A Review Study of the Optimized Cluster Head Placement of Transmit-Only Nodes in Wireless Sensor Networks

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Abstract. Wireless sensor networks (WSNs) with transmit-only (TO) nodes are gaining increased popularity, in particular, in applications requiring heavy deployment of sensor nodes in harsh and inaccessible environments. The data collected by the members of the WSN is relayed to a nearby base station (BS) via a cluster-head (CH). Since the nodes are usually battery-limited, it is important to optimize the location of the CH in the sensing environment to prolong the lifetime of the entire network. In this paper, we describe this problem using a general energy model and review the main articles that discuss the energy optimization problem in WSNs and summarize their important results, in addition to the basic working principles of the different widely used energy-optimization algorithms.

1 Introduction

Wireless sensor networks (WSNs) are rapidly evolving with the development of wireless communication technologies, such as the Internet of Things (IoT) and cognitive transmit-only (TO) sensors. In WSNs, a group of sensors are deployed in a sensing environment to collect data and forward it to a central base station (BS) for further processing. Usually, the sensor nodes are equipped with limited-energy batteries. To reduce the energy consumed by the sensor nodes when transmitting the sensed data to the BS, a cluster-head (CH) is chosen to function as an intermediary device to relay the collected sensing data from its nearby nodes to the BS. Thus, it is important to optimize the location of the CH within the sensing environment in a way that guarantees the longest possible network lifetime [1 – 4]. The CHs are equipped with transceivers to handle data relaying procedures and thus are expected to consume more energy than the TO nodes, which have a transmitter unit only (except for receiving control signals in the case of cognitive sensors [5]. The TO nodes are considered dead when their battery is depleted and therefore will no longer be able to sense and send data [6].

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Generally, to overcome this difficulty, a plethora of methods, procedures, and algorithms have been put forth in an effort to optimize the CH location, reduce power consumption, and increase the lifetime of the TO node. Typically, clusters consisting of a single representative CH are formed by adding all of the nodes. The CH's responsibility is to gather information from the cluster members and provide it straight to the BS. Nodes that are farther away from the base station may experience a higher rate of power loss and a faster rate of death than other nodes due to the uneven power dissipation among them. Clustering is the process that makes the nodes consume minimal power in transmitting data by sending the group's data to the master CH of the network, which in turn coordinates the transmission of data to the BS in a multi-hop type of communication [6], [7].

Static versus dynamic, single-hop versus multi-hop, and homogenous versus heterogeneous are only a few of the numerous criteria that can be applied for clustering. Because of its energy efficiency and simplicity, the Low Energy Adaptive Block Hierarchy (LEACH) protocol was widely adopted [7, 8]. In a single-hop communication model, all sensor nodes' data are typically directed to a master node, which then forwards it to the intended recipient.

Sensor nodes can also be deployed statically or dynamically based on the applications. The deployment method in forest and earthquake monitoring requires nodes to be deployed statically and randomly because there is no prior knowledge of the required locations initially. Dynamic deployment differs from static deployment in that it allows nodes to change their locations to improve network coverage and avoid dead zones [9].

In this paper, we present a review of several research articles that concentrate on minimizing the energy consumption of the entire monitoring field to prolong the lifespan of the WSNs. The rest of this paper is orderly organized as follows: in Section 2, the system model is presented, including the energy model and the network model. We present the literature review of the pertinent papers in Section 3, before concluding our work in Section 4.

2 System model

2.1 Energy model

In WSNs, the TO sensor nodes, usually, have limited energy sources. A large portion of the node's energy is consumed for data sensing and transmission. The distances between the TO nodes and their respective CHs determine how much energy each node uses, as depicted in Figure 1. Mathematically, the energy consumed by the transmitter to transmit p bits of information, ETX , and the energy consumed by the receiver for receiving these bits, ERX, over an Euclidian distance,d, in free space can be modeled as follows:

$$E_{TX} = (E_e + E_a . d^{\mu})p \qquad (1)$$

$$E_{RX} = E_e . p \qquad (2)$$

Where, Ee is the energy lost through the transmitter's (or receiver's) electrical circuitry, and Ea is the energy lost as a result of the transmitter amplification. μ is the path-loss exponent, which is environment-dependent. It is worth noting that the path-loss exponent is positive due to the direct relationship between energy consumption at the transmitter and distance, which is contrary to path-loss models in wireless communications channel models, where the exponent is negative since the received signal power (relative to noise) is usually the important factor when decoding the received data packets.

2.2 Network model

The sensor network consists of a set of sensor nodes that are deployed randomly to collect data from the surrounding environment. Usually, these nodes are divided into several proximity-based clusters, and each cluster is controlled by a CH, which coordinates the data transmission activities of the sensor nodes within the cluster. The sensing data collected by each cluster is sent to the CH, which sends its collected data to the master node of the network that coordinates the transmission of data to the BS to minimize the energy consumption of the network by reducing the communication distances between the TO nodes and the master CH [9–11]. The general architecture of WSN is demonstrated in Figure 2, it shows several sensor nodes divided into three clusters, each with a single CH and one master node. The arrows indicate the direction of transmission of the sensed data.

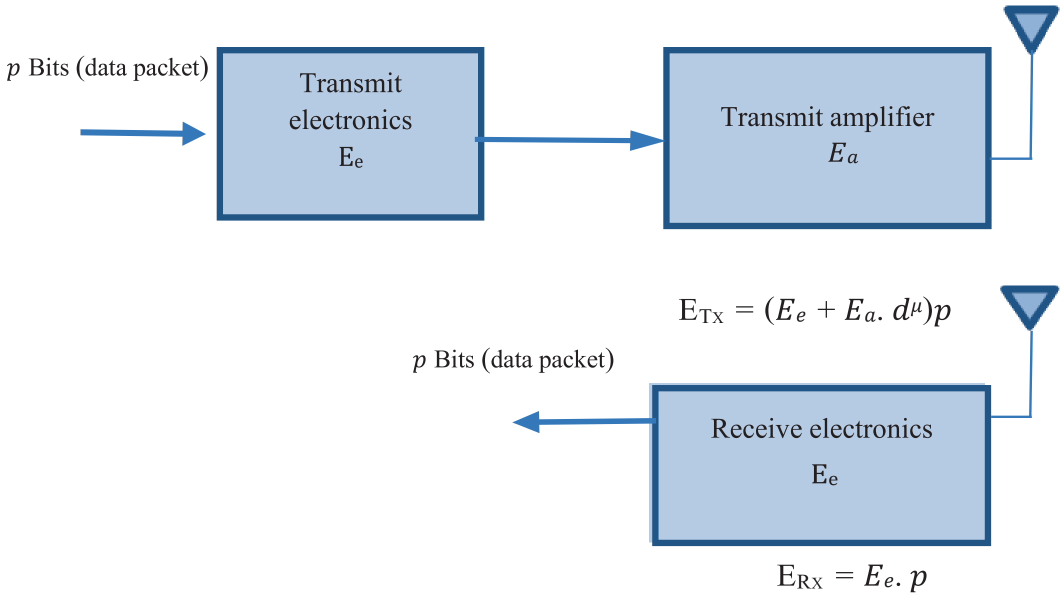

Fig. 1. The energy consumption model.

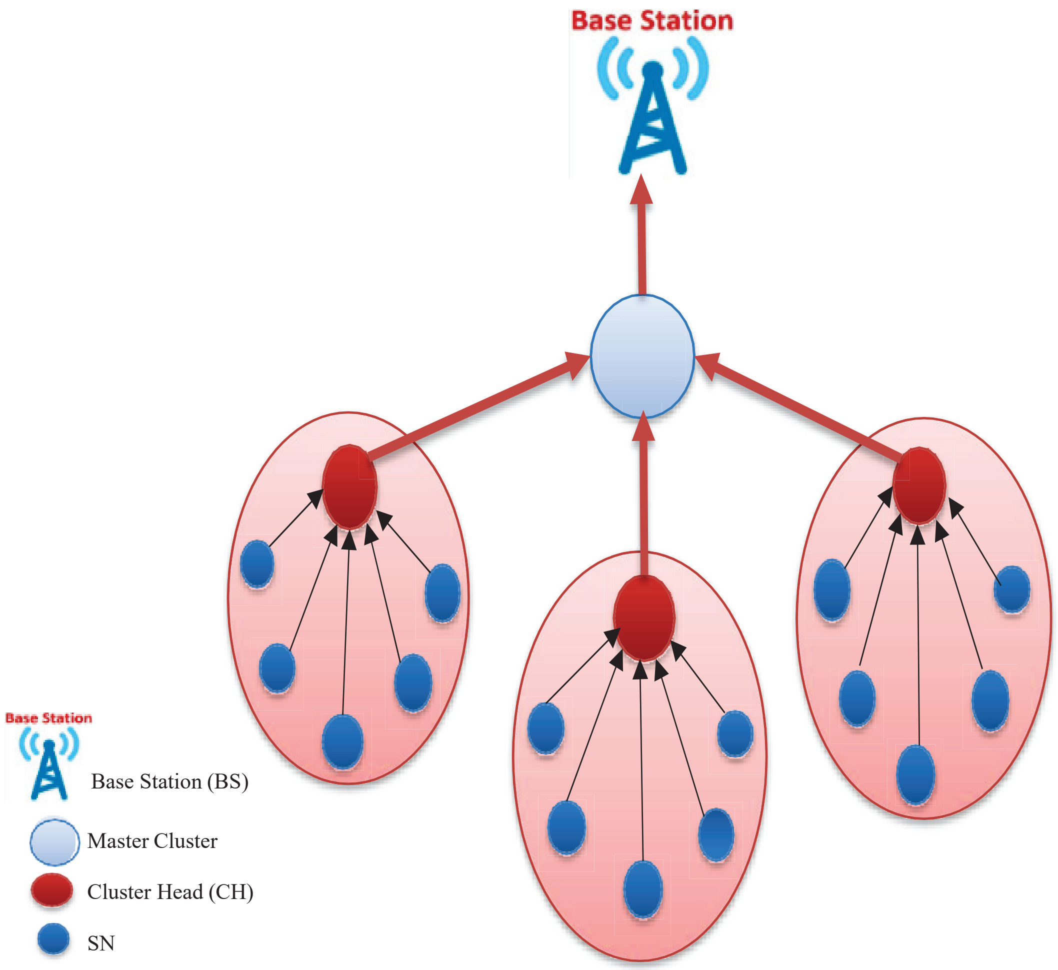

Fig.2. The general architecture of wireless sensor networks. Here, each group of the transmit-only sensor nodes (the grey circles) sends their sensed data to the cluster head (the green circles), and the CH sends its data over to the master node (the yellow circles) of the network, which then forwards it to its destination at the base station (the blue triangle).

3 Literature review

In WSNs, the main purpose of clustering is to improve the overall network efficiency, such as better link quality and energy consumption, thanks to the shorter communication distances between each CH and its sensor nodes as compared with the larger distances to the main CH (or the BS). The different types of clustering and relaying methods are summarized in the literature below. In addition, the main algorithms are compared in Table 1, where the advantages and disadvantages of each algorithm are listed, in addition to the basic operation principle of each algorithm.

3.1 Single–hop communication

We review the research in which sensor data is directed to the final destination via single-hop relays. Data packets are sent over wireless links from sensor nodes to a CH, where the packets are decoded and forwarded to the base station.

Hongxian T., et al in 2021 [5]. The major goal of the two algorithms proposed by the writers in this study is to reduce the power consumption of the sensors while also taking into account the entire cost of the system. The authors analyze a scenario where N sensor nodes have the same transmit power and modulation technique. M-deployed CHs gather data from the sensor nodes while the two algorithms search for the optimal location for the CHs. The sensor nodes are positioned at random throughout the monitoring region. Although it requires more computing power, the first algorithm—the binary graph weighting (WBG) algorithm—is more accurate in identifying the ideal CH location. With somewhat less complexity, it is possible to make the second algorithm, the pixels with gray levels (PGL) algorithm, nearly resemble the exact one. Based on simulation data, the authors showed that the lower complexity technique can get fewer average contentions in varied numbers of sensor nodes, compared to the naive placement. On the other hand, fewer CHs may be needed with ideal placement to achieve the same average contention at a fixed number of sensor nodes, according to the results.

Somasekhar K., et al in 2015 [12].Two clustering strategies to choose the cluster heads and increase the network lifetime are presented by the authors in this research. Utilizing the Low Energy Adaptive Clustering Hierarchy (LEACH) method, the first proposal is Whatever the nodes' remaining energy, in this scenario every node has an equal chance of being a cluster head every round. Because of the early demise of sensor nodes, the network lifetime decreases. Using Cluster-Heads residual energy and ideal CH range levels as a basis, the second proposal is a Single-hop Clustering and Energy Efficient Protocol (SCEEP). As can be seen from the simulation results, SCEEP maximizes the network lifetime and gathers three times as much data as the LEACH.

Ning C, et al, et al in 2017 [13]: In this paper, the authors compare two typical routing protocols the Single-hop protocol and the LEACH protocol by using the lifetime and reliability of wireless sensors network. In the network, Sensors are randomly deployed, and the cluster head is located in the middle of the area. in the Single-hop routing protocol, the communication between the sensor nodes and the cluster head (no intermediate sensors). In the simulation results, whenever the number of sensors goes up the reliability for the LEACH decreases, and the reliability for the single-hop increases. The lifetime of the LEACH increases by increasing sensors elected as cluster heads, always, the lifetime of sensor nodes increases in the single-hop.

3.2 Multi-hop communication

In this section, we review articles in which sensing data is directed to the final destination through multi-hop, where the CH sends its group's data to another higher-level CH, before reaching its final destination.

M. U., et al in 2019 [10]: In this paper, the authors proposed to analyze the throughput, network lifetime, and energy efficiency of the Low-Energy Adaptive Clustering Hierarchy protocol with genetic algorithm (LEACH-GA) in several scenarios with different sink node locations, such as two different network areas and three different BS placements. The simulation findings show that, in comparison to the LEACH protocol, a clustering approach that was proposed in [14], the network lifetime in the LEACH-GA protocol is longer in the two distinct areas. In addition to the kind of protocol being utilized, the positioning of the base station has an impact on network longevity. It has been demonstrated that the best location for the BS is in the middle of the network to achieve the longest network lifetime and the fastest possible data transmission while using the least amount of energy.Nader A. and colleagues in 2021 [8]: In this paper, the authors introduced a protocol called the multi-weight chicken swarm-based genetic algorithm for energy-efficient clustering (MWCSGA), which lowers the power consumption of the nodes to boost energy efficiency and network lifetime. The coverage area is first filled with a large number of randomly dispersed sensors. Nodes are then grouped into clusters, with some of the nodes chosen to be cluster heads. A comparison is made between the suggested approach and rival approaches like LEACH-GA, MW-LEACH (Multi Weight - Low Energy Adaptive Clustering Hierarchy), and CSOGA (Chicken Swarm Optimization Genetic Algorithm). The MWCSGA protocol outperformed the earlier techniques in terms of packet transmission rate and energy efficiency, according to their simulation results.

B P, et al in 2019 [9]: The authors of this report suggested implementing a hybrid technique, known as Firefly Algorithm with Particle Swarm Optimization (HFAPSO), in the LEACH-C (centralized) algorithm to decrease energy consumption and increase network longevity. Using the number of alive nodes, residual energy, and throughput, the suggested methodology is assessed and its performance is compared with that of the LEACH-C and Firefly algorithms.

Kun W, et al in 2021 [15]: The authors of this work suggested a novel multi-chain routing protocol for strip-based WSNs, namely destination Directed Routing Algorithm (DORA), as an orientation method. Each cluster head (CH) in a cluster sends data to its upstream cluster that is located nearer the base station in multi-chain routing. The ascending CH will forward packets to the highest CH until the destination base station is reached and each chain length is shorter than the routing path in Power-Efficient Gathering in Sensor Information Systems (PEGASIS), hence conserving transmission energy in each routing path. According to their simulation results, the network longevity of the DORA algorithm is doubled when compared to the original PEGASIS.

Tata J, et al. in 2020 [16]: In this research, the authors suggested a novel routing protocol, termed Energy Efficient Leveling Protocol (EELP) for optimal cluster head selection and node placement in WSNs, and compared with other two routing protocols, LEACH and Hybrid Energy Efficient Distributed (HEED). EELP operates in this manner: utilizing a tree data structure, data is sent from the base station (BS) to nodes having a lower hop count. The routing protocol works to reduce the number of hops, where the nodes with higher importance value have access to important data and lower importance nodes prevent access to important data. Their simulation results show that EELP is more efficient and has the highest residual energy than LEACH and HEED.

3.3 Dynamic nodes

The sensor nodes can be distributed randomly with a static position and a mobile CH. In this dynamic setup, the CH continuously (or periodically) changes its position to prolong the network lifetime.

Ala K. and others in 2020 [6]: With the primary goal of reducing overall energy consumption and increasing the network's lifetime, the authors of this research suggested an algorithm to locate the CH in the best possible location for both single and multiple clusters. The suggested methodology makes use of a hybrid approach to sensor network deployment, in which it is assumed that the CHs are mobile nodes with the ability to change their positions to decrease energy consumption and lower the CHs' contribution to path loss in the sensor network. To take advantage of convergence and connectivity, the BS is installed in pre-selected places in a spiral route. The sensor network is also dispersed at random around the CH nodes. They can relocate to the best areas thanks to the CH location mobility feature. The main benefit of the proposed algorithm: it can be applied to any clustering algorithm used in mobile WSNs, where nodes find the CH based on the CH selection criteria and then use the proposed algorithm to change the CH's location to minimize path loss, lower overall energy consumption, and extend the node's lifetime.

Murtadha A., et al in 2019 [4]: In this paper, the authors of this research put out a mathematical model that seeks to increase the network's lifespan by lowering the power consumption of its sensors, which are limited to transmitting, while simultaneously preserving network coverage. The authors examined WSN consisting of N TO nodes that were deployed uniformly and randomly in a two-dimensional space. It is believed that the CH is a drone that takes off and flies regularly to gather sensory data for a variety of TO nodes and transmit it to the BS located outside the field limit. When the energy of the TO nodes is lowest, the CH approaches them. The static CH method and the suggested model were contrasted. Their simulation findings demonstrate that, in comparison to the static CH technique, the suggested model offers improvements of up to 50%.

3.4 Heterogeneous

Here, we review research articles of the most practical networks, the heterogeneous wireless sensor networks, and discuss some of the methods for balancing energy consumption in the entire network.

P. A. et al. (2016) [17]: The authors of this work developed a modified and improvised cluster head election technique as well as an overall cluster head modification called Balanced Energy Efficient Network Integrated Super Heterogeneous (m-BEENISH), which significantly extends the network lifetime. An election between the different nodes in a distributed system is the goal of this procedure. A variety of factors are taken into consideration while selecting the top node to serve as the cluster head. These requirements are based on the network or system. According to their simulation results, the suggested m-BEENISH protocol outperforms the Balanced Energy Efficient Network Integrated Super Heterogeneous (BEENISH) protocol in terms of throughput ratio. The efficiency of a node's lifetime, throughput, decreased latency, decreased energy consumption, and total efficiency of 16.3% are all provided by the m-BEENISH protocol. This sets the proposed m-BEENISH protocol apart from the current BEENISH protocol and makes it superior.

Gany Z, et al in 2019 [18]: In this paper, the authors proposed an improved LEACH algorithm suitable for the heterogeneous wireless sensor network. In the LEACH protocol, all nodes have the same initial power, with each node acting as a master node randomly. The contributions of the researchers were to add a threshold switch to overlook the useless data in the sensor nodes and send the useful data, timely and reliably, to the cluster head, which in turn sends the collected data to its final destination. Their simulation results show that the network lifetime is prolonged several times relative to the protocol of LEACH.

Min-Yi W, et al in 2015 [19]: In this paper, the researchers proposed a spontaneous aggregation protocol, the Stochastic Election of Appropriate Range Cluster Heads (SEARCH) protocol. The WSN runs in three stages: the stable period, which includes rounds of all sensor nodes that are alive and running smoothly. After the death of the first sensor node the usable period as the sensing capacity decreases in the network to half. Then the network slips into the weak sensing period the network degrades sharply. In heterogeneous networks: The SEARCH protocol remarkably prevails in terms of effective rounds on constant periods and rounds of half-alive nodes residual. This is not possible in the previous protocols the LEACH, stable election protocol (SEP), and distributed energy-efficient clustering algorithm (DEEC).

3.5 Other methods

In 2018 [20], Taoufik B. et al. To address several issues with long-range communication in Internet of Things applications, the authors of this paper proposed the LoRaWAN wireless communication protocol, which was created by the LoRa Alliance. The goal of this technology is to decrease the cost of the device and extend the life of the sensor batteries. This paper examined the impact of LoRaWAN parameters on the consumption of sensor nodes, including acknowledged transmission, spreading factor, coding rate, payload size, and communication range, while monitoring high-voltage electrical network pylons. The energy consumption varies with different LoRa/LoRaWAN parameters, as the authors demonstrated with numerical findings.

In 2016, Murtadha A., et al. [3]: The authors of this work provided a novel method for meeting the connectivity and coverage needs of sensor nodes while lowering the power consumption of those nodes that have limited power resources. The TO sensor nodes in the WSN are equally dispersed throughout a statically distributed two-dimensional region and grouped into clusters. A fixed CH in each cluster gathers data from the sensor nodes and transmits it to the pre-established base station. Reducing the distance between CH and BS is the foundation of the suggested strategy. The first scenario considers the BS outside the sensing field, while the second scenario considers the BS positioned in the core of the sensing field. The simulation findings reveal that the network consumes more energy when the TO nodes are positioned outside the sensing field, due to the relationship of the transmission distance to the energy consumed by the network. One of the most significant nodes in the network, the master node CH, is used to gauge the lifespan of the network.

Table 1. Comparison summary among a few clustering algorithms in WSNs presented in the literature.

Method	Main advantage /disadvantage	Main working principle
LEACH[18]	Unlike most real-world sensor networks, the LEACH protocol is a traditional clustering routing protocol that makes use of dynamic clustering. Its focus on lowering network energy consumption ignores node heterogeneity.	The Cluster Head (CH) selection procedure in the LEACH protocol is carried out independently. Sending data to the CH, which then sends it to the BS, is how all cluster nodes exchange data.
EELP [16]	EELP protocol is energy efficient and provides secure communication. It outperforms LEACHand HEED protocols.	In the EELP protocol, the average depth of important Cluster Heads from the base station is minimized by reducing the number of hops. Nodes with a higher hop count propagate the data to the BS from nodes with a lower hop count.
LEACH-GA [10]	LEACH-GA is a protocol that maintains energy efficiency, increases network lifespan, and outperforms LEACH protocol.	The LEACH-GA clustering process determines which node is designated as a CH and which node is a member. Only the nodes that meet the threshold are chosen as CH. If a node does not become a CH, it joins the nearest CH. Following the completion of the cluster creation procedure, the process of sending data from the cluster member to the CH or from the CH to the BS begins.
m- BEENISH [17]	m-BEENISH is a protocol used in the routing andselection of CH. It provides efficiency in termsof node's lifetime, throughput, and reduced energy consumption compared to the BEENISH protocol.	The m-BEENISH protocol is designed toperform an election among the nodes in a distributed system. The best of all the nodes, the one with the most leftover energy, is chosen to become the cluster leader. The data flow between the various clusters and the base station is coordinated by the main cluster head.
LEACH-C [9]	LEACH-C is used to minimize the energy. consumption of the network, it outperforms the LEACH protocol in terms of the network lifetime.	The LEACH-centralized algorithm is used to find the best clusters. There are two steps to this algorithm (1) setup and (2)steady-state. During the setup phase, each sensor node collects the node's position and energy levels and sends them to the base station, which

Method	Main advantage /disadvantage	Main working principle
		calculates the node's average energy level . if each node's energy the level is higher than the average , the node will serve as the clusrer head for the current round. The cluster head combines information form the cluster head for the curent members and transmits it to the base station in the steady-state phase.
HFAPSO[9]	HFAPSO is used to prolong the network lifetime and reduce the energy consumption and improvesin network lifetime .Therefore increasing the number of alive nodes in WSNs compared to the LEACH-C protocol	The Hybrid Firefly Algorithm with Particle Swarm Optimization (HFAPSO) is used for the selection of optimal cluster head by using the residual energy and distance between the cluster head and non-cluster members.

4 Conclusions and future research direction

When designing and deploying sensor nodes in WSNs, energy consumption is a key consideration, particularly in hostile settings. The lifespan of wireless sensor networks (WSNs) has become a crucial performance metric to increase energy efficiency. To extend the lifetime of the entire network by reducing excessive energy consumption and making efficient use of the energy that is available, this study reviews a wide range of research articles that focus on energy management guidelines. WSN lifetime optimization requires careful management of the transmission energy dissipation utilizing various technologies and methods.

The spreading factor, coding rate, and bandwidth are other factors that have an impact on the network's longevity but are not the subject of this article. To lower the TO nodes' energy usage, it is crucial to optimize these characteristics. We believe there aren't enough sophisticated methods in the literature for heterogeneous WSNs, where the sensors' sensing and mobility dynamics capabilities vary. In such a scenario, where the nodes in huge observation fields are dispersed across different distances from the base station (BS) and use different amounts of energy, new mathematical models are needed to determine the best placement for the cluster head to achieve energy fairness.

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