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Review

Energy-Efficient Routing Protocols for Wireless Sensor Networks: Architectures, Strategies, and Performance

Trupti Mayee Behera [1], Umesh Chandra Samal [1], Sushanta Kumar Mohapatra [1], Mohammad S. Khan [2], Bhargav Appasani [1], Nicu Bizon [3,4,5,*] and Phatiphat Thounthong [6,7]

1 School of Electronics Engineering, KIIT University, Bhubaneswar 751024, Odisha, India; truptifet@kiit.ac.in (T.M.B.); umesh.samalfet@kiit.ac.in (U.C.S.); skmctc74@gmail.com (S.K.M.); bhargav.appasanifet@kiit.ac.in (B.A.)
2 Department of Computer & Information Sciences, East Tennessee State University, Johnson City, TN 37614, USA; adhoc.khan@gmail.com
3 Faculty of Electronics, Communication and Computers, University of Pitesti, 110040 Pitesti, Romania
4 ICSI Energy, National Research and Development Institute for Cryogenic and Isotopic Technologies, 240050 Ramnicu Valcea, Romania
5 Doctoral School, Polytechnic University of Bucharest, 313 Splaiul Independentei, 060042 Bucharest, Romania
6 Renewable Energy Research Centre (RERC), Faculty of Technical Education, King Mongkut's University of Technology North Bangkok, Bangkok 10800, Thailand; phatiphat.t@fte.kmutnb.ac.th
7 Group of Research in Electrical Engineering of Nancy (GREEN), University of Lorraine-GREEN, 54052 Nancy, France
* Correspondence: nicu.bizon@upit.ro

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Abstract: Recent developments in low-power communication and signal processing technologies have led to the extensive implementation of wireless sensor networks (WSNs). In a WSN environment, cluster formation and cluster head (CH) selection consume significant energy. Typically, the CH is chosen probabilistically, without considering the real-time factors such as the remaining energy, number of clusters, distance, location, and number of functional nodes to boost network lifetime. Based on the real-time issues, different strategies must be incorporated to design a generic protocol suited for applications such as environment and health monitoring, animal tracking, and home automation. Elementary protocols such as LEACH and centralized-LEACH are well proven, but gradually limitations evolved due to increasing desire and need for proper modification over time. Since the selection of CHs has always been an important criterion for clustered networks, this paper overviews the modifications in the threshold value of CH selection in the network. With the evolution of bio-inspired algorithms, the CH selection has also been enhanced considering the behavior of the network. This paper includes a brief description of LEACH-based and bio-inspired protocols, their pros and cons, assumptions, and the criteria of CH selection. Finally, the performance factors such as longevity, scalability, and packet delivery ratio of various protocols are compared and discussed.

Keywords: WSN; clustering; hierarchical routing; LEACH protocol; threshold-based CH selection

1. Introduction

Wireless sensor networks (WSN) have acquired intensive popularity due to the wide range of applications in different fields. A recent emerging application is the Internet of Things (IoT), which allows the interconnection of different objects or devices through the world of the Internet [1,2]. About 5 billion intelligent devices are already connected, and the number is increasing quickly worldwide [3–5]. The number of people interacting can exceed the number of virtual devices that connect to them. As a result, significant traffic will be generated in which humans are the slightest contributor to this traffic [6].

WSNs are of two types, namely, homogenous and heterogeneous [7]. In a homogeneous network, nodes are identical. Resource heterogeneity in WSN can be divided into three categories: Computational, Link, and Energy [8]. Computational heterogeneity describes those networks where nodes differ in microprocessor's power and storage capacity. Hence, the powerful nodes can perform complex data processing and long-term storage. When nodes differ with bandwidth, the networks come under the link heterogeneity category and are suitable for reliable data transmission. Both link and computational heterogeneity consume a considerable amount of energy, reducing the network lifetime. Hence, the type of WSN must be worked out, where nodes are differentiated in terms of battery power.

The energy source consists of limited battery power, which is one of the major challenges in designing any sensor network [9]. The nodes may be deployed over a hostile location owing to the application that makes the battery recharging almost unmanageable [10]. Moreover, the nodes are expected to perform data acquisition for an indefinite time to achieve the application requirements. Hence, many researchers are currently engaged in exploring various techniques to extend the network lifetime to achieve high quality of service by balancing the energy consumption over the network [11].

When WSN is applied on larger platforms, topology control becomes an important parameter in balancing the network load to enhance the network lifetime and scalability. Clustering is an energy-efficient method for the hierarchical organization of sensor nodes in a network [12,13]. However, each node in an ad hoc network communicating directly with the sink node leads to problems such as data collision, network congestion, and unnecessary drainage of power [14]. Low Energy Adaptive Clustering Hierarchy (LEACH) [15] is a classical cluster-based protocol proposed to minimize energy consumption by efficiently selecting cluster heads. Forming small clusters within the network helps overcome these crucial issues through efficient resource utilization. For each cluster, a cluster head (CH) is elected to act as a hop between the sensing nodes and the sink (as shown in Figure 1), thereby reducing the transmission distance. The CHs are elected dynamically after a certain interval to reduce the overhead. Once the CHs are elected, they broadcast an ADV message using the CSMA MAC protocol (see Figure 2a). Based on the RSSI of the ADV message, the nodes decide which CH wants to join for the current round and send a REQ message back to it using CSMA MAC protocol (see Figure 2b).

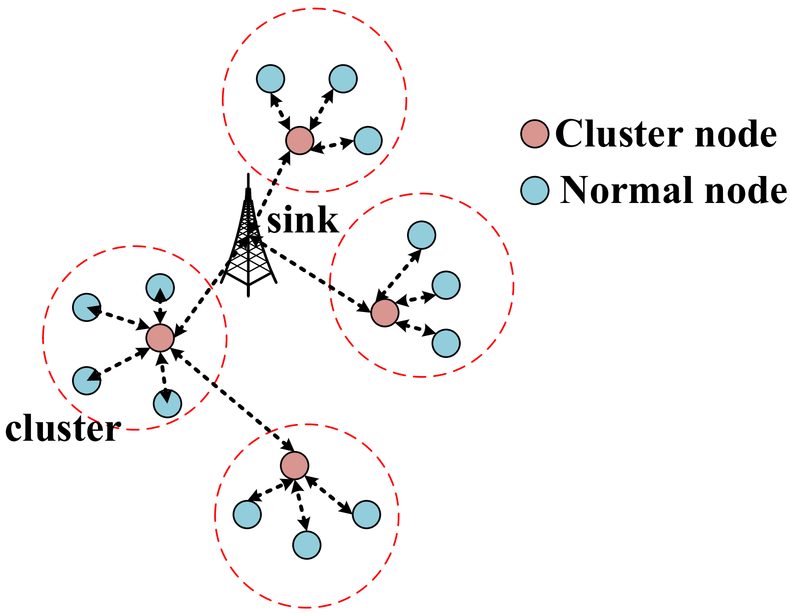
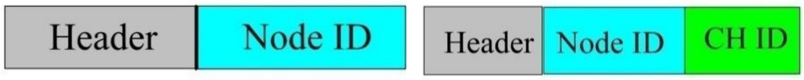


Figure 1. Clustered-based WSN.



(a) (b)

Figure 2. (**a**) ADV message. (**b**) REQ message.

The clustered network helps the system to maintain a longer life term by scheduling a duty cycle between nodes in a cluster without affecting the normal functionalities of the network [16]. The CH sets a time division multiple access (TDMA) schedule for data transmission to prevent any collision of messages. The non-CH node sends its data to the respective CHs with the DSSS (Direct Sequence Spread Spectrum) communication, in which each cluster has its unique propagation code to reduce interference. The CHs add received data and send it to BS through a fixed propagation code with CSMA.

Energy-saving is the utmost priority of a sensor network [17]. Different methods have been adopted according to the requirement of the application and user. The characteristics of WSN-based IoT diverges from traditional network paradigms such as the Internet and even from ad hoc network [18]. Unlike ad hoc networks, WSNs designed for IoT applications confront a slew of additional hurdles, including node density, hardware, communication mode, battery capacity, and computational cost, to mention a few. In an IoT paradigm, nodes are given additional functions and must overcome new hurdles in terms of security, QoS (Quality of Service), and energy management [19]. Ring routing, as proposed by Tunca et al. [20], targets to reduce overhead by introducing mobile sink nodes. These concerns can be alleviated by implementing various technology upgrades in traditional WSN methods and schemes. The potential applications of WSN-based IoT required data to be sent to the user with a minimum delay to provide an immediate response to an event, as in the case of tracking. The query response time in a WSN is another key factor in applications such as forest fire detection. Mobile forest fire patrol units can inject queries into the WSN to monitor environmental variables such as temperature and humidity. The WSN must respond to the inquiries as soon as feasible in order to speed up response to a fire and enhance fire prevention efforts [21]. The monitoring applications require successful data reception by the server irrespective of the transmission time.

WSNs were first used for military and defense applications, which further motivated researchers to explore new technologies that could enhance their performance [22]. The main domains of applications of the WSNs are as follows:

(a) Environment monitoring: Since the attention on sustainable energy solutions has increased substantially, smart technologies for energy conservation have gained importance. Monitoring environmental conditions have been one of the popular applications of WSN that controls and manages services such as air, water, and soil monitoring [23,24]. This network allows the end-user to gather data at a resolution located in areas where accessing data is otherwise difficult. Moreover, long-term monitoring is required to obtain sufficient information to decide.

(b) Home Application: With the expansion of WSN integrated IoT, tiny sensor nodes can be implanted into household equipment such as electric appliances and furniture to access from a remote place [25]. For instance, the nodes can be incorporated into microwave ovens, vacuum cleaners, washing machines, and even air conditioners that can be connected to a room server. Such arrangements are self-manageable and require minimal human interventions to frame a smart home structure.

(c) Healthcare Application: Driven by the convergence of data collection regarding the health of people and maintaining accuracy in collected information with minimal cost, WSN for healthcare has evolved in recent years [26]. Researchers have invented a new branch of WSN exclusive for healthcare, called Body Area Network (BAN), that provides better treatment at a lesser cost. BAN is administered to monitor patients' physiological, cognitive, and psychological information.

(d) Tracking and Military Application: Battlefield surveillance was a wireless medium's most critical application of sensor networks. Characteristics such as self-association, fast organization, and well adaptation to node failures make WSN an extremely desired sensing technique for military applications [27]. Sensor nodes could be located in remote areas to sense and receive data as long as possible that can alert the user about possible blast location, enemy positions, and chemical attacks.
(e) Transportation: WSN helps drivers alert any congestion or traffic problem by regularly monitoring traffic statistics. Vehicular motions can be tracked instantaneously to avoid any blockage or accidents [28]. WSN also reduces the length of the wiring harness and saves time with the cost of its installation.
(f) Industrial Applications: WSNs offer momentous cost reductions and investments that allow innovative functionalities for industry-based technologies. Continuous sensing of the environment, condition monitoring, and process automation are some of the requirements of Industrial WSN [29]. The solutions need to be simple to use and install yet versatile with low-cost devices and a long lifetime.

1.1. Related Work

Inspired by the classical LEACH protocol, numerous hierarchical clustering protocols have evolved over the years that apply different factors to achieve better performances. Different clustering approaches in [30] analyze several clustering methodologies and categorizes current clustering into meta-heuristic, fuzzy logic, and hybrid based on network organization and clustering management strategies. Similarly, Ref. [31] compared the optimized clustering methods based on a few parameters and suggested the best approaches to a WSN application. An in-depth examination of LEACH-based protocols is discussed in [30], where it first focuses on cluster formation and CHs selection techniques and their benefits and drawbacks. As shown in Table 1, several reviews and surveys have focused on LEACH variants and successors.

Table 1. Survey on LEACH-based Protocols.

Reference	Description	Remarks
Daanoune et al. [32], 2021	Classified LEACH-based protocols based on CH selection, data transmission, and both CH selection and data transmission techniques	Discusses the strength and weaknesses of LEACH-based protocols but fails to study bio-inspired LEACH variants
Bhagat et al. [33], 2020	Reviews LEACH successors based on single-hop and multi-hop models	Categorizes LEACH protocols based on the path of data transmission from CH to BS
Guleria et al. [34], 2019	Classification is conducted based on classical and swarm-intelligence approaches	Handling sink mobility, QoS requirement, and overhead due to dynamic topology in an energy constraint environment are still major issues
Prasad et al. [35], 2018	Analysis of different hierarchical routing protocols that are modified from LEACH based on energy efficiency only	Does not provide any information about the method or modification in detail
Singh et al. [36], 2017	Classification of LEACH successors based on single-hop and multi-hop communication is conducted, and comprehensive studies have been provided	The survey presents a detailed summary but fails to inform about the simulation or testing tool, or software used in network analysis
Sabor et al. [37], 2017	Survey on classical-based and optimized-based routing protocols for mobile WSNs	Real-work implantations, overheads, and computational time have not been explored
Arora et al. [38], 2016	LEACH and its extensions were discussed and compared that prolong network lifespan. The survey is not limited to proactive protocols and also focuses on reactive protocols such as TEEN [39], APTEEN [40], and TSEP [41]	The authors prove enhanced network lifetime with increased network area and distance to BS. However, the comparison conducted considered only a few protocols and variants of LEACH

Table 1. *Cont.*

Reference	Description	Remarks
Mahapatra et al. [42], 2015	The timeline of LEACH and its descendants are compared based on selected features such as scalability and mobility	Compares considering a few parameters
Dhawan et al. [43], 2014	Performance comparisons between LEACH protocol variants are made	Less number of examples discussed
Tyagi et al. [44], 2013	Highlights advantages and disadvantages of various routing protocols inspired by LEACH where CH selection plays an important role.	A brief comparison in terms of the CH selection process, load balancing, routing, and security
Bhattacharjee et al. [45], 2013	Performance measurements of energy-efficient protocols conducted	Improvement regarding application-specific deployment of nodes needs to be conducted
X Liu [46], 2012	A comprehensive survey of clustering routing protocols is conducted	Gives an idea about possible future research directions
Ramesh [47], 2012	Comparative study of CH selection algorithm	Scalability and stability factors are not explored

Nevertheless, it will be important to mention that all the reviews mentioned in Table 1 highlight the limited number of LEACH descendants compared to a few parameters. From the literature, it can be concluded that CH selection is the key parameter used by researchers to enhance the performance of any clustering algorithm. Throughout the process of CH selection, residual energy and the number of clusters in the network should be of paramount importance [48]. Other issues found in conventional clustering algorithms can be described as shown in Figure 3. Apart from these, network security is one of the key issues and various routing protocols have been suggested to make the network resilient against insider and outsider attackers [49]. Applications using wireless sensors need to be protected from packet insertion, modification, and eavesdropping. Data cryptography and encryption can avoid these security problems to protect against these issues.

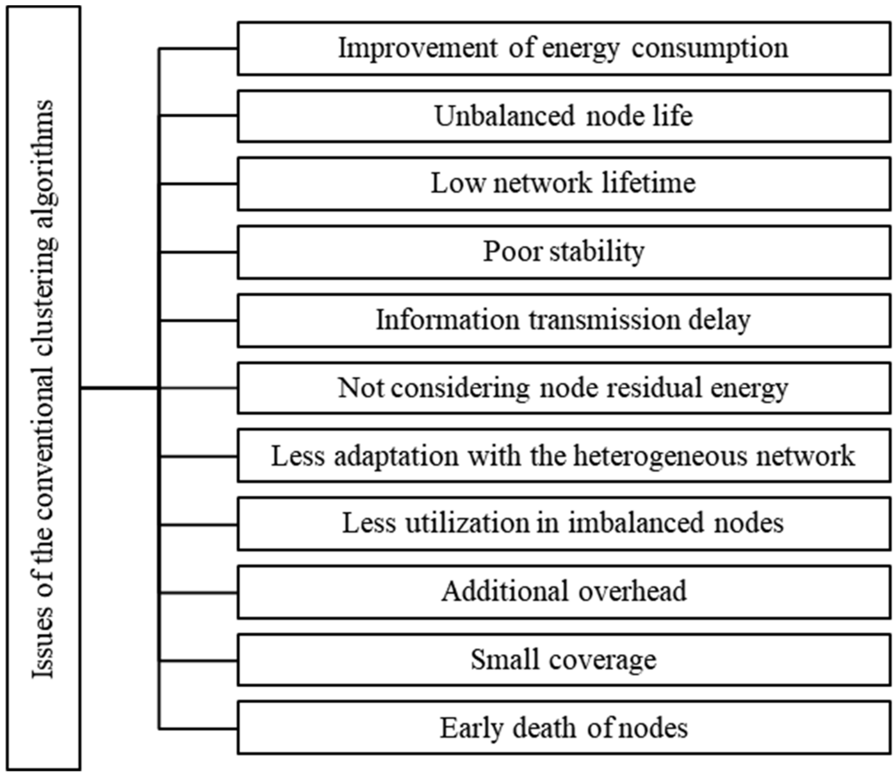


Figure 3. Issues of clustering protocols.

Hence, to overcome these problems, several algorithms have been proposed. As far as possible, this article intends to present a more comprehensive survey that discusses a wide range of routing protocols that will help researchers gain knowledge about routing protocols to work in proper future directions. The classification of routing protocols is performed based on a homogenous and heterogeneous environment suitable for the specific application. A homogeneous WSN consists of nodes with the same initial energy, and a heterogeneous sensor network contains nodes of two or more energy levels. The type of network can be chosen depending on the requirement of the application.

1.2. Organization of the Paper

The rest of the paper is structured as follows: Section 2 presents an overview of WSN, the node architecture, its design criteria, clustering strategies, and methods to overcome the issues. The classical routing LEACH and its successors in terms of CH selection are discussed in Section 3. The bio-inspired algorithms associated with the LEACH protocols are highlighted in Section 4. The performance analysis and discussion are presented in Section 5, followed by the conclusion and future perspectives on clustering protocols in Section 6.

2. Overview

WSN is a bridge element that combines the digital virtual world with the real world [50,51]. A WSN is formed by collecting many sensors called nodes, which have limited computing, sensing, and communication functionaries. The sensor nodes are implemented in a geographical area for monitoring physical phenomena such as humidity, temperature, and vibrations [52,53]. The nodes are small devices with essential components, such as the detection, processing, and communication of subsystems and a power supply unit, as shown in Figure 4.

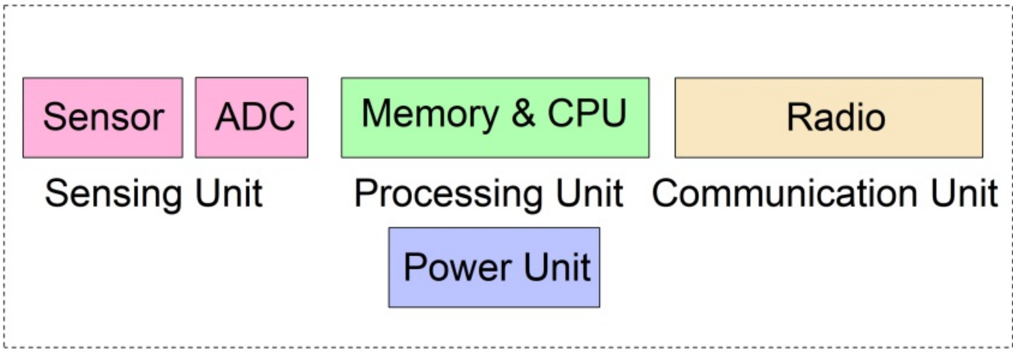


Figure 4. Sensor node structure.

The node architecture shown in Figure 4 has four important units. Sensors and an ADC (analog to digital converter) constitute the sensing unit. The analog signals generated by sensors are converted to their digital form by the ADC and are then forwarded to the processing unit, which consists of a memory-equipped microprocessor or microcontroller. The processing unit is also responsible for controlling the sensor nodes intelligently. Data transmission and reception via a radio frequency (RF) channel are handled by the communication unit. It also connects the nodes to the rest of the network. The most vital component is the power unit containing a battery that supplies energy to all the components of the system. Taking into account the low cost of production and energy consumption, these units are integrated into a small module. There can be other sub-units of the node that are application dependents such as a power generator, location finding system, and a mobilizer.

2.1. Energy Consumption in WSN

Researchers consider various approaches to prolong network lifetime in WSNs because sensors become inaccessible after deployment. Hence, energy reduction is an essential criterion in the design process of a sensor network [54]. The protocol stack for WSN is given in Figure 5 with five distinct layers. Energy minimization approaches in WSN can be analyzed in each layer.

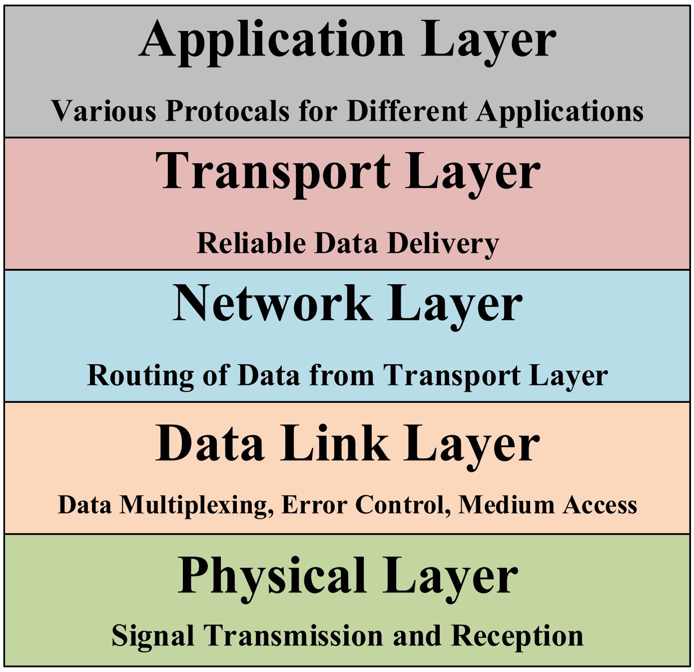


Figure 5. Protocol stack for WSN.

Physical Layer: To receive and transfer data collected from the hardware, the physical layer must meet the needs of the receiving and transmitting device. The layer is responsible for generating and selecting the carrier frequency, signal detection, modulation and signal encryption, and signal reception. Due to the radio channel's usage for transmission and reception of data, the amount of energy consumed is significant. The channel can be operated in three distinct modes: Idle, Active, and Sleep. Consequently, the energy consumed can be minimized by shutting off the radio when the channel is idle [55].

Datalink Layer: This layer is responsible for preventing neighboring signals from interfering with each other in a noisy environment. This layer should have the appropriate access, error control, multiplexing, and error detection and correction. TDMA-based protocols have been extensively used to avoid collisions of packets. However, Halkes et al. [56] reported that their deployment in multi-hop ad-hoc networks is very complex. Another method for efficient energy management is to reduce the time between transmission of a frame and idle listening.

Network Layer: Several approaches, including topology control and routing schemes, have been adopted in this layer, increasing network lifetime. Selecting a suitable topology that could provide a well-connected network is often a difficult task. Routing plays a major role in lifetime enhancement by selecting the most energy-efficient path from sensing nodes to the base station (BS) [57]. Routing techniques can be categorized as location-based, data-centric, hierarchical, mobility-based, and quality of service (QoS)-based. However, hierarchical clustering routing algorithms have proved to be effective in enhancing lifetime and reducing power consumption by determining the optimal route.

Transport Layer: Traffic flow regulation is provided by the transport layer, which distributes network traffic to the distant end. Additionally, traffic is provided with reliability measures. It is divided into sequential segments to forward upper layer application data, which are then reassembled into data packages. The transport layer can perform flow control, congestion control, and error checking at a higher level [58].

Application Layer: The application layer serves as a connection point between users and the network services dedicated to electronic mail, file transfers, virtual terminals, and file servers [59]. Extraction of energy from the environment in solar, thermal, and vibration have evolved as the latest technologies to deal with the energy problem. Energy harvesting is emerging as an efficient technique that recharges sensors after depletion.

2.2. Clustering Strategies in WSN

Because battery power is limited, proper clustering is essential for significantly extending the network's life span. To perform clustering, there are many methods to choose from [60]. The clustering strategies in WSN [61] can be classified as shown in Figure 6.

(a) Deterministic: Here, the CHs are set at fixed positions in the network [62]. The sensors broadcast a HELLO message to their neighbors, and the node that first receives the maximum number of these messages is elected as CHs and initiates the cluster formation phase. The important attributes of these clustering schemes are node identity numbers (IDs) and node degree (number of neighboring nodes).

(b) Adaptive: Instead of random CH selection, adaptive clustering schemes are based on the selection of CH considering particular parameters, such as remnant energy, the distance between nodes, energy dissipated in the last round, and distance to BS [63]. Specific combinations of these parameters form the objective function for CH selection that can adapt to the rapid variations in the network. Adaptive schemes can be further categorized as BS-assisted or probabilistic (self-organized) based on who has the power to initiate the CH selection process. Again, considering the parameters for the role of a sensor node, the probabilistic scheme can be classified as resource adaptive and fixed parameters.

(c) Hybrid: This clustering strategy considers combined clustering metrics with other architectures to increase energy efficiency.

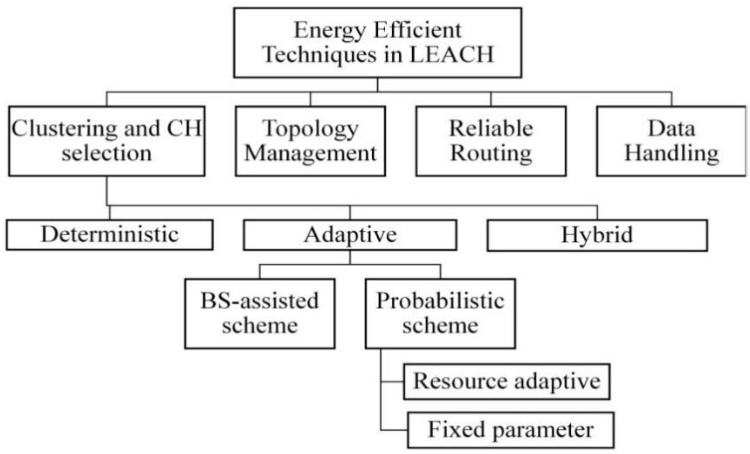


Figure 6. Taxonomy of clustering strategies.

3. Classical Routing Protocols

Due to the network being homogenous, nodes will be identical in terms of hardware complexity and battery energy. In these networks, static clustering has been used only. This implementation utilizes a single network topology, and it is not complicated. However, the most significant drawback of a homogeneous sensor network is that all network nodes may be able to act as cluster heads, which means they must have the hardware capabilities to meet the hardware requirements [64]. Since energy is an extremely critical resource, various routing protocols have been proposed to minimize the energy consumption at different levels of the network [65].

3.1. LEACH

Low Energy Adaptive Clustering Hierarchy (LEACH) [66,67] is a TDMA-based medium access control (MAC) protocol that uses a clustering strategy to ensure uniform energy distribution among sensors on the network. The sensor nodes are organized in groups, transmitting important data to the BS through the CH. As indicated in Figure 7, the end-users can receive data through the core network via the Internet. Additionally, the data transmission modes in cluster-based networks can be categorized into three types [12]: intra-cluster, inter-cluster, and long-haul communication. When cluster members transmit data to their respective CHs according to TDMA scheduling, then it is called intra-cluster transmission. The data exchange between CHs is managed through inter-cluster transmission. Finally, the CH sends their combined data to the BS in the long-haul transmission method.

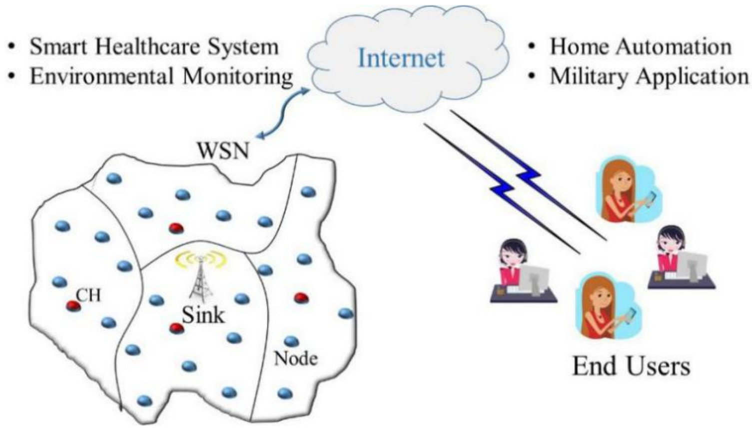


Figure 7. System model of a clustered sensor network.

The LEACH protocol operation consists of several rounds, where each round consists of two broad phases, i.e., the setup phase and steady-state phase, as shown in Figure 8.

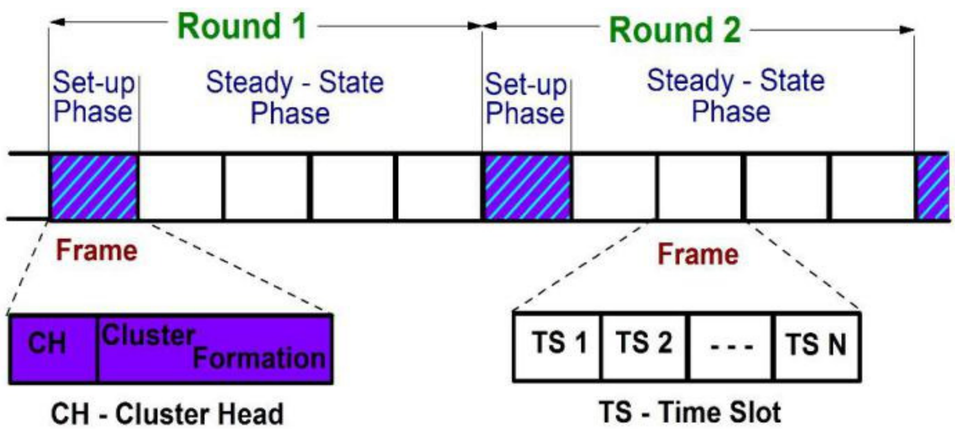


Figure 8. Phases of LEACH protocol.

The initial setup phase consists of clustering and CH selection. Each cluster node is involved by a random value generated in the window [0, 1] during the CH selection process [68]. The node will be declared CH if the number generated is lower than the member node's predefined $T(n)$ value. Equation (1) indicates the value of the $T(n)$ threshold. The CH is also responsible for assigning TDMA schedules for the corresponding cluster members.

$$T(n) = \begin{cases} \frac{P}{1-P\left(r mod \frac{1}{P}\right)}; \forall\, n \in G \\ 0;\ Otherwise \end{cases} \tag{1}$$

where, P is the desired percentage of sensor nodes which may be CH, r refers to the current round, and G to a set of nodes that in the previous $1/P$ rounds have not been involved in the CH selection. Since only these nodes participate in the CH selection process, which in the last $1/P$ rounds was not CH, every sensor node of a cluster is therefore equally likely to become CH. The energy dissipation between the sensor nodes is therefore spread uniformly over the network.

During the steady-state stage, cluster nodes will transmit sensed data based on the assigned TDMA schedule to their respective CH nodes. The nodes can transmit data only during a particular time slot; all other nodes go to sleep state by switching off their radios. In this way, the intra-cluster collision can be avoided. The main objective of the LEACH protocol is to increase energy efficiency by adopting a rotation-based CH selection procedure using a random number.

3.1.1. Advantages of LEACH

1. The concept of clustering in LEACH effectively increases the network lifetime;
2. Traffic reduction due to aggregation of data at the cluster head level;
3. One-hop data routing from node to CH reduces energy consumption;
4. Global knowledge of the network is not required as LEACH is a distributed protocol, and BS does not control nodes in cluster formation.
5. Intra-cluster collisions are avoided due to the allocation of TDMA slots for data transfer.

3.1.2. Disadvantages of LEACH

1. Due to the random selection of CH, the probability of CH election remains the same for each node, indicating that the probability of a node with high residual and low residual energy remains the same [69]. However, if a low residual energy node gets elected as CH, it will eventually limit the network lifetime to a short span;
2. The number of CHs in each round varies randomly in LEACH. Moreover, the position of CH is not fixed and may be centrally or boundary placed [70]. This will eventually contribute to extra energy consumption in cluster-level communication and degrade network performance;
3. CHs have responsibilities such as data collection, aggregation, and transfer to BS. Hence, it is very likely that the CHs will deplete energy faster than other nodes [71]. Moreover, if a CH fails, all the member nodes connected to it will run out of power, resulting in a broken network;
4. The CHs communicate with the BS in a single-hop mode, making LEACH not preferably used in large-scale wireless sensor networks [72].

3.2. Modification of LEACH Based on CH Selection

Over time, several improvements have been incorporated into the LEACH protocol considering various parameters to enhance network performance [73]. Researchers have mainly focused on enhancing the CH selection criteria and the clustering process that prove to conserve energy more efficiently.

3.2.1. LEACH-C

In LEACH Centralized, proposed by Heinzelman [67], the base station performs decisions for cluster formation, CH selection, and data distributions. It ensured uniform energy distribution among all sensor nodes and created better clusters than LEACH. The overhead during the cluster formation phase is reduced due to control by BS. CH selection process considers residual energy and evaluates the optimal number of clusters K using the formula

$$K = \sqrt{\frac{N \in_{fs}}{2\Pi \in_{mp}} \frac{M}{d_{toBS}^2}} \tag{2}$$

The node distance to BS is given as d_{toBS} and M is the sensing area of interest. The BS communicates the CH ID to each node, and if the CH id matches a sensor node, it is declared as CH; otherwise, it behaves like a normal node. To achieve this, the location of each node is known to BS with the help of a Global Positioning System (GPS) receiver. The steady-state phase is the same as that of the LEACH protocol. Since the entire process is controlled and processed by *BS*, LEACH-C has proved more energy-efficient than LEACH. However, the usage of GPS increases the cost and also consumes energy.

3.2.2. LEACH-DCS

The stochastic CH selection in LEACH is enhanced in [68], which modifies the CH selection threshold using a deterministic approach. Two modifications of $T(n)$ have been considered to enhance the network lifetime. The first approach multiplies the remaining battery power level ($E_{current}$) of each node and is given as:

$$T(n) = \frac{P}{1 - P\left(rmod\frac{1}{P}\right)} \times \frac{E_{current}}{E_{max}} \tag{3}$$

where E_{max} is the initial node energy. However, after a few rounds, the network becomes stuck, with nodes having high energy levels alive for data transmission. Hence, the $T(n)$ value is further expanded as:

$$T(n) = \frac{P}{1 - P\left(rmod\frac{1}{P}\right)} \times \left[\frac{E_{current}}{E_{max}\left(r_s div\frac{1}{P}\right)\left(1 - \frac{E_{current}}{E_{max}}\right)}\right] \tag{4}$$

where r_s represents the number of consecutive rounds in which a node has not acted as CH. The method proved to be energy efficient as nodes themselves decide to be the CH, as no global information needs to be stored in BS. With the modified values of $T(n)$, the network lifetime was enhanced by 30%, but the frequent cluster formation process degraded the network performance and demanded recursive cluster maintenance.

3.2.3. Solar-Aware Distributed LEACH

Since battery-driven sensor nodes run out of power faster, Voigt et al. [74] proposed solar-operated WSN and imposed it on a LEACH environment. The preferable candidates for CHs are given to solar-driven nodes only, while battery-driven nodes act as member nodes [75]. Hence, the threshold for CH selection needs to be changed to increase the probability of solar-operated nodes and is given as:

$$T(n) = sf(n) \times \frac{P}{1 - \left(\frac{CHeads}{numNodes}\right)} \tag{5}$$

where *CHeads* is the number of CHs since the start of the last *(1/P)* round and *numNodes* is the total number of nodes, $sf(n)$ is a scaling factor higher than 1 for solar-operated nodes and is set to reciprocal for battery-operated nodes. The introduction of solar-aware WSN increased the network lifetime for typical scenarios as compared to centralized LEACH.

3.2.4. Multi-Hop LEACH

A simple multi-hop routing protocol was proposed by Xiangning et al. [72] that selects CH based on the residual energy of each node. In the first round, the CH is selected randomly; the node with the highest residual energy acts as CH, and so on. Since all the CHs send data to BS directly irrespective of its distance in LEACH, much energy becomes consumed. Hence, in this multi-hop protocol, an optimal path is selected, and each CH sends its data to the node nearest to the sink. Both modifications enhanced the energy consumption and node lifetime more than the LEACH protocol.

3.2.5. A-LEACH

LEACH protocol was modified by Abuhelaleh [76] to achieve better security with less energy consumption and minimal data overhead. The protocol combines the features of Security-LEACH [77] and the Time-controlled Clustering Algorithm (TCCA) [78] that protects the network from various attacks such as sinkhole and selective forwarding attacks. The TCCA forms multi-hop clusters using timestamp and time-to-live (TTL) messages. To decide the eligibility of a node to become CH, TCCA adds some modifications to the threshold value as given in (6):

$$T(n) = \begin{cases} max\left(\frac{P}{1-P\left(rmod\frac{1}{P}\right)} \times \frac{RE}{E_{max}},\ T_{min}\right); \forall n \in G \\ 0 \qquad\qquad\qquad\qquad\qquad\qquad ;\ \text{Otherwise} \end{cases} \tag{6}$$

where T_{min} is the minimum value of the threshold to avoid the residual energy (RE) shortage. After the CH selection, it sends an ADV message to become its member, as shown in Figure 9. The nodes whose TTL value matches join the CH to form a cluster by sensing a REQ message consisting of the original timestamp and the remaining TTL value.

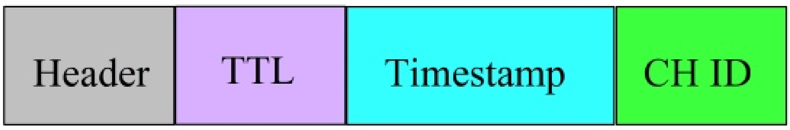


Figure 9. ADV message.

Compared to LEACH, Sec-LEACH, and TCCA, it was found that A-LEACH outperforms in terms of energy consumption and lifetime. Moreover, the protocol protects the network from sinkholes, jamming, and replay attacks. However, the only disadvantage of this protocol is the wastage of bandwidth due to the exchange of large control packets.

3.2.6. T-LEACH

T-LEACH, a CH replacement protocol based on a threshold value, was discussed in [70]. As CHs change in each round for most of the clustering protocols, a huge amount of energy is consumed during exchanging message signals. T-LEACH comes with a solution where the same CH operates for consecutive rounds if it has sufficient residual energy. A threshold value is calculated, and only if a CH has residual energy below it, the new CHs selection process starts. It reduces the number of times a CH selection process is conducted by considering a threshold of residual energy. This reduces the cost of CH replacement and enhances the network lifetime. However, the process leads to uneven energy consumption and generates control overhead. The T-LEACH is further modified as MT-CHR [79], which modifies the threshold so that the death of the first node is further delayed and reduces overhead. The threshold energy to retain the CH is given as

$$E_{Th} = Count_{RND} \times E_{TX} \times q + 5 \times ADRSE \tag{7}$$

$$ADRSE = \underbrace{E_{RX\_elec} \times q \times \left(\frac{N}{k} - 1\right)}_{\text{Received power per cluster}} + \underbrace{q \times \frac{N}{k} \times \left(E_{TX\_elec} + \varepsilon_{amp} d^{m}\right)}_{\text{Transmit power to BS}} \tag{8}$$

E_{TX} is the total energy of the transmitting node, and $ADRSE$ is the approximated data transmitting and receiving energy. The multiplying factor 5 is chosen experimentally from the range 1 to 10, giving maximized performance metrics [75]. Since no setup is required in every round, the control overhead is considerably reduced, thereby giving better performance than T-LEACH.

3.2.7. Improved-LEACH

The hotspot problem in single-hop communication such as LEACH is overcome using an unequal clustering scheme [80] in the LEACH protocol. Since CHs in the LEACH protocol transmit data directly to BS, leading to the death of nodes located farther from BS. Hence, the authors here consider clusters of unequal concentric circles so that the cluster size would decrease with distance from BS. The CH is selected considering residual energy, weight factor, and distance as major parameters. Simulation results proved improved network lifetime but do not discuss other factors such as throughput, average residual energy, and network stability.

3.2.8. LEACH-SWDN

A dynamic method of CH selection is proposed by Wang et al. in [81], where a sliding window is set up for the election probability of nodes. A random number is generated between 0 to (E_{avg}/E_{max}) during the setup state by each node. E_{avg} is the average energy level of nodes that are never elected as CH and E_{max} is the initial node energy. In a network of k clusters and N sensors, a node is declared CH only if the generated number is less than a threshold $P(i)$ given as

$$T(n) = \begin{cases} \frac{k}{N-k\left(r mod \frac{N}{k}\right)} \frac{E_{current}}{E_{max}} & \\ 0 & ; C(t) = 0 \end{cases} \tag{9}$$

The non-CH node of the present round sends its remaining energy information to the CH of the last slot, which is then forwarded to the *BS* for *Eavg* calculation. The simulation result shows improved network metrics such as FND and HND that are 41% and 36% higher than LEACH. However, repeated transfer of residual energy information increases the network load.

3.2.9. MOD-LEACH

Another modification of LEACH is proposed in [82], which segregates the intra and inter-cluster communication by allocating two different signal amplifications. Since intra-cluster communication deals with the transfer of information between nodes, a low amplification signal is allocated. On the other hand, inter-cluster communication is the transfer between CHs, and a high amplification signal is chosen.

The protocol was further modified as EMOD-LEACH by Singh et al. in [83] using dual transmitting energy levels. EMOD-LEACH is a reactive protocol that uses two threshold values: a soft and a hard threshold. The hard threshold is the absolute sensed value, and the soft threshold is the minor change in the sensed value attribute. If the energy of a CH falls below the threshold value, then only that CH gets replaced in the next round. As a result, the network longevity increases due to optimal data transmission. Both MOD-LEACH and EMOD-LEACH perform better in terms of power consumption and network lifetime. However, synchronization is a significant issue in these protocols due to different signal amplifications.

3.2.10. EC-LEACH

Bsoul et al. [84] proposed a variant of LEACH based on a centralized approach with a multi-hop clustering methodology. The CH selection process is conducted by *BS* by calculating threshold $T(n)$ using Equation (12).

$$T(n) = \frac{R_E(n)}{\sum_{i=1}^{m} \frac{d(i,m)}{R_E(i)}} \tag{10}$$

The residual energy of each node is $R_E(n)$ and $d(i,n)$ is the distance of node i to node n in a network of m nodes. The node with the highest value of $T(n)$ is selected as the CH and then its distance from the node with second-highest $T(n)$ is computed. This leads to the following two possibilities:

- If this distance is greater than or equal to the minimum distance between every CH and the next (MDCH), then the second-highest $T(n)$ node is declared as CH.
- If this distance is lesser than the minimum distance between every CH and the next (MDCH), the BS does not select any of these nodes as CH.

As a result, a node with less energy will never be chosen as CH, saving significant amounts of energy. However, the protocol suffers a problem with scalability and extra overhead.

3.2.11. LEACH-MAC

In the LEACH protocol, an optimum value of CHs is pre-defined. However, the number varies randomly in a clustering algorithm. This randomness in LEACH is controlled in LEACH-MAC [85], which uses MAC layer information. The method tends to restrict the number of ADV messages of CH. When the selection of CHs starts, a variable *CHheard* is initialized to 0 and is incremented by 1 when it receives an ADV message. After the threshold value, the node selects a random time between interval [0, *total_adv_time*], where *total_adv_time* is the total time for CH transmission and reception given as

$$total\_adv\_time = adv\_time \times (Num\_of\_clusters) \times 4 + 1) \tag{11}$$

$$adv\_time = Transmission\_time \text{ of}(ControlPacket\_size \times 4) \tag{12}$$

$$Transmission\_time = \frac{(Number\_of\_bytes \times 8)}{Bandwidth} \tag{13}$$

If the selected time is R_t, then the ADV sending time t_{adv_CH} can be evaluated $t_{adv\_CH} = \frac{R_t}{CurrentEnergy}$ so that nodes with higher energy could send ADV messages earlier than those with lower energy. Then, the node checks the variable *CHheard*, to know the number of ADV messages received. If the value is less than the optimal value of clusters formulated by Equation (1), it will send the CH ADV; otherwise, it remains a normal node. LEACH_MAC performs better than ALEACH and LEACH-DCS in terms of network lifetime and energy consumption.

3.2.12. Modified-LEACH

LEACH protocol is modified for a heterogeneous network in [86], where CHs are selected from advanced nodes only. The network has two categories of nodes called normal and advanced, where the latter has higher energy than the former. After nodes are deployed, the threshold value for CH selection is set as

$$T(n) = \begin{cases} \dfrac{p \times a}{1 - a \times p[r\text{mod}(\frac{1}{p \times a})]}, n \in G \end{cases} \tag{14}$$

If the node is normal, then a = 1 and 5 otherwise. Simulation results with a network with 10% advanced nodes show that the network lifetime is considerably increased. The paper does not discuss other parameters such as stability period, throughput, and energy dissipation.

3.2.13. I-LEACH

One disadvantage of the LEACH protocol is that a new CH is selected in each round, requiring energy to form a new cluster. This also leads to excessive energy use through routing overhead, which is unacceptable for any IoT device [87]. Behera et al. [2] proposed an effective CH replacement method, which can be used to avoid extra energy during the formation of the cluster and the transmission of advertising messages to the cluster members. A threshold value is calculated, and only when the remaining energy of the CH is lower than the threshold does a new cluster and CH need to be formed; otherwise, the same CH will continue to the next round. It can be considered that the minimum energy level that is the best for the CH replacement method is evaluated as:

$$P_{Th} = Count_{Rnd}(P_{kTx} + P_{kRx})P_{Tx} \tag{15}$$

$Count_{Rnd}$ is the number of rounds to act as member nodes within a cluster. P_{kTx} and P_{kRx} are the transmission and reception packet sizes, and P_{Tx} is the power required to transmit 1 byte of data.

3.2.14. R-LEACH

The R-LEACH protocol is a variation of LEACH that chooses the CH based on two essential parameters: the individual node's remaining energy and the network's ideal number of CHs [50]. After each round, the non-CH nodes' residual energy is examined, and the one with the highest energy level in relation to the others has a higher possibility of being chosen as CH for the current round. This would prevent the network from dying out too soon, extending its lifespan. The threshold value for CH selection is modified as:

$$T(n) = \begin{cases} \frac{P}{1-P\left(rmod\frac{1}{P}\right)} \times \frac{E_{residual}}{E_{initial}} k_{opt}; for \text{ all } n \epsilon G \\ 0; \text{ Otherwise} \end{cases} \quad (16)$$

where $E_{residual}$ is the remaining energy level of the node and $E_{initial}$ is the initial assigned energy level. The optimal number of cluster k_{opt} can be written as in [88].

$$k_{opt} = \sqrt{\frac{n}{2\pi}} \sqrt{\frac{E_{fs}}{E_{amp} d^4 (2m-1) E_{initial} - m E_{DA}}} M \quad (17)$$

M is the network diameter, m is the number of CHs in each cluster and d is the distance between nodes.

The R-LEACH was further modified using Fuzzy logic to evaluate the value of k_{opt} using a Fuzzy base rule called FR-LEACH [89]. An exponential member function based on energy is used to find the number of clusters adapting to the network energy changes.

3.2.15. Enhanced LEACH

In [90], the LEACH protocol is modified to select the CH based on the lowest degree of distance from the BS, decreasing energy consumption in the network. When normal nodes select appropriate CHs located at a minimum distance from the BS, it was proved that there is reduced battery power consumption. The goal is to determine how sensitive the network is to power consumption and how long the network can last.

3.2.16. SE-LEACH

According to the authors in [91], a protocol named stability enhancement for LEACH (SE-LEACH) is proposed to expand the stable zone of WSN by balancing the load and ensuring that all nodes dissipate power in the same way. Because the most critical requirement for the job of cluster head is the best candidate selection, the selection criteria consider node density, residual energy, distance from the base station, and the candidate's power dissipation.

3.2.17. AvgRLEACH and VarRLEACH

Regarding CH selection, the threshold equation is modeled using first and second-order statistics to give prominence to network information on a local and global scale [92]. To meet this requirement, overall energy information must be collected and used to aid in selecting the CH. Not only can this help to extend the network's life by maintaining a balanced network power distribution, but it can also help increase overall throughput. To account for the average and variance of energy, the threshold was modified as in AvgRLEACH given in Equation (18) and VarRLEACH given in Equation (19), where $N_a(r)$ is the number of alive nodes in each round. $A_n(r)$ denotes the normalized average value of the node energy concerning initial energy E_0 for each round r and $V_n(r)$ is the normalized variance of the energy of nodes in round r.

$$T(n) = \frac{p}{1 - p\left(r \, mod\left(\frac{1}{p}\right)\right)}\left(\frac{E_i(r)}{E_0}\right)A_n(r)N_a(r) \tag{18}$$

$$T(n) = \frac{p}{1 - p\left(r \, mod\left(\frac{1}{p}\right)\right)}\left(\frac{E_i(r)}{E_0}\right)V_n(r)\; N_a(r) \tag{19}$$

4. Advent of Bio-Inspired Algorithms

To prolong the network lifetime of WSN, the use of routing protocols based on intelligent algorithms has been quite popular. Adaptive mechanisms that exhibit intelligent behavior in complicated and dynamic contexts, such as WSNs, are provided by a few bio-inspired algorithms [93,94]. Numerous social insect community traits, such as self-organization, self-adaptation, and cooperation, meet the most of the requirements for routing protocols for next-generation sensor networks [93]. The routing protocols in cluster-based WSNs that rely on intelligence algorithms are discussed in several papers [94].

CH-selection is an NP-hard optimization problem. Canonical optimization approaches become useless as the network grows in size. Several engineering areas are used to solve various challenging optimization problems, revealing their superiority or cost-effectiveness over existing metaheuristics such as the genetic algorithm (GA), Ant Colony Optimization (ACO), and Particle Swarm Optimization (PSO), and others. Artificial Bee Colony (ABC), ACO, and Cuckoo Search (CS) are three techniques that help the WSN network live longer. A good Swarm Intelligence (SI) algorithm improves global search and brings the global best solution closer together. GA and Krill Herd (KH) optimization algorithms are bio-inspired algorithms that work well for NP-hard problems. Furthermore, these algorithms are simple to construct and have good exploration and exploitation capabilities, leading to speedy convergences and the ability to escape from local minima. To improve this, a variety of hybrid strategies have been proposed.

4.1. PSO

The social behavior of a flock of birds inspired this algorithm. A swarm is a collection of possible solutions to an optimization problem, each referred to as a particle. The PSO aims to locate the particle position that yields the best fitness function assessment. During the PSO startup procedure, each particle is given random beginning parameters and 'flown' over the multi-dimensional search space. Each particle uses knowledge about its past best individual and global positions during each generation to increase the likelihood of shifting to a better solution space, resulting in improved fitness. The social behavior of a flock of birds inspired this algorithm. When fitness superior to the individual's best fitness is discovered, it will be utilized to replace the individual's best fitness and update the candidate [95].

PSO-based CH selection finds the fittest position for the head nodes. Clustering in WSN using PSO was proposed in [96] and implemented at BS. The cost function aims to minimize the intra-cluster distance to optimize the network's energy consumption. When compared to LEACH and LEACH-C, it was found that data delivery and lifetime were improved to a great extent.

Lobiyal et al. [97] state that the head node is in the best position only when the intra-cluster distance is minimized. The PSO-based method localizes the head nodes around the center of cluster density. The distance covered by packet transmission from a sensor node to its cluster head is computed using the optimum CH position. The PSO-based approach is semi-distributed because it runs in a cluster rather than on the BS. The objective function selection is based on intra-cluster distance, residual energy, node degree, and the number of feasible CHs. The suggested energy consumption model impacts the projected number of packet retransmissions with the approximated route to the CHs.

Rao et al. [98] considered intra-cluster distance, distance to sink, and residual energy of nodes as fitness function parameters to be implemented using PSO to select the next CH. The optimal CH selection aims to minimize the linear programming function F:

$$F = \alpha f_1 + (1-\alpha) f_2 \tag{20}$$

The functions f_1 and f_2 are given by:

$$f_1 = \sum_{j=1}^{m} \frac{1}{l_j} [\sum_{i=1}^{l_j} dis(s_i, CH_j) + dis(CH_j)], f_2 = \frac{1}{\sum_{j=1}^{m} \left(E_{CH_j}\right)} \tag{21}$$

The f_1 represents the average sink distance and f_2 is the residual energy parameter. Simulation results proved reduced energy consumption and enhanced network lifetime.

4.2. ABC

Karaboga et al. [99] proposed an energy-saving clustering algorithm. The ABC algorithm is used to improve the life of the network. In the clustering method, the intelligent foraging of the bee colony is simulated. In order to minimize energy consumption, the distance between the node and the CH and the distance between the cluster head and the base are considered in the selection process. Since a CH should have enough energy to feed the current round of communication, the energy level of the candidate node is also important for selection. Another important parameter that defines energy consumption is the distance between the transmitter and receiver nodes. Ahmad et al. [100] considered the distance to BS, residual energy, and node to node distance to optimize the ABC algorithm's fitness function. The algorithm aims to select the optimal CH in a cluster by reducing energy consumption.

4.3. HBO

Selvi et al. [101] suggested that HBO (Honey Bee Optimization) intends to reduce energy consumption by finding the best way to reduce costs. The purpose of this concept is to improve network life and throughput. Existing technologies provide better performance in energy efficiency parameters such as scalability and connection quality. Yuvaraja et al. [93] proposed energy distrusted clustering for effective cluster head selection based on the HBO algorithm. This algorithm considers the energy and distance factors as a parameter to improve CH selection. The main goal of EDC-HBO is to enhance the network lifetime and improve the power consumption of the network.

4.4. FLION

Sirdeshapande et al. [102] introduced the Fractional Lion (FLION) clustering method as a competent optimization algorithm for creating an energy-efficient routing plan. This clustering approach can develop the energy and longevity of network nodes using a rapid collection of CHs. This fitness function is built on the foundation of five objects: delay, normal energy nodes, cluster, and inter-cluster distance, and CH energy. The recommended fitness function locates the quick cluster centroid for an optimal routing path. The proposed FLION-based multi-objective clustering technique has been proven to improve network lifetime with results.

4.5. Tabu PSO

A new technique proposed by Vijayalakshmi et al. [103] chooses the optimal path to route that can enhance the lifespan of the network and its energy effectiveness. Researchers have used PSO extensively but with a decreased local optimal problem. TPSO uses Tabu Search (TS) algorithms which creates a more flexible search. The scheme chooses CHs effectively, optimizes the routing path, and increments the network's lifetime. Due to the optimized routing path, the average packet loss rate and end-to-end delay are also reduced.

4.6. WOA

An energy-efficient CH selection algorithm is discussed [104] whose basis is on WOA (Whale Optimization Algorithm) called WOA Clustering (WOA-C). The CHs are chosen based on a fitness function where residual energy and the sum of the adjacent node's energy. The BS is authorized to select the CH following WOA by minimizing the fitness function. When compared with LEACH, LEACH-C, and PSO-C, it is found that WOA-C performs better in terms of energy utilization, lifetime, and stability period.

4.7. LEACH-GA

GA was used in [105] for optimized CH selection for centralized clustering protocol to obtain a load-balanced network. The fitness function used to select the CH depends on residual energy, intra-cluster distance, CH count, and CH to BS distance. Simulation results proved, LEACH-GA extended the network lifetime better than LEACH and LEACH-C. LEACH-GA proposed by Liu et al. [106], where the optimal probability P is determined using GA that depends upon the distance to BS. The value of P is highest when the BS is positioned at the center and decreases gradually when it moves in an outward direction. The network lifetime was effectively enhanced in LEACH-GA as compared to LEACH, MTE (Minimum Transmission Energy), and DT (Direct Transmission) protocols.

4.8. KH Algorithm

The KH algorithm was first proposed by Gandomi et al. in [107], inspired by a non-random and under-dispersed group of oceanic animals. Shopon et al. [108] presented a central method regarding an energy awareness of WSNs using the Krill Herd (KH) algorithm that focuses on data aggregation by an effective clustering scheme. After a certain round, the KH selects the CH based upon energy possessed by the node and distance from member nodes. The CHs are uniformly distributed, thereby extending the network's lifetime compared to LEACH, LEACH-C, and PSO. An optimized CH selection that used the KH algorithm was discussed in [109] that optimizes the energy expenses within the nodes concerning their residual energy.

4.9. FL-LEACH

Decision fusion is a key issue in WSN [110]. With two systems, a two fuzzy-based cluster head selection was performed [106]. Systems 1 and 2 consider linguistic parameters such as battery power of nodes and distance of cluster centroid. In addition, system 1 takes the traffic of the network instead of system 2, which takes the degree of the number of neighbor nodes to select the CH. Simulation results proved that system 2 gives better results than system 1 and that residual energy of nodes and the number of neighboring nodes are important parameters in CH selection compared to the node's distance from the sink. Kim et al. developed a Cluster Head Election mechanism using Fuzzy (CHEF) [111], which takes a distributed approach for CH election. This mechanism considers two descriptors: residual energy and proximity distance to reduce the collection and calculation overhead, thereby prolonging the network lifetime. Lee and Cheng [112] considered a method of uniformly distributed load based on fuzzy logic, which considered CH selection based on energy prediction, aiming to extend the life of the network. CH selection in [113] is based on a fuzzy decision-making approach. In order to extend the life of the network, several attributes are considered, including the remaining energy, the number of neighboring nodes, and the distance between the nodes and the BS. Battery power, mobility, and centrality are the fuzzy descriptor used in [114] to select the CH in a mobile sensor network. When compared with LEACH, it demonstrated better results in terms of longevity and end-to-end delay.

4.10. SMOCH (Spider Monkey Optimized CH Selection)

To improve convergence performance and exploitation capabilities, this algorithm adjusts the position of individual nodes based on their fitness scores. By nominating cluster leaders with better placement coordinates, SMOCH [115] improves the ability of the original Spider monkey optimization algorithm and LEACH to increase the overall network performance in terms of the fewest dead nodes and energy usage.

5. Discussion

Different routing protocols are designed to enhance different performance metrics in WSN. Some of the major metrics are

- Network Lifetime: The precious resource of WSN nodes is energy, and the lifetime of WSNs is completely dependent on the amount of energy the nodes contain. The network lifetime is defined as the total time the network is fully operative until the last nodes run out of energy. It depicts the total time of network operation.
- Network Throughput: It is an important parameter that estimates the overall successful data transfer rate.
- Residual Energy: Every device on the network requires a certain amount of energy to carry out various network activities. The total energy consumption is calculated as the total sum of energy used by all the nodes in the network. If it is assumed that nodes consume energy while sending data, then the total energy consumed is equal to the total number of packets sent in the network. To be more precise, the residual energy represents the overall network energy level after the operation is complete.
- Packet Delivery Ratio (PDR): PDR is the ratio between the total packets sent from the source to the number of packets received at the destination. The network performance is better for higher PDR values.
- Scalability: It is a key criterion of WSN studied to observe the impact of network size on network lifetime. As the routing of data in a large-scale WSN is conducted with nodes having limited resources, the routing process becomes a very challenging issue. Hence, an efficient and scalable routing protocol design becomes essential to constrain such limitations.

5.1. Comparison of LEACH, A-LEACH, and LEACH DCS

The stability period is indicated by calculating the number of rounds until the network's first node dies out. It is an important parameter to predict how stable the protocol is. Lifetime and stability period analysis for 100 nodes deployed over 100×100 m^2 with an initial energy of 5 J shows LEACH-MAC outperforms LEACH, A-LEACH, and LEACH DCS, as indicated in Figure 10.

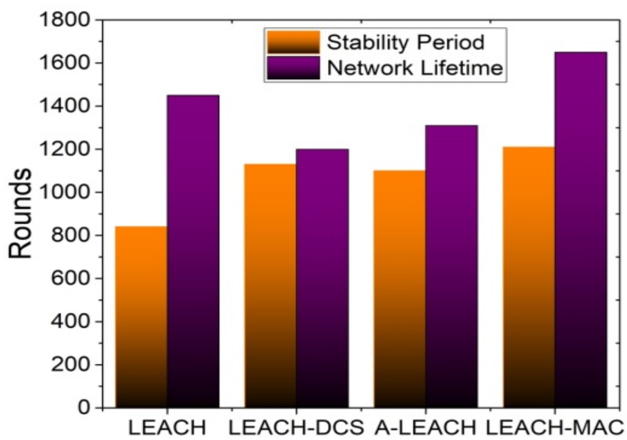


Figure 10. Lifetime metrics comparison for BS location (50, 175).

5.2. Comparison of LEACH, I-LEACH, and MOD-LEACH

For a network with 100 nodes and BS located centrally in a 100 × 100 m^2 field, the I-LEACH protocol gives a better result than the LEACH protocol, with a 67% rise in throughput and network lifetime extended to 1750 rounds. The analysis conducted in Figure 11 shows that I-LEACH is a more scalable protocol than MOD-LEACH and LEACH.

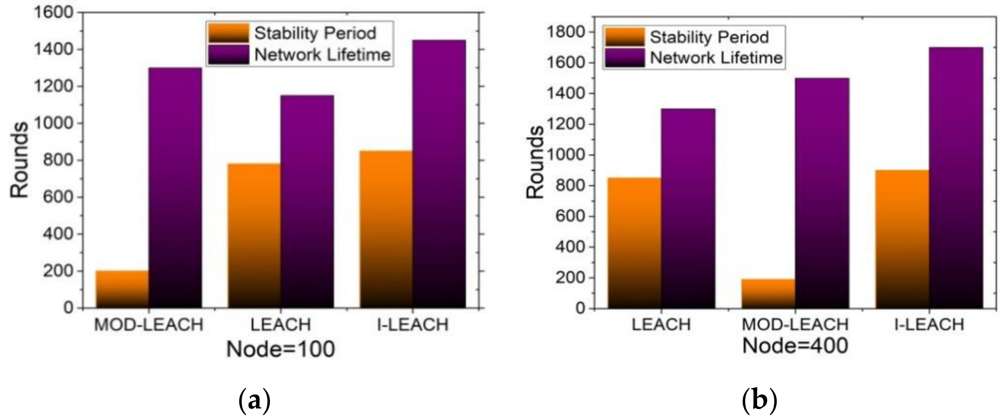


Figure 11. Lifetime metrics (**a**) n = 100 (**b**) n = 400. Deployment area = 100 × 100 m^2. BS location (50, 50). Initial energy = 0.5 J.

5.3. Comparison of LEACH, LEAC-GA, and LEACH-KH

Compared to the CH selection mechanism in LEACH and LEACH-GA [105], and LEACH-KH, the latter proves to have a higher average PDR with the higher residual energy of the network, as shown in Figure 12.

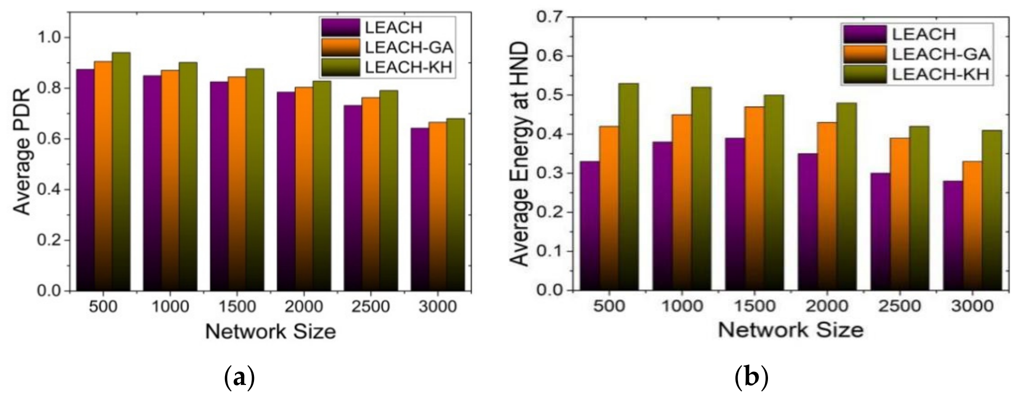


Figure 12. Comparison graph of LEACH, LEACH-GA, and LEACH-KH. (**a**) Packet delivery ratio; (**b**) Residual Energy at Network half-life.

To summarize, it can be said that LEACH can equally disperse energy among the sensors, resulting in reduced transmission between nodes and BSs. This saves energy at each node and hence extends the network's lifespan. It also saves energy by applying data aggregation techniques to locally gathered data before sending it to a sink node or base station. The main problem with LEACH is that the CHs are chosen at random, without concern for the amount and distribution of CHs in a cluster. As a result, nodes with lower residual energy may be chosen as CH, resulting in the network's premature death.

Although this technique ensures equitable energy dissipation across the network, cluster creation is unpredictable, resulting in uneven cluster distribution across the network. It also does not count the number of clusters in the area or their location inside each cluster.

As a result, LEACH protocol restricts intra-cluster communication due to increased energy consumption. Because the CHs interact with the BS in a single hop, LEACH is not suitable for large-scale networks. Computational Intelligence paradigms, on the other hand, are well suited to be used and can adapt to the dynamic nature of WSN.

6. Conclusions and Future Perspective

Routing techniques differ depending on the applications and dependability of the node's hazardous condition. The robustness of the routing strategy is dependent on the network architecture and design of the WSN. The design challenges for routing protocols in WSNs are outlined. Numerous clustering strategies are highlighted, which are projected with comprehensive routing techniques, resulting in improved performance. Fully demonstrated and tested LEACH extends network longevity while eliminating intra-cluster collisions. Researchers have mostly focused on enhancing the CH selection criteria, which have been demonstrated to save energy more efficiently. Owing to the challenges such as power, network scalability, security, and packet-delivery ratio, the LEACH protocol has been modified by researchers over time. This paper intends to present a more comprehensive survey of LEACH-based classical and bio-inspired protocols that will help researchers understand routing protocols with diverse architectures, novel strategies, and enhanced performance. It can be concluded that the LEACH-MAC protocol can be used in networks where life is a major issue. I-LEACH protocol can be beneficial in large scale as well as small networks. Similarly, the LEACH-KH protocol yields a high PDR and can be adopted in networks where reliability is the prime factor.

There are still research possibilities in real-time applications that solve difficulties with video and image sensors. Because stationary sensor nodes cannot match demand, the network must include node mobility. The primary issue is that the frequent updating locations of the sensor nodes and BS's position deplete the network energy. As a result, the overhead of mobility and topological fluctuations necessitates the invention of unique protocols. Additionally, the wireless connection technology used in a WSN commonly facilitates various types of cyber-attacks when transferring data packets and the randomly moving sensors provide hackers with several opportunities to launch denial of service attacks, thus decreasing the WSN's security. Despite significant research efforts and advances in recent years, there are still many unanswered research concerns with routing in WSNs that need to be addressed. The development of cryptographic methods for authenticated encryption in WSNs that enable privacy and network security can be explored.

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