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# Energy Optimization in Wireless Sensor Networks: A Review

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RESEARCH ARTICLE

# Energy Optimization in Wireless Sensor Networks: A Review

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**ABSTRACT**

The use of wireless sensor networks (WSNs) has become an inevitably necessary for a smart world, such as smart cities and environmental fields. WSN consists of hundreds or even thousands of sensor nodes that have the ability to sense physical conditions from the target field, and also consists of a device that acts as a link between the sensor nodes and the base station (BS) called cluster head (CH). In the recent years, researchers have become interested in optimizing the energy efficiency of the WSNs due to the limited and non-replenish energy sources of their sensor nodes. In this paper, we present a review of main methodologies used in the literature to improve the energy efficiency of WSNs and extend the lifetime of the network. In addition, we present the general energy model that is used in these networks. Moreover, we discuss new research directions for efficient network-energy utilization that need to be considered for implementing power-constrained WSNs.

**Keywords:** WSNs, Energy optimization, Sensor nodes, Cluster head

## 1. Introduction

Wireless Sensor Networks (WSNs) have been the focus of researchers' attention in recent years due to their versatile applications. WSNs are widely used in environmental, security, military, medical, health care, agricultural, and industrial applications [1]. WSNs consist of large numbers of small, low-power, and inexpensive electronic devices called sensor nodes. Each sensor node is responsible for sensing the target field, processing the sensed data, and sending the sensed data to the cluster head (CH) or to the base station (BS). Each CH is responsible for aggregating the sensed data from a specified number of sensor nodes and sending it to the BS.

For many WSNs, the normal sensor nodes within the monitoring field are selected as CHs, which affects the lifetime of the selected sensor nodes due to the additional workload [2]. Several researchers have proposed the use of nodes equipped with additional energy (special nodes) called gateways, and these gateways are similar in their work to the CH [2]. Each sensor node is equipped with a battery of limited power, and due to the presence of these sensor nodes in harsh and hard-to-reach environments, it becomes difficult to replace or recharge the batteries of the sensor nodes [3, 4]. Therefore, many research articles have focused on reducing the energy consumption and extending the lifetime of the network through, mainly, CH position optimization and data communication optimization.

To optimize the position of CHs in WSNs, the nodes are usually grouped together in a proximity-based groups or clusters, each with a single representative CH. Various clustering approaches have been reported in the literature. For example, the nodes can be grouped based on their physical distance relative to each other, and the distance from the chosen CH to the base station, in addition to the remaining energies of the nodes [5]. In this type of clustering, the CH is one of the nodes in the cluster. The selection of the candidate CH node should be optimized under limited

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energy constraints. Other variations of this approach can include using an additional super-energy node to work as a CH within each cluster. The selection of routing protocols in cluster-based networks is crucial for energy-optimum network architectures.

There are several types of routing protocols used in WSNs. Generally, routing protocols are divided into hierarchical, flat, and location-based [6]. In hierarchical routing protocol, the network is divided into distinct clusters. The most popular hierarchical technique is the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol, which has been popularly used due to its simplicity and efficiency in the energy consumption. With flat routing protocol, all nodes have similar functions and work together for sensing and routing operations. Location-based technique use the location information of sensor nodes to create a routing path. In all these types of routing protocols, the distance over which data is transmitted, in addition to the amount of communicated data are considered for network optimization.

There are two types of communication within the WSNs: single-hop and multi-hop communication. In a single-hop communication, the sensed data of each sensor node can reaches directly to the destination, while in a multi-hop communication, the sensed data is routed over several hops until it reaches the end destination [7]. A power limited WSN should account for the optimal placement of sensors nodes and their corresponding CH relative to the destination point.

**Our contribution:**
We summarize our contribution in this review article as follows:

- We review different types of solutions presented in the literature to solve the problem of energy optimization in WSNs. This review helps the new researchers investigating in this specific research direction to have a quick overview of the problem and its already-thought-of solutions.
- We classify the different ideas around the considered problem into multiple groups, along with a few relevant references, which helps the reader to be familiar with the different common solutions trends.

In this paper, we present a review of several research articles that focus on minimizing the energy consumption of the entire monitoring field to prolong the lifetime of the WSNs. The rest of this paper is organised as follows: in Section 2, we present the system model, including the network model and the energy model. We present the literature review of the relevant papers in Section 3, the challenges and practical implications is presented in Section 4, before concluding our work in Section 5.

## 2. System model

### 2.1. Network model

Wireless sensor networks generally consist of $N$ sensor nodes that are spatially distributed in the target field to monitor changes in the environment or physical conditions. Most researchers divide wireless nodes into multiple clusters to reduce the communication distances and thus minimize the energy consumption of the network as a whole [8–10]. Each cluster is headed by a node, called a cluster head, that collects the sensed data from the corresponding sensor nodes and forwords it to a remote base station. The general architecture of wireless sensor network is demonstrated in Fig. 1, and it shows a number of sensor nodes divided into three clusters, each with a single CH, and the arrows indicate the direction of the transmission of the sensed data.

### 2.2. Energy model

All sensor nodes and CHs in WSNs contain an RF antenna to perform data transmission and reception operations between them to reach the final destination. A general energy model for these networks is the first order radio model, where the energy, $E_{Tx}$, consumed by each sensor node or CH, as transmitters, in the network is as follows [8]:

$$E_{Tx} = \left(E_e + E_a \cdot d^{\mu}\right) \cdot p \quad (1)$$

where $E_e$ is the energy dissipated by the electronic circuits of the transmitter (or receiver). $E_a$ is the energy

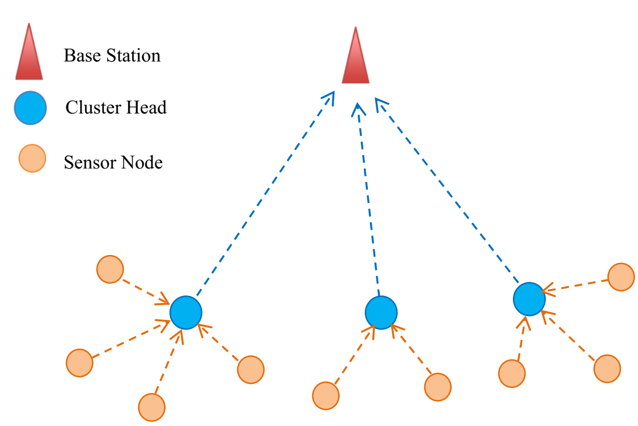


**Fig. 1.** The general architecture of wireless sensor networks. Here, each group of the transmit-only sensor nodes (the yellow circles) send their sensed data to the cluster head (the blue circles), which then forward it to its destination at the base station (the red triangle).

dissipated by the transmitter amplifier. $d$ is the Euclidian distance between the transmitter and receiver sides. $\mu$ is a constant, and $2 \leq \mu \leq 6$ depending on the environment in which the sensor nodes are deployed [11, 12]. $p$ is the number of sensed data packets, measured in *bits*. The energy consumed as a receiver, $E_{Rx}$, in the sensor nodes and the CHs is calculated as follows [8]:

$$E_{Rx} = E_e \cdot p \quad (2)$$

From the above two equations, we notice that the energy consumed during transmission operations is proportional to the distance between the sender and the receiver, where the rest of the parameters are approximately constant. Therefore, position optimization is crucial for energy-efficient WSN, where transmission distances are usually reduced by dividing the network into clusters and allocating a node to be CH, which in turn is responsible for communicating the data sensed by its group to the destination.

## 3. Literature review

In this section, we provide a review of several research papers that seek to optimize the energy efficiency of the WSNs by minimizing the energy dissipated at the different network components. We classify, in subsections, the common strategies used by each group of research articles. In addition, in Fig. 2 we show a brief overview of the different aspects discussed in the literature around this specific problem, in addition to a few relevant references for further details.

### 3.1. Multi-hop communication

In this section, we review research in which the sensing data is routed to the final destination through several hops, where data is transferred from one node to another adjacent node until the final destination is reached, where the first sensor node sends its sensed data to the adjacent sensor node and the second sensor node collects the received data and its sensed data and forwarded it to the other adjacent sensor node. Below are the papers that use the multi-hop method:

S. Ebadi, et al. in 2010 [13]: In this paper, the authors proposed an algorithm to prolong the lifetime and minimize the energy consumption of WSNs. They propose the hierarchical and multi-hop clustering algorithm. This algorithm seeks to divide the network into clusters and assign two CHs for each cluster, one is called low-level cluster head and the other is called high-level cluster head. The low-level CH is responsible for collecting, aggregating, and sending data to the high-level CH. The high-level CH is responsible for receiving data from the low-level CH and sending it to another high-level CH or to the base-station. The communication process among CHs and the BS is a multi-hop process, whereas the communication between the sensor nodes and their CHs is a single-hop process. Simulation results showed that their proposed algorithm is optimal to LEACH protocol in terms of network lifetime by more than 28%.

T. J. Swamy, et al. in 2019 [14]: An Energy Efficient Leveling Protocol (EELP) is proposed to ensure communication security, reduce message delay, and maintain energy efficiency in military communications. The optimization problem is solved by selecting the optimal CH and determine the sensor node locations in WSNs. The network is divided into clusters, each has its own cluster head. Among the CHs, some are important, and others are normal. The important CHs are responsible for transferring data between the BS and other CHs. These important CHs are identified by reducing their depth from the BS by minimizing the number of hops. The proposed EELP protocol are compared with the LEACH and the Hybrid Energy-Efficient Distributed (HEED) protocols. Simulation results show that their proposed approach increases the network lifetime, providing secure data compared to LEACH and HEED protocols.

E. Natalizio, et al. in 2008 [15]: The authors proposed a mathematical model to maximize the lifetime of network data flow by determining the optimal

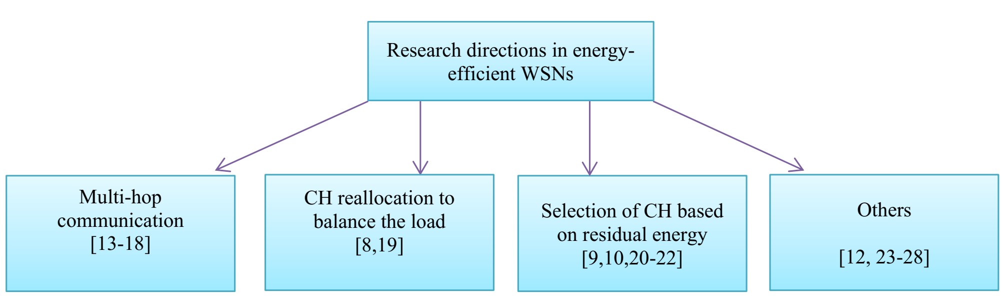


Fig. 2. Common ideas presented in the literature for energy-aware wireless sensor networks (WSNs).

placement of the sensor nodes on a single data flow in wireless sensor networks. These sensor nodes are located between source and destination that have previously determined their location. The placement selection of the sensor nodes depends on the residual energies of the sensor nodes.

In this paper, the results do not show any specific correlation between the path length and the lifetime. A longer path can contain more sensor nodes than a shorter path. Also, the authors compared their proposed approach, called energy spaced approach, to other two approaches: a random, and an evenly spaced placement of the sensor nodes along the path between the source and the destination. It was observed that the proposed approach was the best of the other two approaches in terms of the path lifetime.

J. Wang, et al. in 2017 [16]: The Energy-balanced Unequal Clustering Routing (EUCRP) algorithm is proposed to balance the energy consumption of the network. The aim of this algorithm is to divided the network into clusters using non-uniform clustering approach. Thus, create shortest path tree to find the best multi-hop transmission paths to achieve efficient data transmission between the sensor nodes and the base station. The selection of the CHs in the proposed algorithm depends on the density of the sensor nodes in the target field, the residual energies, and the distances between the sensor nodes and the BS. Simulation results show that the EUCRP can efficiently balance the energy consumption of the sensor nodes, reducing the speed of the death of the sensor nodes, and extend the lifetime of the network.

P. Zhuojin, et al. in 2019 [17]: The authors proposed an Energy Efficient Sleep-Scheduled Tree-Based Routing Protocol (EESSTBRP) algorithm to minimize energy consumption of the sensor nodes in WSNs by dividing the network into four groups such that each group contains an equal number of sensor nodes. In EESSTBRP protocol, it is assumed that every two adjacent sensor nodes at a certain distance sense collect similar data from the target field, and thus they make these two sensor nodes work alternately to prevent data duplication. These sensor nodes are called paired nodes. All sensor nodes that do not have adjacent sensors are assigned an active mode throughout the rounds until they are dead, while the paired sensor nodes are switched between active and sleep modes during rounds until they die out. The CH selection in each round is based on the weight value that depends on the residual energy of the active nodes and its distance to the BS. Therefore, they built a minimum spanning tree for each group, where the roots are represented by the CHs. This procedure is done by using prim's algorithm. The child active node transmits its sensed data and residual energy data to its parent node. The parent node collects the received data and its sensed data in addition to its remaining energy information. This procedure is done throughout the tree, until data is received by the CH nodes. Therefore, the CH node in turn sends its information and the received aggregate data to the BS.

S. Lindsey and C. S. Raghavendra in 2002 [18]: The authors proposed a Power-Efficient Gathering in Sensor Information Systems (PEGASIS protocol) to improve the lifetime of the sensor nodes in the network. In PEGASIS protocol, a chain is created to connect all sensor nodes with each other using the greedy algorithm, where the data is sent along the chain until reaching the chain leader. The chain leader in turn collects the data and sends it to the BS.

### *3.2. CH reallocation to balance the load*

In this section, we will review the papers which dealing with the idea of switching CH work between sensor nodes through rounds to reduce workload on a single CH and to balance energy consumption between all sensor nodes in the sensing field.

W. R. Heinzelman, et al. in 2000 [8]: The authors proposed a Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol to minimize energy consumption of the network. LEACH is a clustering-based protocol that uses random allocation of cluster heads to evenly distribute the energy load between sensor nodes in the field. This protocol contains two phases, one is called set-up phase and the other is called steady-state phase. In the set-up phase, CHs selection and clusters formation tasks are performed, while in the steady-state phase, the CHs aggregate the data from sensor nodes and forward it to BS. These phases are repeated during regular time intervals to reallocate the role of the CH between all sensor nodes and re-clustering to balance the network load. LEACH does not consider the remaining energy of the sensor nodes when they are selected to be CHs (i.e., each sensor node has equal probability of becoming a CH).

Simulation results demonstrate that LEACH protocol can achieve large reduction in energy dissipation compared to traditional routing protocols, where it can evenly distribute energy dissipation in the network and doubling the network lifetime.

V. Pal, et al. in 2015 [19]: The authors proposed a clustering algorithm by determining a head for each cluster and optimize the number of the cluster heads using genetic algorithm. The authors proposed switching the role of the CHs between the sensor nodes. The proposed technique (LEACH-GA) is compared with LEACH and LEACH-C protocols. LEACH-GA optimizes the number and selection of the

CHs. The authors found that the LEACH-GA is optimal in terms of the first node death and half node death.

### 3.3. Selection of CH based on residual energy

In this section, we will focus our attention on researches in which the allocation a sensor node as a CH from group of sensor nodes depends on the residual energy of each sensor node, where the sensor node with the highest residual energy is nominated to be the CH.

W. B. Heinzelman, et al. in 2002 [10]: In this paper, the authors propose a protocol called LEACH-Centralized (LEACH-C), which is an improvement to LEACH protocol in [8]. In the set-up phase, all sensor nodes transmit information about their locations and energy levels to the BS. The BS utilizes this information to find a predetermined number of CHs and forms clusters. Then, the BS sends a message that contains the cluster head ID with their TDMA schedules for all sensor nodes. The steady-state phase of LEACH-C is similar to the LEACH protocol. Simulations show that LEACH-C protocol is better than LEACH protocol in terms of the network lifetime.

N. M. Abdul Latiff, et al. in 2007 [9]: Their proposed protocol has been compared with LEACH and LEACH-C and showed better results in terms of network lifetime and data delivery to the BS. The proposed approach is based on the energy aware cluster-based protocol to minimize energy consumption of the network, using Particle Swarm Optimization (PSO) algorithm. The main objective of this paper is to determine the CH that can reduce the intra-cluster distance with its sensor nodes, and optimize energy management in the network. Each sensor node transmits its information regarding location and current residual energy to the BS. The BS in turn calculates the average energy of all sensor nodes to make sure that only sensor nodes with enough energy are chosen as CHs. The PSO algorithm performs the clustering process of the sensor nodes and select the best number of CHs that minimize the cost function. The BS sends the information about the ID of the CHs for each sensor node.

S. E. Khediri, et al. in 2014 [20]: The authors proposed another variant of LEACH algorithm, called Optimized Low Energy Adaptive Clustering Hierarchy (O-LEACH), by selecting the cluster according to the remaining energies of the sensor nodes dynamically. Their proposed algorithm was compared to LEACH and LEACH-C, and showed better network stability performance by keeping the sensor nodes alive as long as possible (the network is called stable network, when all sensor nodes are alive). Hence, the selection of the CHs from the sensor nodes is based on the residual energy after each round.

A. John, et al. in 2017 [21]: Energy Saving Cluster Head Selection (ESCHS) method is proposed in this paper to improve network lifetime. This is performed by using uniform clustering to form clusters, and the residual energy of the sensor node to select the CH in each cluster. The sensor nodes with higher residual energies than the average residual energies of their corresponding clusters are selected as CHs. The number of clusters are decided initially. They calculate the mid-points by calculating the central point and the average distance between the central point and all sensor nodes. Thus, clusters are formed according to the distance between the sensor nodes and each mid-point, where the sensor node with a minimum distance to a certain mid-point is selected as the CH. The ESCHS is compared with LEACH and D-LEACH algorithms. The results showed that the ESCHS is optimal in terms of the rate of the residual energy of the sensor nodes in each round (energy saving), and in terms of the first sensor node to die.

M. Aldeer, et al. in 2019 [22]: In this work, the authors proposed to increase the lifetime of the network (reduce energy consumption), and maintain network coverage. The sensor nodes are randomly distributed and are static while the CH is moving among the sensor nodes in the monitoring field. The position of the CH changes with each round as the CH tends to be located near a sensor node that has less residual energy than the rest of the sensor nodes in the monitoring field. The optimization problem is solved by maximizing the total residual energy of the sensor nodes and the CH in each round.

### 3.4. Others

In this section, we review the papers in which the authors used several technologies to divide the network into clusters and find the optimal CHs that reduce the energy consumption of the network and thus extend the lifetime of the network.

S. Babaie, et al. in 2010 [23]: Here, the authors use Genetic Algorithm to minimize the energy consumption of WSNs based on the cluster head (CCGA). Initially, the algorithm chooses $k$ cluster heads from the sensor nodes according to some constraints, and the remaining sensor nodes become members of the closest CH (i.e., create clusters). There are several constraints that must be used in order to get the optimal CHs and divided the network into clusters. This is performed using Genetic Algorithm (GA) to find the optimal solutions. The constraints that determine the selection of the CHs and clustering the network are:

- The chosen CHs should not be close to each other, otherwise the member of nodes of each CH is not equal. Violating this criterion cause the CHs with large number of member nodes to lose their energy prematurely, because they receive and transmit a lot of data within this cluster.
- Number of cluster members (number of the sensor nodes associated with each CH to form clusters). This constraint depends on the previous constraint. Thus, regulating the distance constraint leads to an approximately equal number of cluster members (i.e., an approximately equal number of sensor nodes in each cluster).
- The last constraint is the distance between the sensor nodes and their CHs. This constraint is considered one of the most important constraints, as it specifies the sensor nodes that have a minimum distance to the CH from other CHs.

Simulation results show that their proposed CCGA algorithm produces better clusters and extend the network lifetime compared to the conventional approaches.

V. Pal, et al. in 2015 [24]: The authors proposed a clustering approach for extending the network lifetime by balancing the cluster size using thresholds that are used initially in cluster configuration in each round. Two thresholds are used in such approach: $Th_{cluster}$, which represents the number of sensor nodes in clusters, and $Th_{distance}$ (distance threshold), which represents the maximum distance between the CH and the un-clustered sensor nodes (i.e., when the distance between un-clustered sensor node and the CH is less than $Th_{distance}$, this sensor node joins the cluster). $Th_{distance}$ is determined initially and its value remains constant in all rounds, while $Th_{cluster}$ changes its value at each round according to the number of remaining live nodes in each round. $Th_{cluster}$ is calculated as the number of active sensor nodes divided by the number of CHs, whereas $Th_{distance}$ is determined by the trade-off between the total cluster distance and cluster size to obtain the best cluster quality. CH forms the TDMA schedule and sends it to its cluster members. Hence, each sensor node has a time slot to send its sensed data to the corresponding CH and remains in sleep state otherwise, i.e., in the rest of the time slots. The results demonstrate that the proposed clustering approach is better in terms of network lifetime and has a lower rate of expired sensor nodes compared to the traditional clustering approach.

M. Aldeer, et al. in 2016 [25]: In this paper, the authors proposed a new model to increase network lifetime and reduce energy consumption in the network by clustering the static transmit-only (TO) sensor nodes into clusters. Moreover, the optimal location of the CH within each cluster was also determined to reduce the energy consumption of the TO sensor nodes and the CHs. Therefore, reducing the energy consumed by the network as a whole through minimizing the energy dissipated by TO sensor nodes and the CHs. The optimization problem is solved by minimizing the total distance between the CH and its sensor nodes as well as minimizing the distance between CH and the BS. The authors compared their proposed model with two other models in two scenarios, where in each scenario the proposed model outperformed the other two models in term of the network lifetime.

M. Zivkovic, et al. in 2020 [26]: The authors proposed an improved version of the firefly algorithm (IFA) to extend the lifetime of the network and reduce power consumption by dividing the network into clusters and determine the optimal CH for each cluster. Their proposed approach took two things into consideration when dividing the network into clusters, the first is the energy consumed during the transmission process from the sensor nodes to the corresponding CH, and the second is the energy consumed by the CH to collect data and send it to the BS. The proposed approach (LEACH-IFA) was compared with LEACH, LEACH-PSO, and LEACH-FA, which were conducted for the same network infrastructure. Simulation results proved that LEACH-IFA is the best in terms of the death of the first sensor node, the death of half of the sensor nodes and the death of all sensor nodes, as well as in terms of the number of data packets sent to the BS for a certain number of iterations.

Z. Hammodi, et al in 2021 [12]: The authors proposed an algorithm to minimize the energy consumption of the network as a whole. They splitting TO sensor nodes into clusters, as they assume that each cluster senses similar data from its own part of the field, to prevent redundant data, they assume only one TO sensor node from each cluster operates in the network. Then, the problem transformed to find the optimal position of the CH in the network, this is achieved using particle swarm optimization (PSO).

J. Singh, et al. in 2021 [27]: The authors proposed a clustering approach to obtain uniform size clusters (USCs) and reduce the intra-cluster communication distance, hence increasing the lifetime of the network. They compared their proposed approach (LEACH-USCs) with [10, 24] in terms of the number of sensor nodes in each cluster, the intra-cluster distance, and the lifetime of the network (in terms of first node death, half node death, and last node death). The selection of the CHs is similar to [10, 24] after which the formation of clusters begins, as the sensor nodes join the nearest CH. Each cluster after this step contains

Table 1. Comparison summary among a few energy-efficiency algorithms in WSNs presented in the literature.

| Method | Main advantage/disadvantage |
|---|---|
| EELP | EELP provides secure communication, reduce message delay, maintain energy efficiency, and outperform LEACH protocol. |
| EUCRP | EUCRP balances the energy consumption of the network to extend the lifetime of the network. |
| EESSTBRP | EESSTBRP is used to minimize energy consumption of the network. Each two closely spaced sensor nodes operate in turns to prevent data duplication, and outperform the PEGASIS protocol. |
| PEGASIS | PEGASIS is used to improve the lifetime of the sensor nodes in the network by creating a chain that connect all sensor nodes in the network. |
| LEACH | LEACH is a clustering-based protocol that is used to minimize the energy consumption of the network. |
| LEACH-C | LEACH-C is used to minimize the energy consumption of the network. it outperforms the LEACH protocol in terms of the network lifetime. |
| O-LEACH | O-LEACH outperforms the LEACH and LEACH-C in terms of the network stability. |
| ESCHS | ESCHS is better than LEACH protocol in terms of energy saving in each transmission round and the first sensor node to die. |
| CCGA | CCGA is a clustering approach based on CH, and it achieves better clustering and network lifetime compared to conventional approaches. |

a different number of sensor nodes. Then the cluster refurbishes phase beginning, as the sensor nodes of large clusters try to join to other clusters based on the second best choice CH. Simulation results show that the LEACH-USCs outperforms the comparative methods.

Z. Hammodi, et al in 2021 [28]: The authors proposed a model that addresses the presence of obstacles in the sensing environment that may lead to a break in communication between the sensor nodes and its CH due to the lack of line-of-sight between them. The authors divide the sensing field into two groups according to the availability of the line-of-sight between the sensor nodes using graph partitioning algorithm. Their model ensures no data redundancy as well as reduced energy consumption by dividing each group into ten clusters, where only one sensor node from each cluster will operate at a higher energy, representing the energy of all sensor nodes in its cluster. Their model also ensures that there is a line-of-sight between each sensor node and its CH.

## 4. Challenges and practical implications

In WSNs, sensor nodes are usually equipped with limited, non-rechargeable, and non-renewable power supplies, especially in hard-to-reach environments. This power limitation imposes a practical challenge that researchers face in the field deployment of sensors, which is to keep the network running for as long time as possible by reducing the energy consumption in the network. This can be realized by the use of different types of technologies, such as the method of network partitioning, as well as finding the optimal location of the CHs. In this review paper, we highlighted several of these techniques and brought them together in one place.

Another important practical challenge is the real implementation of the energy-saving algorithm. Practically, these algorithms need to consider a more complex energy model than the one used in Eq. (1) to capture several other wireless channel impairments, such as the possible fading and the additive channel noise, in addition to the path loss, and antenna gain if directional antennas are used.

## 5. Conclusions and future research directions

Energy optimization is a crucial topic in WSNs with energy-limited nodes. Thus, several methods have been proposed in the literature to minimize the energy consumed by the sensor nodes and prolong the lifetime of the network. This paper presents a review of a broad set of research articles that deal with this problem and compare different techniques used to optimize energy efficiency and extend the lifetime of WSNs. From the discussed literature, we notice that the main parameters that largely affect the rate of energy consumption of sensor nodes in WSNs are the clustering mechanism, the residual energy of the sensor nodes, and the optimal location of the CHs.

We think that the literature lacks advanced approaches that handle the presence of obstacles in the monitoring field. This type of scenarios requires a new mathematical model to capture the effect of the obstacles on the communication links between the source and destination points. In addition, the standard approaches presented in the literature cannot capture the stochastic nature of environments at which the sensor nodes are deployed in a field with non-stationary or movable objects. The object statistics, as part of the sensing field, need to be specifically modeled or learned to maintain a working WSN with energy optimization capability.

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## Conflicts of interest

The authors declare no conflict of interest.

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