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An Insight on Clustering Protocols in Wireless Sensor Networks

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Abstract**:** *Wireless Sensor Networks* (*WSN*) *have drawn the attention of many researchers as well as general users in recent years. Since WSN has a wide range of applications, including environmental monitoring, medical applications, and surveillance, their usage is not limited. As energy is a major constraint in WSN, it is necessary to employ techniques that reduce energy consumption in order to extend the network's lifetime. Clustering, data aggregation, duty cycling, load balancing, and efficient routing are some of the techniques used to reduce energy consumption. In this paper, we discuss in details about clustering, its properties, the existing clustering protocols. The clustering protocols that support data aggregation will also be discussed. The paper concludes with considering the impact of clustering and data aggregation in WSN.*

Keywords**:** *WSN, clustering, data aggregation.*

1. Introduction

A wireless sensor network is a collection of tiny devices called sensors which can monitor the physical and environmental phenomena. These sensors can be in size like a dust particle to the size of a shoe box states Nagarajan, Sneha and Ezhilarasi [1]. For the purpose of keeping track of physical phenomena, a wireless sensor network makes use of sensor nodes spread out across a large area. This network can be used in various applications such as animal monitoring, environmental monitoring, medical applications, military surveillance and infrastructure maintenance. There are various sensors deployed in WSN such as acoustic, visual, magnetic, radar and infrared. These sensors deployed in a network sense the information of the coverage area, aggregate the data and transmit to the base station directly or using cluster heads discusses Shahraki et al. [3]. Fig. 1 displays the working of WSN in general. WSN has constraints like limited battery, limited memory and hardware constraints states Ezhilarasi and Krishnaveni [2]. One of the important requirements in wireless sensor network is to improve the life time, since each sensor is provided with limited battery capacity. With this limited power, the sensor has to sense, transmit, receive and process states Nagarajan and Karthikeyan [5]. Each phase consumes certain amount of power, which leads to depletion of capacity of the battery. The greatest challenge in wireless sensor networks is balancing the energy consumption of the source as the energy level of the source is an important factor in wireless sensor network, in which each sensor node depends on its limited source of power for all the functionalities like data acquisition, processing and data dissemination as stated by Ning, Chen and Gu [63]. Due to this limited source capacity, efficient management of source power is necessary to improve the life time of the network. Therefore, the usage of resource must be optimized to increase the lifetime of the network is suggested by Rostami et al. [6]. There are various techniques to minimize the energy consumption of the network. Clustering, data aggregation, load balancing and routing are the important phases where the energy utilization is more in a WSN as explained by Jiang, Yuan and Zhao [27]. In this paper we have concentrated on the impact of clustering and data aggregation in WSN. Section 2 explains the clustering process in details, Section 3 discusses about various existing clustering protocols in WSN, Section 4 elaborates about data aggregation in WSN and Section 5 concludes the paper by emphasizing the importance of clustering and data aggregation in WSN.

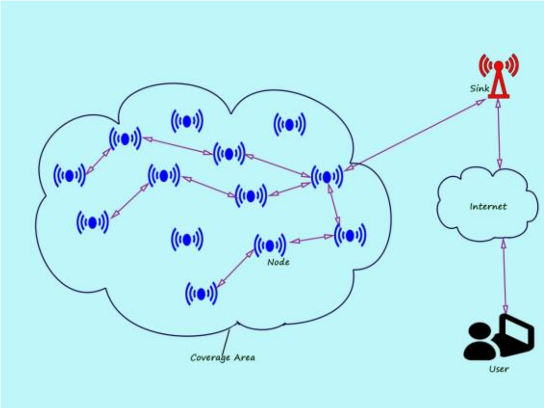

Fig. 1. Working of WSN

2. Clustering

Clustering is a mechanism used in WSNs to extend network lifespan and provide more efficient routing states Mazumdar, Roy and Nayak [4]. Clustering is the process of dividing a sensor network's sensing field into numerous clusters. Each cluster chooses a leader from among its members which is denoted as the cluster head. Data is collected from cluster nodes and transferred to the destination via Cluster Heads (CHs). Clustering techniques are widely used by researchers to improve lifetime and scalability goals explains Jan et al. [7]. A simple clustering in WSN is shown in Fig 2.

Numerous clustering methods can be employed to create a hierarchical structure that minimises communication costs with the base station. Clustering that is optimised can save a lot of energy in the network specifies Jain, Sinha and Gupta [8]. The overview of clustering is displayed in Fig. 3. The method of forming clusters, its properties, capabilities, Cluster Head (CH) selection and formation are described by Akyildiz et al. [9].

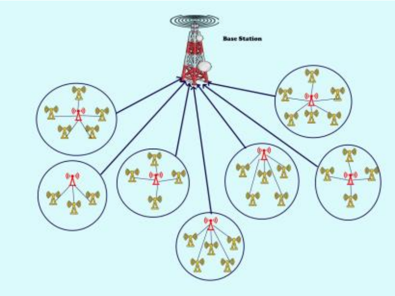

Fig. 2. Clustering in WSN

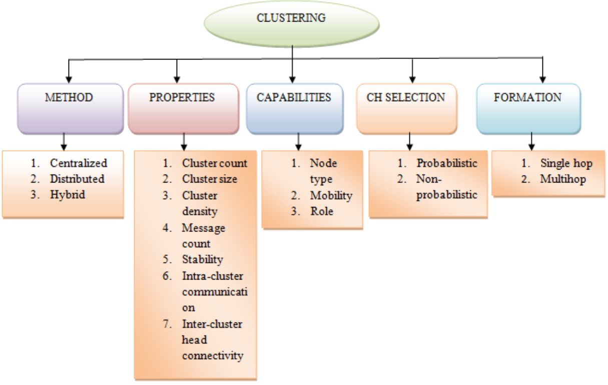

Fig. 3. Overview of clustering in WSN

2.1. Method

There are two methods for clustering: distributed and centralized clustering. Every sensor node in distributed clustering is able to execute its own algorithm to choose whether or not to become the cluster head discusses Sneha and Nagarajan [10]. A centralized node organizes the nodes into clusters and cluster heads in centralized clustering. A hybrid scheme, which combines distributed and centralized methods, can also be implemented at times.

2.2. Properties of cluster

1. Cluster count. The number of clusters formed in a round is referred to as the cluster count. The size of the clusters will be smaller as the number of nodes increases, which is better in terms of energy consumption. Data communication to the base station becomes more difficult as the number of clusters decreases states Sivakumar and Radhika [12]. Some clustering methods assign cluster heads from deployed sensor nodes in advance to form clusters, while others enable cluster heads to be chosen at random, resulting in variable number of clusters.

2. Cluster size. The maximum path length between member nodes required to interface with the cluster head is known as the cluster size. Smaller clusters consume less energy because the transmission distance and load on the cluster head is reduced. When clusters are fixed for the duration of their life, their size is fixed; otherwise, it can be variable.

3. Cluster Density. Cluster density is defined as the ratio of the number of cluster members to the cluster area. In dense clusters, cluster heads consume more energy. Fixed clustering always has a sparse density of clusters to balance energy, whereas dynamic clustering has a variable density of clusters.

4. Message count. The number of messages sent for cluster head selection is referred to as the message count. The greater the number of messages transmitted, the greater the amount of energy consumed for cluster head selection.

5. Stability. The clustering approach is said to be adaptive if the constituents of a cluster are not fixed. Since the clusters do not fluctuate during the clustering process, fixed clusters can enhance the stability of sensor nodes.

6. Intra-cluster communication. This determines whether communication is one-hop or multi-hop within the cluster. The communication is dependent on the distance between the cluster head and the sensor.

7. Inter-cluster head connectivity. This refers to a sensor node's or cluster head's capacity to communicate with the base station. Clustering methods must include some intermediary mechanism for routing to the base station if the cluster heads fail long-distance communication capabilities.

2.3. Capabilities of cluster head

The characteristics of Cluster Heads (CHs') have an effect on the whole clustering process, namely on the stability and lifespan of sensor networks. Several features may be utilised to categorise clustering systems.

1. Node Type. Some sensor nodes are pre-assigned as cluster heads during deployment because they have more energy, connectivity, and computation resources.

2. Mobility. CHs' mobility in sensor networks can be assigned based on the objectives defined in clustering schemes. If the cluster heads are mobile, we can use this to create a more balanced cluster for improved network performance. If the sensor network requires it, mobile cluster heads can also be relocatable.

3. Role. In sensor networks, cluster heads can operate as transmitters of information produced by cluster members, as well as perform data aggregation and fusion activities.

2.4. Cluster head selection

CHs' can be allocated in advance or chosen at random from the existing set of nodes [9].

1. Probability Based. The sensor nodes in a probability-based clustering algorithm use a predetermined probability to determine the initial CHs'.

2. Non-Probability Based. Non-probability-oriented clustering algorithms include more precise criteria for cluster head selection such as sensor node proximity, connection, and degree.

2.5. Cluster formation

In order to establish a cluster, the cluster heads will send a request packet to all sensor nodes within radio range. In a single hop configuration, nodes communicate directly with the cluster head, but in a multi hop configuration, all sensor nodes communicate via neighbour nodes.

3. Clustering protocols in WSN

Clustering protocols play an important role in energy conservation in WSNs and this section discusses on few of them. The main role of the clustering protocols is to minimize the energy consumption of the sensor nodes and enhance network lifetime. The various clustering protocols discussed by N. Sharma and K. Sharma [11] are briefly given in this section.

3.1. LEACH and its variants

LEACH (Low Energy Adaptive Clustering Hierarchy), the first type of hierarchical protocol, is self-organizing and adaptive. According to N. Sharma and K. Sharma [11], it assumes that almost all nodes are similar, the sink node is constant, all nodes utilise the same transmitter, and the channel is balanced. LEACH groups the sensor nodes, with the cluster head for each cluster decided by the limit imposed for it [71]. TDMA access is employed to minimise collisions between and within clusters. The CH is dynamically selected at predetermined intervals. It provides network scalability because communication is controlled within the cluster. Data aggregation is used by the cluster head to manage the traffic load. As mentioned in the article by Abdul, Abdulgader and Joshi [19], the LEACH approach uses a strategy for cluster formation and how to choose a CH that provides a drawback in the condition of isolated nodes. LEACH-C, also known as centralized LEACH [72, 77], is an improved version of LEACH. At the start of each round, the residual energy value and location information are relayed to the base station. BS performs energy calculations and goal function minimization based on the information received. LEACH-C has been improved to focus on better cluster head placement, which can help reduce energy loss that is common in every round [77]. Sivakumar and Radhika [12] outlines in his study how the cluster heads with the optimal placements are picked to minimize energy loss in each round. MODLEACH has two levels of power transmission, which helps to reduce energy wastage as discussed by Nikunj et al. [18]. A different mechanism for CH selection is employed, and if the energy value of a cluster head selected once is larger than the threshold value, it is retained for the second round. MODLEACH is improved in this study by employing a new mathematical approach for selecting CH nodes and limiting the number of CHs. Nodes with energy remaining below a threshold value are put into sleep mode using an energy hole removal process. PEGASIS, a near-optimal chain-based protocol, has eliminated the drawback of LEACH, but it lacks the dynamicity that LEACH gives. A novel approach called PEGASIS-LEACH (P-LEACH) is introduced to overcome the shortcomings of both and combine their benefits [73]. It helps to decrease the restrictions and provide enhancement over both PEGASIS and LEACH, with the best merging of chain type and cluster type protocol. An ideal routing approach is also used in this method to convey information effectively. The stated protocol’s purpose is to produce an optimum wireless transmission and networking route with low energy usage [74]. The data forwarding task is done by a group of CH nodes in LEACH, but the PEGASIS implementation of chain construction is handled by an energy efficient algorithm. D. T. Nguyen and D. V. Nguyen [25] presents Energy Efficient Two-Level Distributed Clustering (EE-TLDC), an enhanced version of LEACH wherein the quantity of remaining energy of member nodes in present time, and the chance of it happening, are used to choose the CH.

3.2. TEEN and its variants

Threshold Sensitive Protocol Developed for Reactive Network (TEEN) is based on LEACH protocol and has been discussed by Samant et al. [13]. The selection of cluster head is done twice in this protocol, with a second level CH. The two fold approach in selecting CH aids in determining how quickly the perceived input data changes. TEEN improves data packet delivery ratio by providing only sensitive information when a specific user demands it, and it is ideal for time-sensitive applications. Shi, Liu and Gu [14] highlights how an equitable distribution of CHs is achieved saving energy and increasing network lifetime, which is not achieved in LEACH and LEACH-C. APTEEN (Adaptive Threshold Sensitive Energy Efficient Sensor Network Protocol) is an extension of TEEN used for data collecting on a regular basis discusses Manjeshwar and Agrawal [15]. The architecture of APTEEN is comparable to that of TEEN, and its performance is in the middle between TEEN and LEACH. Both proactive and reactive methods can benefit from it. Madhuri and Saraswat [16] presents in an article a modified technique for data collecting that takes into account the energy remaining with separate sensor node as well as their degree. The purpose of the new method is to create a network of sensor nodes that generates a graph with varying degrees of nodes. Cluster Heads are chosen based on node degree, proximity from the BS, and residual energy. Garg and Suhali [17] explains that DAPTEEN is a blend of two techniques, TEEN and APTEEN that appropriately addresses the issue of high node energy consumption in these two schemes owing to redundant data transmission. Since nodes in the same area would gather comparable data for a certain region, redundancy is decreased in this scheme by taking into consideration the distance between nodes, resulting in reduced redundancy which attempt to enhance energy efficiency [65]. DAPTEEN is based on an adaptive distance measurement between nodes inside a cluster. The distance is determined, and only data from that distance is delivered if it is less than a particular threshold. In DAPTEEN, node average balance energy is greater than node average balance energy. APTEEN’s nodes have a low number of dead nodes and more residual energy. Allowing member nodes to return to sensor nodes modifies this chain building process. They will also be able to do so if the networks are nearer to the sensor nodes. By raising the degree of active nodes, the energy cost of generating a scene of a nearby tree is reduced. For leader selection and data transmission, a factor that is inversely proportional to both degree and distance is used.

3.3. Energy efficient clustering protocols

Jiang employs Fast LOcal Clustering (FLOC), where throughout the cluster creation operation, the algorithm produces clusters of the same size with nodes which do not overlap. During the testing, procedures that favour low energy consumption, low transmission costs, and reduced load balancing have been evaluated. Rathna [28] examines that we need to do a thorough examination to categorise the protocols according to our requirements. Bo, Wang and Zhang [30] uses Geographic and Energy Conscious Routing (GEAR), a routing algorithm that promises to optimize the energy efficiency by including input and output regions, network density for disrupted communications, and energy cost. Sqatish, Singh and Kumar [31] focuses on HEED, an energy-efficient method that examines nearby nodes throughout cluster head distribution and picks the cluster head at random without repetition. To extend the lifetime of a network, the Hybrid Energy Efficient Distributed (HEED) protocol works well. CHs are chosen based on node density and residual energy. The Deterministic Energy-efficient Clustering (DEC) methodology, stated by Almas [33], is a preferable alternative for picking CHs. To complete communication, single hop or numerous hops can be employed. In a single hop, only a specific data packet is transmitted to neighbours, but multi-hop data packets are sent to a large number of neighbours at the same time, consuming more resources. According to Sajid et al. [24], the approach known as the LCH strategy, which stands for Linear Cluster Handling, tries to address the energy limits faced by sensor networks with a significant number of static sinks as part of their sensing region. DEECLCH, a combination of distributed and linear clustering, is another proactive routing solution developed by. This approach employs a multiple sink mechanism, in which CHs send their data to the nearest sink node. This study suggests two approaches: first, we can enhance the sensor node's energy, and second, we can limit the amount of data in some way. According to studies, the presence of a single static drain in the network causes a reduction in energy quantity and throughput. The next stage, after constructing the subarea, is to strategically arrange the nodes in the field for optimum coverage. In each created sub region, an equal number of nodes are installed [65]. By sectoring the whole network region, Sector-Chain Based Clustering (SCBC) Router Protocol aids in balancing the number of nodes (clusters). SCBC lowers network energy consumption by forming a chain for each cluster, with the SCH having the highest remaining energy and the shortest path between the BS and networking candidate nodes, or the chain leader acting as the Cluster Head (CH). Han et al. [32] has developed the spanning tree technique to concentrate on energy efficiency. By constructing spanning trees, the GSTEB algorithm demonstrates efficient routing, resulting in an improvement in network lifespan. In a study, Leu et al. [26] presents Regional Energy Aware Clustering with Isolated Nodes, a sensor network clustering technique based on regional energy awareness and isolated nodes. The suggested algorithm's energy usage is uniform, similar to LEACH, because the role of CH is rotated [26]. In the previous conducted cycle, the distance between the isolated node and the sink has an impact on whether the isolated node sends its information to the sink or the Cluster Head. Previous systems only considered global average energy, resulting in an irregular distribution of energy; as a result, a new method has been developed that accounts for global average energy in order to equalize out the distribution. Because each cycle does not provide all nodes with the same quantity of energy, the REAC-IN utilises a value of a variable (p) and a desired amount of CHs for each round [65]. CHs are selected based on their weight in REAC-IN [76]. The amount of energy left in the sensor nodes, as well as the average energy per cluster region, define the weight. When connecting with a sink node or base station, these isolated nodes consume more energy. Saranya, Shankar and Kanagachidambaresan [41] introduces the Energy Efficient Clustering Scheme (EECS), which use equitable clustering to choose cluster heads and takes into account a number of factors to maximise energy efficiency.

3.4. Routing support clustering protocols

Mehdi, Kavian and Siavoshi [20] provides a new form of a distributed algorithm called SEECH, which stands for Scalable Energy Efficient Clustering Hierarchy. Relays and cluster heads are chosen individually in this protocol, based on the eligibilities of the member nodes. As a result, nodes of low and high degree are assigned the responsibilities of relays and cluster heads, respectively. Two fitness functions for cluster head selection are investigated in the study by Han and Zhang [39]. Due to optimum cluster head distribution, coverage area may be expanded with a minimal number of CHs employing low-power transmission, balanced CH load, and reduced long-distance intra-cluster communications. Reduced intra-cluster latency, avoidance of long-distance transmission, and consequently energy savings are all advantages of uniform CH distribution. The cluster head is chosen initially, followed by the relay node, and then the cluster formation in the SEECH protocol [65]. The start phase of the protocol is completed first, which determines each node's position, distance from the sink, and the count of neighbours. The computed data is disseminated to all the other nodes prior to the start of the setup and steady state phases. Depending on the topology employed, paths between different nodes are discovered during the setup phase, and data is delivered to the sink node during the second phase. Yasha and Verma [36] employs the Dual Cluster Head Routing Protocol (DCHRP), which maximises network life time by exploiting three levels of heterogeneity in CH selection. Because CH selection uses more energy, the protocol's ultimate goal is to reduce CH selection as much as possible in order to conserve energy. It has three stages namely CH selection, cluster creation, and lastly interaction with the base station. This approach minimises the number of clusters and achieves the three degrees of heterogeneity. Time of delivery, energy usage, and data dependability are all taken into account. Bomgni et al. [34] has proposed the Improved Permutation-based Routing Protocol (IPRP) as a way to save energy. It settles the dispute about the unlimited memory capacity of routing systems. Multiple Level Route aware Clustering (MLRC) has been suggested by Sabet and Naji [35] as a route consciousness-based technique for allocating energy among sensor nodes. Based on the amount of data acquired, stored, and sent over the network, it maintains a consistent drain rate. The Weighted and Parameter Optimization-based Energy-Efficient Clustering Routing Protocol (WPO-EECRP) proposed by Han, lowers the number of clusters, hops, and inter-node lengths in the network between base stations and sensor nodes, therefore boosting energy efficiency. This protocol is considered to aid the network's long-term survival. The hotspot problem is solved by Mazumdar and Om [40] with Distributed Unequal Cluster-based Routing (DUCR), which uses unequal clusters that become smaller as they move closer to the sink. The cluster head is the most energy-efficient node, and load is spread among cluster heads using an energy-saving transit method. Darabkh et al. [42] discusses that the Effective and Energy-Aware Clustering and Routing Protocol (EA-CRP) will reduce the amount of energy used by network sensor nodes. The distribution field is separated into layers, each of which has a number of nodes and the depth of the layers decreases as you get closer to the sink. The life of the network is divided into rounds, with the length of each cycle determined by the sink node. For energy conservation, there are two CHs, one of which serves as the Leader Head and the other as the Support Head. The cluster members' information is gathered and analysed by the Leader Head. The Cluster Head's job is to simply transmit data across levels till it gets to the sink. The energy of the node and its distance from the sink defines the Cluster Head. The main problem with this protocol is that it gives out an exorbitant number of control messages, reducing the network lifespan. The Balanced Energy Efficient Routing Protocol (BEERP), developed by Zhou and Yu [43], aims to balance the drain rate between the network's inner and outside sections. Improved Clustering by Fast Search and Finding of Density Peaks (ICFSFDP) (Chand, Singh and Kumar [89]) regulates the rate of energy consumption by allowing for the residual energy of sensor nodes; it gathers data and uses the homogeneity principle to identify the shortest paths for effective routing. The source of the energy gap is called unbalanced energy. It provides a reactive threshold for deferring the death of the network's first node. Hosen and Cho [45] has proposed the Energy-based Clustered Routing Protocol (ECCRP) for ranking cluster leaders. The nodes' rankings are estimated based on a set of criteria, and these ranks are spread throughout the nodes in a regular pattern using the piggy banking idea. This protocol minimises the amount of control messages provided during cluster creation and cluster head selection. Reduced energy consumption rates have been shown to extend network life. The Cluster-based Routing Protocol (ECRP) developed by Noureddine, Hamidi-Alaoui and El Belrhti El Alaoui [46] illustrates that cluster installation is done only once over the lifetime of the network. It selects CHs in each round depending on leftover energy and employs a variety of factors to arrive at the best solution. This protocol is unusual as it can accept sensor nodes without CHs along their transmission range, making it much easier to add more nodes. Concerns like fault tolerance and CH replacement on a regular basis are addressed by this protocol (Kiran, Kant and Gupta [48]). It streamlines cluster configuration by only considering network topology once. It is expected to increase network flexibility.

3.5. Clustering protocols focused on cluster size

To enhance network lifetime, a clustering technique with balanced cluster size is incorporated as suggested by Vipin, Singh and Yadav [21]. In the suggested solution, two thresholds are used. First, for each cluster group, one threshold is set for a specified number of nodes. A cluster threshold is utilized during the earliest stages of creation, and a distance threshold is used for people who are not part of the group. The unclustered nodes then join CH based on the threshold values after clustering at the start is discussed in paper [82]. Most clustering techniques make the assumption that node density in each cluster is equal, and this influences all subsequent operations, as Heinzelman, Chandrakasan and Balakrishnan [22] and Amini et al. [23] discuss in their papers. However, because the clustering methods are distributive and random in nature, homogeneity in the size of all groups generated is not guaranteed. Performance suffers as a result of non-equal sizes, and network demand is imbalanced. When the cluster size is tiny, the area beneath it is over detected, while the broader area is under sensed or not sensed at all during the permitted period [65]. To accomplish proper data sensing and avoid such difficulties, a balanced cluster size is essential. DWEHC (Distributed Weight-Based Protocol for Energy-Efficient Hierarchical Clustering) has been utilised by Xuxun [29], which employs the Weight-Dependent Protocol to construct balanced clusters with no overlaps and distribute them throughout the network. To some extent, these two algorithms typically seem to be the most effective in preserving energy in WSN.

3.6. Other variants of clustering protocol

Table. 1. Focus and limitations of clustering protocols

Protocol	Focus	Limitations
LEACH [11]	Energy aware	Low performance
LEACH-C [66]	Centralized	Better routing expected
TEEN [13]	Timely data delivery	Time sensitive
Optimized LEACH-C [14]	CHs deployed deterministically	Rotation of CHs is difficult
APTEEN [15]	Data Collection	Poor performance
EDC-PEGASIS [78]	Chain based protocol	Route faults
DAPTEEN [17]	Redundant data transfer	Distance based routing
MODLEACH [18]	CH selection based on threshold	Computational overhead
P-LEACH [19]	Isolated nodes	Route breakage
SEECH [20]	Scalable energy	Dependent on Fitness functions
BCSS [21]	Balanced Cluster Size	Suitable for micro sensor network
LCH [24]	Static Sinks	Transmission range
DEECLCH [24]	Multiple sinks	Equal number of nodes is required in each region
EE-TLDC [25]	Residual energy	Not suitable for centralized applications
REAC-IN [26]	Energy efficient	Weight dependent
FLOC [29]	Balanced clusters	Not suitable for large scale networks
DWEHC [29]	Balanced clusters	Weight-dependent
GEAR [30]	Difficult deployment	Computational complexity
HEED [31]	Deployment aware	Depends on the node density
GSTEB [32]	Network lifetime	Overhead associated with computation
DEC [33]	CH is nominated on various parameters	Consumes more energy
IPRP [34]	Energy distributed evenly	Additional strain on CH
MLRC [31]	Frequent rotation of CH for energy conservation	Low stability
DCHRP [22]	Cluster formation is controlled	Complicated
SEP [37]	CH Residual energy	During transmission, advanced nodes require a greater amount of energy
PEDAP [38]	Power efficient	Optimal spanning tree construction
WPO-EECRP [22]	Energy is considered for CH selection	Energy imbalance exists
DUCR [40]	Resolves Hotspot Problem	Unequal clusters
EECS [41]	Clustering that is balanced	Energy is in flux
EA-CRP [42]	Deployment that has been planned	There are much too many control messages
BEERP [43]	Load balancing that is consistent	In a multilayer heterogeneous network, performance is poor
ICFSFDP [44]	Trust computation may be used to choose a potential CH	Inconsistency in energy
ECCRP [25]	Issue of energy hole is resolved	The use of energy is not optimal
ECRP [46]	Single setup phase	Insufficient CHs

The Stable Election Protocol (SEP), according to Samayveer and Malik [37], is a hybrid clustering procedure based on each node's weights, with CH being the component with the most residual energy. Regular nodes and specialised nodes are the two types of nodes in it. Advanced nodes demand more resources for data aggregation and transfer than regular nodes. Power Efficient Data Collection and Aggregation Protocol (PEDAP) is a framework described by Kai [38] and it consists of two algorithms that use optimum spanning trees to achieve its primary aim of power efficiency. The method uses a probabilistic strategy for picking nodes as CH, ensuring that each node is selected as CH at least once in each round.

Table 1 summarizes the clustering protocols frequently used in various WSNs.

Table 2 shows a list of clustering protocols which concentrate in minimizing energy consumption and prolonging network lifetime.

Table. 2. Clustering protocols that focus on minimizing energy consumption

Protocol	USC
LEACH [20]	It guards against battery depletion and maintains node energy consumption stability
LEACH-C [80]	To create balanced clusters, the base station initiates a centralised mechanism for selecting CHs based on their location data
LEACH-F [68]	After the development of a cluster, it becomes fixed. It reduces setup overhead while balancing energy consumption between sensors
CLUDDA [74]	In-network processing is used to eliminate unnecessary transmission and avoid the problem of flooding
LEACH [86]	It is employed in both centralized and distributed CH selection algorithms for network longevity using solar power
LEACH-ET [16]	It saves energy by shortening the round rotation time
E-LEACH [87]	Nodes' residual energy is conserved, but energy is squandered due to fixed time rounds.
RRCH [16]	A single set-up process achieves significant energy efficiency
TB-LEACH [30]	Changes how CHs are selected dependent on time
MLEACH-L [16]	Within the same cluster, neighbours are allotted channels
V-LEACH [69]	Chooses a backup-CH to take over the role of the CH in the event that it dies
PEACH [17]	It equalizes the amount of energy wasted by sensors
WST-LEACH [81]	The CHs are chosen according to three weighted criteria that optimise the transmission route while minimising power consumption
EBC [49]	It saves energy that would otherwise be wasted during unneeded re-clustering processes
LEACH-SC [83]	When creating clusters, it improves scalability
M-LEACH [76]	It is appropriate for big networks, although it has a hotspot issue
TL-LEACH [36]	It lowers energy usage by distributing the load across sensors in dense networks
LEACH-L [70]	It decreases energy usage while balancing network load
MS-LEACH [86]	Energy usage is minimized by mixing single-hop and multi-hop transmission nodes
EECHE [33]	It provides superior throughput, lifespan, and latency, but scalability is limited
NEAP [21]	Choose a CH that is far away from the sink.
SEP [89]	After each round, there is no need to collect data on the energy of the nodes
HEED [10]	It increases delay while stabilizing power among nodes
EEUC [79]	It avoids hotspots by forming unequal clusters
LEACH-HPR [34]	To keep energy consumption stable, CH chooses the strongest nodes as assistant nodes
DEUC [16]	It eliminates the hotspot problem, but it comes at a cost: more overhead and unbalanced clusters

4. Data aggregation

Data aggregation is a crucial paradigm for wireless sensor network routing that tries to aggregate data from multiple sources. Data aggregation can also save energy by reducing redundancy, reducing the number of transfers, and reducing the number of transmissions. Signal processing can also be used to aggregate data, which is referred to as data fusion. Data fusion adapts a variety of approaches to combine different signals and eliminates signal noise, thereby producing accurate signal. According to Dagar and Mahajan [47], data aggregation is used to decrease the quantity of transmission necessary at various levels, therefore decreasing overall energy consumption.

4.1. Data aggregation based network

The data aggregation process is performed by the nodes of the network with specific responsibilities. Topology of the network is an essential feature involved in aggregating data. Given below are few topological network structures and their process in aggregating data is discussed.

1. Flat networks [47]. Each sensor node serves a similar purpose and consumes roughly the same amount of battery power. Aggregation of data occurs in such networks through data centric routing, in which the sink sends a query message to the sensors.

2. Diffusion. Directed Diffusion (DD) [32] is a data-centric and application-aware paradigm that uses attribute-value pairs to express sensor node information. It eliminates duplication and reduces the number of transmissions by combining information returned from multiple sources to the sink. It reduces the energy consumption of WSN networks and enhances their lifetime. The base station sends a message to each supply node that is interested, and each node receives attention as a result. Each node that receives attention saves it for subsequent use. Multihop communication is used in the network. The configurations utilized to pull data satisfying the question towards the requesting node are measured in gradient squares. The gradient could be a response link to the focus site.

3. SPIN. The initial node that has new data promotes it to the neighbouring nodes using Meta data (Vaibhav, Kaur and Chand [49]). The leader node receives data request from a nearby node that is interested in this particular type of data. Sinks receive data from the leader node, and the leader node reacts. Each node in the sensing network has resource management feature that allows it to monitor its energy use. Before transferring data, each node polls its battery power. SPIN is well-suited for environments with mobile sensors due to the fact that forwarding choices are made using native neighbourhood data.

4. Hierarchical networks. In a hierarchical network, data aggregation takes place at particular nodes. The number of data packets transmitted to the sink is reduced by special nodes. As a result, the total energy efficiency of the network improves.

5. Cluster-based networks [84]. Sensors can transmit data packets to a cluster head (local aggregator), which aggregates data from all regular sensors in the cluster and transmits it to the base station. With the help of this setup, we can preserve the sensors' energy.

6. Chain-based networks. Each sensor transmits data to the sensor immediately adjacent to it. For data aggregation, all sensors are arranged in a linear chain discusses Wendi, Chandrakasan and Balakrishnan [50]. The nodes can generate a chain greedily, or the sink can do that in a centralized environment. The Greedy chain requires that all sensors have a firm grasp on the network. The chain begins with the node furthest from the sink, and each step selects the node's closest neighbour to succeed it in the chain. A node gets a datagram from one of its neighbours during each data-gathering cycle, merges the data with its own, and transfers the consolidated data packet towards the next node down the chain.

7. Tree based networks. The nodes are arranged in a tree, with intermediate nodes facilitating data aggregation and transmission through leaf nodes [47]. For applications that involve the entire network, tree-based data aggregation is acceptable.

Table 3 summarizes the role of data aggregation in different types of network.

Table. 3. Summary of data aggregation in various network topologies

Network	Role in data aggregation
Flat networks	Data aggregation is done at central nodes of the network
Directed diffusion	Data aggregation is done at all the nodes in the network
SPIN	Data aggregation is done by the Leader nodes of the network
Hierarchical network	Data aggregation is done at pre-assigned nodes of the network
Cluster-based networks	Data aggregation is done by the Cluster Heads in the network
Chain-based networks	Data aggregation is done by the generated linear chain
Tree-based networks	Data aggregation is done by the intermediate nodes of the tree

4.2. Protocols that support data aggregation in WSN

WSNs employ a clustering-based aggregation approach to minimise communication while increasing the network longevity. Clustering lowers the immediate transmission to the base station and energy consumption by decreasing the transmitting distance states Stephanie and Raghavendra [51]. In this section we will look into few clustering protocols that support data aggregation process to minimize energy consumption.

Table. 4. Features of data aggregation protocols

Protocol	Feature
Mobile Sink-based Routing Protocol (MSRP) [6]	Balanced energy consumption and extended network life
Energy Efficient Dependable Routing Protocol [7]	Extended network life
MUSTER [37]	Optimum routing pathways
Compressed Sensing (CS) [35]	Recovery fidelity
MDG-SDMA [44]	Controlled mobility
Data fusion [46]	Decreased resource utilization
Slice-based energy model [51]	Energy balancing
Low-energy Designated Path (DP) [54]	Reduced energy wastage
Trade-off Precision [66]	Effective energy constraints
Data aggregation with Global Cost Minimization (DaGCM)	Sensor compatibility
Wireless Energy Replenishment and anchor point-based Mobile Data Gathering [75]	Energy replenishment
Multi-resolution hierarchical structure with Compressed Sensing [85]	Optimized data transmission
SN-MPR [88]	Multi-Point Relay Forwarding

Babar Nazir and Halabi Hasbullah [52] have addressed the problem of hotspots in a clustered WSN and propose the Mobile Sink-based Routing Protocol (MSRP) to extend the network lifetime. It results in more balanced energy consumption of WSNs and an extended network life. Basavaraj et al. [53] utilise data aggregation to develop an Energy Efficient Dependable Routing Protocol for Wireless Sensor Networks (WSN). Data aggregation is a technique for collecting and aggregating data in an energy-efficient way in order to extend the life of a network. Chi Yang et al. [54] has pioneered the use of order compression algorithms to suppress aggregate data inside a network. Dawei Gong and Yuanyuan Yang [55] have constructed a data collecting tree based on a dependability model, timed the data transmissions for the tree's connections, and have allotted transmitting power to each link. Fei, Zhan and Wang [56] has suggested a data aggregation technique in WSN based on data density correlation degree clustering. MUSTER is a routing system developed by Mottola and Picco [57] for many-to-many communication. The results demonstrate that this approach provides almost optimum routing pathways and increases the lifespan of the WSN. Xiang, Luo and Rosenberg [58] has proposed a compressed data aggregation approach for WSNs of any topology that makes advantage of the Compressed Sensing (CS) technique to maximise energy efficiency and recovery fidelity. Zhao and Yang [59] have developed a collaborative SDMA method with several mobile collectors. Zhao, Ma and Yang [60] describes the MDG-SDMA and MDG-MS challenges as a joint design of controlled mobility and SDMA technology for data gathering using a single SenCar and a large number of SenCars. Zhao, Li and Yang [61] have suggested mobility for combined energy replenishment and data collection. SenCar has been used as both a mobile data collector travelling the field collecting data via short-range communication and an energy transporter charging static sensors by wireless energy transmissions during its migration tour. Soltani, Hempel and Sharif [62] has devised a data fusion technique for enhancing resource efficiency in large WSNs. Data fusion is utilised to determine the network's active nodes, which results in decreased network resource consumption. Ning, Chen and Gu [63] has used a slice-based energy model to separate the energy balanced data collection issue into inter- and intra-slice energy balance problems. Bista, Kim and Chang [64] has presented a low-energy Designated Path (DP) technique for aggregating WSN data. The DP system establishes many routes and handles them in a round-robin mode, allowing all nodes to share the data gathering and transmission work. On the other side, the amount of energy wasted has been increased. Mottaghia and Zahabi [65] develop a method that combines the concepts of a mobile sink and rendezvous nodes while retaining the LEACH algorithm's advantages. Xiao, Li and Yuan [66] has increased data aggregation precision by utilising the trade-off between data quality and resource usage when per-node energy constraints are adjusted. Guo and Yang [67] propose a data collection Cost Minimization (DaGCM) architecture with concurrent data uploading that is restricted by flow conservation, energy consumption, connection capacity, sensor compatibility, and the mobile collector's total stay time at all anchor points. In view of the many forms of energy consumption and the time-varying nature of energy replenishment, Guo, Wang and Yang [68] propose a framework for collaborative Wireless Energy Replenishment and anchor point-based Mobile Data Gathering in WSNs. Xu, Ansari and Khokhar [69] proposes a data aggregation architectural model that incorporates a multi-resolution hierarchical structure with Compressed Sensing (CS) to further optimise data transmission. Faheem and Boudjit [70] have suggested SN-MPR, a distributed sink position update and tree-based data collection technique for mobile sink WSNs. For sink location updates and queries, this method makes advantage of Multi-Point Relay (MPR) forwarding. However, there has been a snag in the data delivery process. Table 4 summarizes the different protocols supporting data aggregation and its salient features.

5. Conclusion

On the basis of a thorough categorization of all protocols presented in the literature, we discuss the two main approaches – clustering and data aggregation, as well as their role in wireless sensor networks. As a result of the discussion, we conclude that clustering and data aggregation are both required to reduce energy consumption in wireless sensor networks. Balanced clusters are effective at managing network traffic. Data aggregation is useful for avoiding duplication of data transmitted to the base station. These techniques have the potential to be effective in balancing energy and making the network more stable. This paper may assist researchers in gaining a clear picture of the aforementioned techniques and in developing new ones.

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