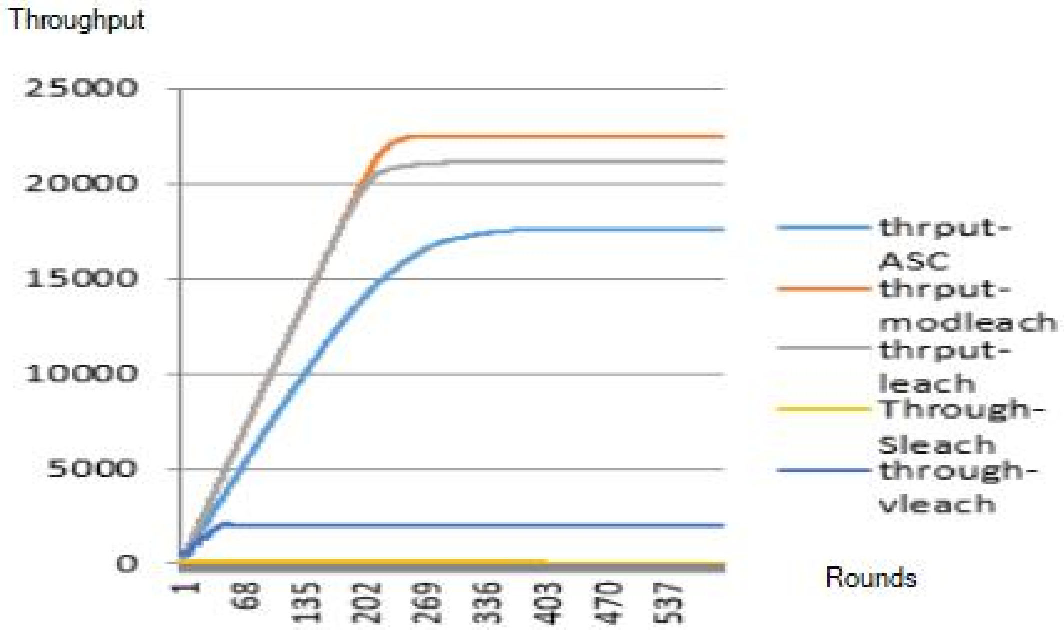

Figure 5.5: Throughput graph

5.3 Conclusion

This chapter had introduced an Area Splitting for Clustering (ASC) protocol to optimize energy consumption and increase network lifetime. The ASC protocol proposes an innovative approach using geometric equations for selecting Cluster Heads, thus differing from classical probabilistic methods. This helps identify the optimal nodes to act as Cluster Heads based on their positions relative to other nodes. Minimizing communication distances between nodes and CHs leads to lower power usage, thereby extending the battery life of sensor nodes. The ASC protocol ensures a more uniform and efficient distribution of CHs compared to probabilistic methods. This results in better resource management and enhanced overall network performance.

In future work, we aim to investigate the protocol's resilience and dependability by evaluating its robustness under various failure scenarios, such as node failures and disruptions in the communication link.

General Conclusion

This thesis makes two key additions to energy-saving protocols in wireless sensor networks. The first contribution is UDLeach, a new implementation of the LEACH protocol that distributes the nodes uniformly in the Sensing Area to conserve energy as the data flows toward the central point at the start of each round. The second contribution is a new protocol called Area Splitting for Clustering (ASC) that takes into account the amount of energy remaining in the nodes and then chooses the cluster head based on the neighbouring nodes in order to save energy when communicating within the cluster.

The simulation results showed that the first method for using uniform distribution of nodes greatly increased WSN's lifetime while reducing the number of dead nodes operating as CHs. The results for the second method for selecting cluster heads reveals the supremacy of choosing Cluster Heads based on the number of neighbouring nodes. Furthermore, the testing revealed that both new approaches, UDLEACH and ASC, required far less energy from the sensor nodes than older methods, allowing the network to last longer.

In addition to these contributions, we believe that this thesis lays the groundwork for future research that will refine the ideas given here, resulting in improved energy-saving solutions for Wireless Sensor Networks.

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Work has been completed during this thesis:

International publications in journals: 1

Mohammed Lamine Baaziz, Zibouda Aliouat, Makhlouf Aliouat, «Efficient **Energy-Aware Clustering Approach Area Splitting-basedfor Wireless Sensor Networks**", published in: Ingénierie des systèmes d'information journal (ISI), Vol 29, No 4, August 2024

Paper Accepted and published in IEEE national conference : 1

Mohammed Lamine Baaziz, Zibouda Aliouat, Atta Allah Amine, "**A uniform node distribution in a grid format utilizing LEACH within a wireless sensor network**, : published in **C3ETCV'24** national conference.

Internship: 1

Short-term internship, 1 month, at the 10th November institute of technology, Surabaya, Indonesia, November-December 2019