Performance Analysis of Heterogeneous Wireless Sensor Networks

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ABSTRACT
Lifetime enhancement is the significant trial in the design of energy-constrained wireless sensor networks. This leads the researchers to explore energy preservation for wireless sensor networks. Due to the energy-constrained nature of wireless sensor networks, hierarchical energy-efficient routing protocols have gained significant attention. In the recent era, Heterogeneous Wireless Sensor Network Clustering Protocols have drawn tremendous attention due to their energy efficiency. Numerous states of the art heterogeneous clustering protocols have been proposed by the researchers to improve network life-time but still, some of the parameters need to be addressed. In this article, a complete overview of the overall clustering mechanism is presented and emphases on the routing concepts for various heterogeneous WSNs scenarios.

Keywords:
WSN, Heterogeneous, lifetime, clustering, cluster head, energy.

1. Introduction

Term Wireless Sensor Network (WSN) can be defined as, “Integrating sensing, processing, communication and storage capabilities into small-scale, low-cost devices and joining them into so-called wireless sensor networks” [1]. Boost in wireless networking technology, micro-manufacturing, integration, and embedded systems have spread modern generations of sensor networks desirable for a wide array of commercial and military applications. WSN promises to inspire our way of living, interaction with the physical environment and work [2,3,4].

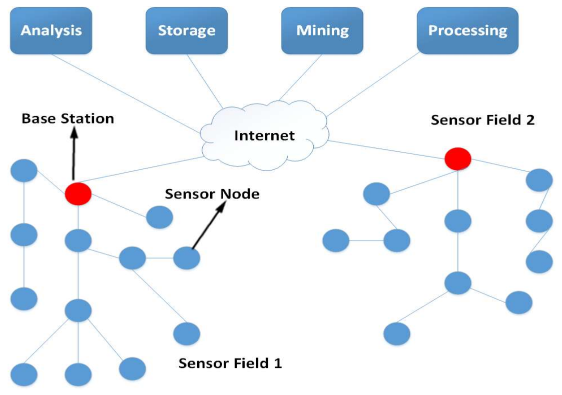

Figure 1: Sensor Network [1]

The WSN comprises an enormous number of sensor nodes ranging amongst few hundreds to thousands dispersed randomly through a geographic region or organized nearby to the phenomena. But network nodes have severe limitations in terms of limited energy, memory and transmission and computation power [5]. Subsequently, the network nodes have restricted energy, it will result in energy depletion faster, as a result, the overall network lifetime will be reduced. To optimize the network life and management strategies certain goals like prolonged network lifetime, scalability, coverage and network simplicity are desirable, consequently, it is essential to purpose an efficient and flexible network layer protocol. To address the above-stated problems clustering protocol has been proposed by numerous investigators [6,7].

Clustering protocols offer the solution to exploit the nodes and network energy consistently to enhance the network lifespan time, maximize the packet delivery ratio and throughput as well clustering of nodes avoids long-distance communication of nodes to BS. Heintzelman et al. [8] presented LEACH, a pioneering benchmark on hierarchical clustering.

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2. Clustering Mechanism

In the clustering technique, the nodes are partitioned into clutches known as clusters. In general, one CH is elected from the clusters and remaining cluster members (CM) connects with the CH based on the minimum transmission distance from the CH. The CMs communicate only with the CH and forward the sensed data to the CH. The CH then executes data aggregation and eliminates the correlated data and data fusion on the data obtained by the CMs and communicates the fused data to the BS for the further end-user processing.

3. Clustering Benefits

In literature, the clustering protocols differ in their objectives. Usually, the clustering objectives are application-specific e.g. delay-sensitive, intra and inter-cluster connectivity, the distance between the CH and BS for CHs selection, cluster size, and members. The following are the famous objectives proposed by various researchers [9].

3.1 Load Balancing

Partition the network into equal size of the cluster can greatly improve the time period. Due to the unbalance size of the cluster the network performance can be degraded. Since the CH performs multiple tasks and data aggregation due to which the energy of the CH is depleted rapidly as compared to other sensor nodes. It is very essential to balance the load between them to achieve the desired performance objectives. Load balancing is a critical factor in clustering [10], where CH is randomly selected from the network nodes [11]. Besides load balancing the rotation of CH also helps in fault tolerance [8].

3.2 Fault Tolerance

In certain applications, nodes are organized in a harsh environment due to which the nodes are exposed to malfunction or physical damage. To avoid the data loss, fault tolerance property of CH is desired in some applications. The most common method is to re-cluster the network but due to excessive resource utilization, this method is not very encouraging. Another approach to overcome the cluster failure is by adding a backup or secondary CH and the function of the secondary or back CHs varies. By round rotation of CHs between the network nodes provide additional benefit by means of fault tolerance [8].

3.3 Guaranteed Connectivity

This objective of marginal cluster count is primarily mutual when some CHs are particular is node is equipped with more resources, processing, and computational power as compared to normal CHs [12]. Due to their size, cost and vulnerable nature, network designer tends to deploy the minimal number of these nodes.

3.4 Enhancing the Network Lifetime

When cluster heads are highly equipped as compared to other network nodes, it is very vital to decrease the intra-cluster communication energy [13] and the distance amid the CH and member nodes should be kept minimum [14].

3.5 Percentage of CH

The percentage of CHs in the network should be optimal. When the node is nominated as CH, it depletes additional energy as compared to its member nodes. If the number of CHs in a network is not optimal. It will diminish the network lifetime as the rate of energy consumptions at CHs is higher.

Besides data aggregation the CHs are also responsible for communicating with the BS and nodes transmits to their respective CHs. In this way, a substantial amount of energy of non-CHs nodes is saved and moreover, the energy utilization is further reduced by inter-cluster and intra-clustering communications as it minimizes the number of nodes that are taking part in distant communication. The data aggregation also helps to reduce energy utilization as data aggregation is executed by the CHs

3.6 Energy Efficiency

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3.7 Scalability

Clustering protocols restrict the number of transmissions among nodes, thus allowing a maximum number of nodes can be installed in the network. Compared to traditional routing protocols, clustering protocols are simple to manage and are more robust to react to the events in the environment.

3.8 Maintenance

The clustering methods also benefit the network maintenance in terms of, node mobility, topology control, node failures, reacting to network changes triggered by network dynamics and local changes. Since these tasks are performed by the concern CH and the whole network does not take part in making the maintenance process simpler and easier.

4. Taxonomy of Clustering Attributes

4.1 Clustering Approach

To consume the network energy effectively and limit the correlated data, data aggregation and sensor fusion many novel techniques have been proposed by the researchers [8]. To consume the network energy uniformly and enhance the lifetime of the network clustering has gained much attention in WSN due to their CH selection and data aggregation. In the clustering method, the nodes are partitioned into groups known as clusters. In general, one CH is selected from the clusters and other CMs connect with the cluster head. The CMs communicate only with the CH and forward the detected information to CH. The CH then executes data aggregation and data fusion on the data obtained by the CMs and communicates the fused data to the BS for subsequent end-user analysis.

Clustering-based techniques play key role in improving energy efficiency and guaranteed to prolong network lifespan, for reusing the bandwidth and data gathering [15] and target tracking [16], single-hop or multi-hop communications, routing [8,17,18-20], etc. Clustering is predominantly suitable for a large type of network comprising of a hundred or thousand nodes that requires scalability. Scalability in those network environments which involves load balancing, well-organized resource exploitation, and data aggregation [21].

4.2 Clustering Elements

Commonly the cluster is comprised of three main elements. Cluster Heads, Member Nodes, and BS [22].

- **Cluster Head:**

The CH plays a crucial role in HWSN since it performs multiple roles. The CH is selected from the network nodes and the selection process of CH selection varies from protocol to protocol. After the selection of CH, it exchanges messages with the network nodes for cluster formation

The CH is involved in intra and inter-cluster communication and moreover, it also performs data aggregation and data fusion and it also acts as a gateway among the nodes and the BS due to which the energy of CH is depleted at a faster rate as compared to other network nodes. To sustain the power depletion, the CH is nominated again in every round [9].

- **Cluster Member Nodes:**

The cluster member nodes or network nodes are those are not elected as CH during the clustering selection phase. After the cluster selection phase, the nodes join the nearest CH forming a cluster. The cluster member senses or monitor the area within their sensing range and transmits it to the CH.

In some applications, the nodes are equipped with more processing and computation power as compared to other CHs. Generally, HWSN consists of two trier nodes i.e. normal and advance nodes. The normal nodes are equipped with more energy as compared to normal nodes. In some articles, the HWSN is extended to three-tier nodes, i.e., normal, intermediate and advanced nodes. The energy of the intermediate node is kept between the normal and advance nodes. In most of the networks, it is anticipated that the network nodes are fixed but sometimes it is essential to provision the mobility of nodes in scenarios like target detection. It becomes very challenging to sustain the connectivity of the network nodes with the CH.

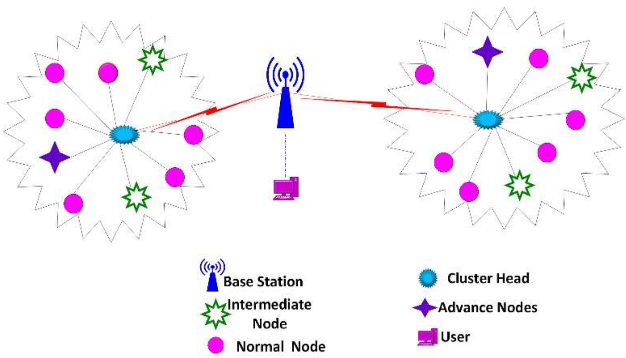

Figure 2: Clustering Element

- **Base Station:**

The BS performs further desired computation on the data forwarded by the CHs for end-user requirements. Usually, the base station is static but in some desired application it can be mobile too [7]. The static BS is deployed at a distance from the nodes while in the case of the mobile

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base station it follows a fixed trajectory. In most research, the BS is deployed in the middle of the network.

5. Clustering Properties

Generally clustering methods attempt to attain some features for the generation of clusters. These features can be linked to the internal configuration of the cluster or in what way it transmits to others. The following are the applicable clustering properties [23].

- **Cluster Count**

In various published works, the number of CHs is fixed and consequently the number of clusters fixed. In other researches, the CHs are randomly generated and the number of CH varies. Since the energy consumption is maximum in CHs the number of clusters should be kept balanced or minimum to preserve the network energy.

- **Dynamic and Static Clustering**

In Dynamic or adaptive clustering, the number of clusters and node membership changes in every round while in static clustering it is remains fix. In dynamic clustering, the energy of the network is uniformly distributed among the network nodes but it inserts additional overhead in reelecting the CH in every round by exchanging discovery messages. Node membership remains static i.e. the association of nodes with their respective cluster head remains unchanged. Likewise, in dynamic clustering, the energy wasted in the selection of CH is preserved but to static membership, the power of the CH is exhausted at a faster rate and the energy is not uniformly distributed among the network nodes.

6. Cluster Head Capabilities

As argued above the network design affects the clustering method; mainly the node abilities and the choice of the in-network handling. Attributes of the CH nodes are discussed as [23].

6.1 Static or Mobile

In most of the researches the CH is static while in some applications the CHs are mobile and due to their mobility, the membership of the clusters changes dynamically which results in continuous cluster management. In the case of static clustering, cluster formation is steady. In some scenarios, 's the CH can be relocated to a new location to maximize the coverage.

6.2 Data Aggregation/Fusion

Due to the random placement of the nodes, sometimes the nodes are deployed very close to each other and their sensing region overlaps with each other. As a result, nodes might produce a lot of correlated data, identical packets can be collected from multiple nodes. The CH implements data aggregation on the packets received from the network nodes and eliminates the identical copies of the packets. After the data aggregation process, the CH performs data fusion and transmits the data to the BS for end-user processing. This method has ensued in power consumption and traffic optimizing in clustering protocols and the network life is also enhanced. To guarantee that CH is not overburdened the number of cluster members should be balanced in every cluster.

6.3 Routing

In most literature, heterogeneous networks are classified as two-tier energy protocol, where the nodes are divided into high energy nodes and low energy nodes but in few types of research, they are termed as multi-tier protocol. The routing in clustering protocols is accomplished in dual phases, first is intra-cluster routing and the second is inter-cluster routing [41].

6.4 Role

A CH performs the task like a network router. The CH performs multiple tasks. Firstly, it communicates with its CMs for collecting data and forwards the collected data to the BS for end-user processing. Secondly, the CH accomplishes data aggregation and data fusion on the data received from its CMs.

7. The Clustering Process

Designing of the clustered network is on the most crucial step for effectively utilizing the network energy. During the designing issue, certain aspects should be considered; like optimal cluster head size, CHs selection criteria, etc. The clustering establishment process can be divided into three main phases' i.e. (i) CH selection, (ii) cluster creation and (iii) data transmission phase [22].

7.1 Cluster Head Selection

CH selection can be classified into three categories, centralization by the BS, decentralization by the nodes or hybrid selection and some by the nodes themselves.CH selection is a foremost task to prolong the network lifetime and make the network energy efficient. The CH is selected among the existing sensor nodes and the selection measures of CH varies in the suggested research but the key intention these studies is to decrease the energy consumption and prolong the network life span. To minimize the routing complexity and make the network more energy efficient it is necessary to decide the optimum number of CH, which will minimize the overhead while maintaining the network connectivity in case of topology changes occur. Researchers have proposed different mechanisms to select cluster head but still it open research problem.

HSWSN are generally two-level protocols equipped with normal nodes having initial power of "E_0 "and "m" advance nodes having extra power "α" as related to normal nodes. The total energy of the network is increased to "(1+m.α)" times. So, the whole initial energy of the network develops to:

$$E_{TOT} = nE_0(1 + m\alpha) \quad (1)$$

The probability of normal nodes (P_{NS}) and advance nodes (P_{AS}) to be elected as CHs becomes [11]:

$$P_{NS} = \frac{P_{opt}}{(1 + \alpha * m)} \quad (2)$$

$$P_{AS} = \frac{P_{opt}}{(1 + \alpha * m)} * (1 + \alpha) \quad (3)$$

The CHs is election is based on threshold value which is set between 0 and1. If the computed value is higher than the previous one, CHs are selected. The threshold value for normal nodes and advance nodes is:

$$T_{(S_{NS})} = \begin{cases} \dfrac{P_{NS}}{1 - P_{NS} * (r * \mathrm{mod}(\frac{1}{P_{NS}})} & \text{if } S_{NS} \in X' \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

$$T_{(S_{AS})} = \begin{cases} \dfrac{P_{AS}}{1 - P_{AS} * (r * \mathrm{mod}(\frac{1}{P_{AS}})} & \text{if } S_{AS} \in X'' \\ 0 & \text{Otherwise} \end{cases} \quad (5)$$

Where, "r" is the present round, "X' and X''" are nodes that are not selected as CH with in the last round.

7.2 Cluster Creation

In cluster creation or set-up phase, the cluster formation takes place. The CHs declare their selection to network nodes by broadcasting advertisement messages and each network node responds back by sending a join message to the CH. For N number of network nodes, a certain number of clusters are formed during each round.

The energy consumed by the CH in a certain round is computed by the following equation [11].

$$E_{CH} = P.E_{Ckt}\left(\frac{n}{C} - 1\right) + P.E_{AD}\frac{n}{C} + P.E_{Ckt} + P.\epsilon_{fs}d_{TX}^2 \quad (6)$$

Where C is the sum of clusters, E_{AD} aggregated data and d_{TX} is the distance amongst the CH and BS. The energy utilized by a non-CH is as follow

$$E_{NCH} = \begin{cases} P.E_{Ckt} + P.\varepsilon_{fs}.d_{CH}^2 \text{ if } d_{CH} < d_{BS} \\ P.E_{Ckt} + P.\varepsilon_{mp}.d_{BS}^2 \text{ if } d_{CH} > d_{BS} \end{cases} \quad (7)$$

Where d_{CH} is the distance between the member node and the CH and its average value can be computed by "$d_{CH}=M/(\sqrt{2\pi})$". d_{sk} is the distance amongst the nearest node and the BS.

7.3 Data Transmission

In data transmission or steady-state Phase, the CMs forwards sense data to their respective CHs, and the CH performs data aggregation and forwards it to the BS. The entire energy consumed in the network becomes equal to,

$$E_{TOT} = P.\left(2nE_{Ckt} + nE_{AD} + \epsilon_{fs}\left(C.d_{TX}^2 + n\frac{M^2}{2\pi C}\right)\right) \quad (8)$$

8. Types of Clustering

Commonly the clustering can be group into two types' homogeneous clustering or heterogeneous clustering and static or dynamic clusters. In formal type is the clusters are established on the function of the nodes within the cluster while the earlier deals with cluster formation [23].

8.1 Homogenous Clustering

In the homogenous type of clustering, the network nodes have the identical initial energy, processing capabilities, and sensing range.

A homogeneous sensor network comprises of BS and

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network nodes are equipped with the similar capabilities and energy level, for example, their computation and processing power is the same. The homogenous networks require high hardware cost. To overcome the limitation of homogenous networks heterogeneous networks were proposed in which two types of sensor nodes were introduced [8].

8.2 Heterogeneous Clustering

Generally, the heterogeneous network has dual categories of nodes having dissimilar energy levels termed as high energy or advance node and low energy or normal nodes. The advance nodes have maximum energy than the normal nodes. Depending on node heterogeneity the heterogeneous network can be classified into categories such as two-tier or multi-tier heterogeneous networks [6].

8.3 Static Clustering

In static clustering, the clusters are created nears the high energy nodes at the time of placement. The properties of cluster elements remain static such as cluster size, number of CHs, number of nodes. The static clustering can be deployed in limited a predefined Scenario.

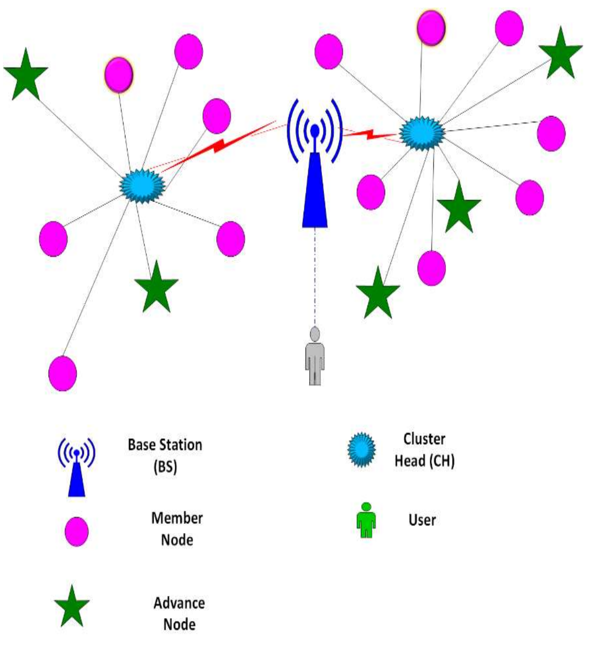

Figure 2:Heterogeneous Clustering

8.4 Dynamic Clustering

In the dynamic clustering, the membership of the network's nodes may vary to different clusters in the network. The formation of clusters may be periodic or dependent on occurrences of certain events [23].

9. HWSN Lifetime Stages

In clustering protocols, the network operations are measured in rounds. When the network becomes operational, the whole network will progress into three phases: stable period, usable period and weak sensing period

- **Stable Region**

It is a region where all network nodes perform smoothly or in other words the network is stable.

- **Unstable Region**

Unstable regions begin when the first network nodes drain their energy till the half of alive network nodes. The instability period affects the cluster head criteria adversely and the number of cluster heads per round is not optimal which degrades the network performance.

- **Weak Sensing Region**

The weak sensing covers the unstable region from the remaining half of the network nodes until the last network node. In the weak sensing phase, the sensing capability of the nodes declines rapidly [24]. In weak sensing regions, the cluster head selection criteria become highly unstable and even in most of the rounds no cluster head is elected which means no communications have been taken place in those rounds.

10. HWSN Node Deployment

The node deployment is similarly significant, which is scenario specific and affects the requirement and aim of the clustering protocols. The node distribution can be either random or deterministic. In deterministic method nodes deployed manually. However, in random node deployments, nodes are distributed randomly in an area. In this organization, the site of CH or the BS is too critical in terms of network performance and power efficiency. If the node distribution is not uniform it could lead to serious energy issues and degraded network performance. Additionally, the transmission range and the relative CH vicinity to the BS are critical concerns that needs to be addressed. Communication range is generally restricted and a CH might not be able to connect with the BS though if a node is directly linked to the BS.

Random node deployment is the most frequently considered node deployment method in the HWSN [18]. Though, it is inefficient from an energy efficiency perception due to Node's different energy levels. The unfeasibility usually arises in two sorts of conditions, one where the number of nodes is vast, and the other when the network is comprised of heterogeneous nodes i.e. nodes having various energy levels. In these scenarios, the requirement of a well-designed node deployment algorithm is becoming viable to maximize the network lifetime. But all this prior research work ignores the placement of advance nodes which have a higher priority to be elected as CH.

11. HWSN Energy Predication Model

According to node energy heterogeneity, the HWSN network can be designed by introducing different energy levels, i.e. two, three or multi-energy levels.

11.1 Two Level HWSN

The two-level HWSN model contains two kinds of node normal nodes N and advance nodes m, equipped with unlike energy levels. Where normal nodes are energized with energy "E_0" and advance nodes are equipped with higher energy as related to normal nodes i.e. "E_0 $(1 + \alpha)$". Since the N is the total number of network nodes, then "Nm" is the sum of advance nodes while "N (1-m)" is the number of normal nodes. Therefore, the network's total initial energy is equivalent to the sum of energies of both types of nodes.

$$T_{IE=} N(1-m)E_0 + Nm(1+\alpha)E_0 \quad (1)$$

$$T_{IE=} NE_0(1-m+m+\alpha m) \quad (2)$$

$$T_{IE=} NE_0(1+\alpha m) \quad (3)$$

11.2 Three Level HWSN

In this type of network three kinds of nodes, having different energy levels are organized in the area i.e. normal, intermediate and advance nodes. The energies of both normal and advance nodes are the same as the two-level HSWN whereas the energy "μ" of the intermediate node is set among normal and advance nodes "$E_0(1+b)$". Since N is the sum of network nodes, then the total number of intermediate nodes becomes "N_{bm}" and "Nm (1-b)" advance nodes. Therefore, in three-level HWSN, the over-all initial network energy becomes,

$$T_{IE=} NE_0(1-m-b) + mNE_0(1+\alpha) + NbE_0(1+\mu) \quad (4)$$

$$T_{IE=} NE_0(1+m\alpha+b\mu) \quad (5)$$

Where b represents the number of intermediate nodes equipped with energy μ and "$\mu=\alpha/2$". The three-level HWSNs hold "$(\alpha + \mu b)$" times additional energy as with respect to homogeneous WSNs. SEP-E and T-SEP is the example of three-level HWSN.

11.3 Multi-Level HWSN

In multi-level HWSN, the initial energy of the network nodes is arbitrarily dispersed over the close-set [E_0, E_0 $(1 + \alpha max)$], where E_0 represents the initial energy and αmax represent maximum energy. Initially, the node the nodes are energized with "E_0. $(1 + \alpha i)$", which is "αi" times additional energy. So overall initial energy of the networks becomes

$$E_{Total=} \sum_{i=1}^{N} E_0\,(1+\alpha_i) = E_0\,(N + \sum_{i=1}^{N} \alpha_i) \quad (6)$$

12. Summary of Heterogeneous Clustering Protocols

In this section, a summary of state-of-the-art Heterogeneous Clustering protocols is presented in Table 1 at the end of the article.

12.1 SEP

In [9] the author has introduced energy heterogeneity to prolong stability period beforehand the expiry of the first network node, which plays a critical role for certain applications in which the response from the network must be consistent. In SEP the cluster head selection is centered on the weighted probability of individual nodes related to remaining power. Since the advance nodes have additional energy which ensures that, this increment will work perfectly and the increased energy will have used efficiently, the advance nodes will elect cluster head more often than the normal nodes. The election of CH is made in the start of each round by choosing a random number [0, 1], if the value of the random number

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generated is less than the set threshold, the node will become CH in the current round. The threshold for both advance T_{AN} and normal nodes T_{NN} is given as,

$$T_{NN} = \begin{cases} \dfrac{P_{NN}}{1 - P_{NN} * (r * \mathrm{mod}(\frac{1}{P_{NN}})} & \text{if } S_{NN} \in X' \\ 0 & \text{Otherwise} \end{cases} \quad 8$$

Where r is the existing era, X' is the number of normal nodes which were not nominated as CHs within the previous $\frac{1}{P_{NN}}$ rounds of the epoch, and to ensure that every normal node will be selected as CH precisely once in every round.

$$T_{(AN)} = \begin{cases} \dfrac{P_{AD}}{1 - P_{AN*} * (r * \mathrm{mod}(\frac{1}{P_{adv}})} & \text{if } S_{AD} \in X'' \\ 0 & \text{Otherwise} \end{cases} \quad 9$$

Similarly, X" is the number of advanced nodes which were not designated as CH within the last $\frac{1}{P_{AN}}$ rounds of the epoch SEP is based on election probability which focuses on the initial energy of every network node to be selected as CH by allocating a weight equivalent to the initial energy of individual nodes divided through initial energy of the normal nodes. The weighted probabilities for normal nodes and advanced nodes in SEP were selected to reveal the additional energy presented in the network. The weighted probability for normal P_{NN} and advance nodes P_{AN} is given by,

$$P_{AN} = \frac{P_{opt}}{(1 + \alpha * m)} * (1 + \alpha) \quad 10$$

$$P_{AN} = \frac{P_{opt}}{(1 + \alpha * m)} * (1 + \alpha) \quad 11$$

SEP protocol claims to maximize the stable region which as a result minimizes the unstable region and the protocol claims to improve the response of Clustered WSN in the occurrence of heterogeneous nodes. The downside of SEP is advanced nodes. Advanced nodes have extra energy and their probability to be selected as CH is higher with respect to the normal node which results in higher energy depletion and at a certain stage, their power becomes equivalent to the normal nodes but still, the probability of advance nodes to be elected as CH is maximum

12.2 On Lifetime Maximization of HWSN With Multi-Layer Realization

In [25] the author has proposed a horizontal intra-layer and vertical inter-layer optimization technique to find the global minima, which involves a minimized number of repetitions as compared to traditional single-layer realization of an HWSN. Additionally, cooperation amongst nodes is considered to transmit data to the fusion Centre receiver to increase data transmission reliability in adaptable transmission channel conditions. A dynamic CH selection method is presented in this article which minimizes the overhead within the intra-cluster communication and reduces the non-uniform energy utilization. Subsequently, the proposed article delivers an energy effective solution for HWSNs to boost the life-time of the network.

12.3 HT2HL

In [26] the author proposed a hybrid two-level heterogenous protocol. The protocol adopts the best features of [8] and TEEN [27] Protocols. The author has introduced energy heterogeneity in the network nodes and moreover, the cluster head selection is both probability-based [9] and threshold-based. Based on the threshold value the nodes having the highest energy are selected as a CH for the existing round.

12.4 HACSH/MH [28]

In [28], the author has adopted the hierarchical agglomerative clustering (HAV) protocol for CH selection. It is a dual step process the cluster is created by applying HAC on the network nodes and Euclidean distance amongst nodes. The election of the CHs is established on the closeness with a virtual network node representing the optimum head site with respect to energy ingesting. The protocol is re-executed after each round to balance the energy utilization of the network nodes.

12.5 NEECP

Singh et al. [29] presented a novel energy-efficient clustering protocol for enhancing the network lifetime in HWSN. This method selects the CH in an active way with a variable sensing range and executes data aggregation by means of the chaining method. It also evades the broadcast of correlated data by implementing a redundancy check function for maximizing the lifetime of the network. It is applied by considering the data with aggregation and without aggregation.

12.6 EADUC

In this paper [30], an energy-aware distributed unequal clustering protocol (EADUC) has been improved in order to enhance the network lifetime. In this work, the un-uniform strategy for clustering was explored.

Figure 2: Energy-Aaware Distributed Unequal Clustering protocol (EADUC)

S. No	**Protocol Name**	**Energy Efficiency**	**CH Selection Parameter**	**Data Transmission**	**Location Of BS**
1	On Lifetime Maximization of HWSN With Multi - Layer Realization	High	Dynamic /Minimum Reduce Energy Consumption	Single Hop	Center
2	HT2HL	Good	Probability Based	Single Hop	Center
3	HACSH/MH	Good	Euclidean Distance	Both	Center
4	NEECP	Good	Threshold / Residual Energy Based	Multi-hop	Center
	EADUC	Poor	Ratio Between the Average Outstanding Energy of Neighbor Nodes and The Residual Energy of The Node Itself	Multi-hop	Center
	Improved EADUC	Fair	Distance, Residual Energy, Number of Neighbors	Single Hop	Center
	Heterogenous DEEC	Excellent	Weighted Probability	Single Hop	Center
	MLHEED	Good	Residual Energy, Node Density	Single Hope	Center
	PSABR	Good	Battery Power and Residual Energy	Single Hop	Center
	DCHSM		Redundant Nodes/Remaining Energy and Average Energy	Multi-hop	Center
	EECCCP	Excellent	Probability/ Euclidean Distance	Single Hop	Center
	BEECP	Good	Biogeography-Based Optimization	Single Hop	Center
	SEECP	Poor	Residual Energy	Single Hop	Center
	P-SEP	Good	Average Nodes Energy Of Current Round, Advanced Nodes Initial Energy	Single Hop	Center
	DSEP-FL	Poor	Fuzzy Logic/Maximum Energy	Single Hop	Center
	FECR and FEAR	Good	Node initial Energy and Current Energy	Single Hop	Center
	DEECIC [55]	Good	Neighbor	Multi-Hop	Center
	WBCHN		Residual Power, The Number of Active peers and Transmission Distance To BS	Single hop	Center
	EHE-LEACH	Average	Probabilistic	Multi-Hop	Center

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The clusters created by the use of uneven competition radius are of unequal size. The clusters near the BS are smaller in The size than clusters far from the BS. The nodes are given uneven competition radius by means of multiple aspects, viz. the transmission distance to BS, the outstanding energy and the number of neighbors. Thus, the energy ingesting amongst the CHs is more efficiently sustained.

12.7 Improved EADUC

Improved EADUC [31] aims to extend EADUC's lifespan and prevent hot spot problems in heterogeneous multi-hop WSN. It is broadly utilized in persistent information-collection tasks. It varies from [30] in terms of node degree while calculating competition range besides remaining power and transmission distance from BS. Node degree is involved in sustaining inappropriate power in the network. In [31], CHs are nomination is based on the ratio of the average energy of peer nodes and outstanding power of the node itself. The competition range is computation is based on three parameters: residual power, node degree and distance to BS. [31] uses energy as a relay metric for choosing relay nodes whilst [31] makes use of distance to BS as a relay metric. The same cluster configuration is used for multiple rounds, reducing re-clustering overhead and minimizing energy utilization.

12.8 Heterogeneous DEEC

In [32], the author has proposed a three-tier HWSN model categorized by a sole model metric and described it as, level-1,2, and 3 energy heterogeneity in the network. Liable upon the value of the vector parameter, it can describe level-1,2, and 3 heterogeneity. In this article, the HWSN model additionally helps to choose CHs and their corresponding cluster contributors by means of weighted election chance and threshold value.

12.9 MHLEED

In this paper [33], the author proposes a heterogeneous multi-level network model with dual sorts of parameters: primary parameters and secondary parameters. The first parameter specifies the degree of heterogeneity and depending on the level of heterogeneity, the secondary parameters are determined. Cluster formation is dependent on node energy levels. Two parameters such as a node's residual energy and node density are taken into account simultaneously during cluster creation

12.10 PSABR, [40]

In [34] the author recommended Power Source Aware Backbone based Routing (PSABR), which represents powered nodes together with battery-powered nodes. It is a tree-based distributed method with a backbone routing framework mainly consisting of infinite powered nodes. The powered nodes are assigned to the resource-intensive jobs to decrease the energy ingesting of battery-powered nodes. [34] shows substantial enhancement in the life time of the network over the shortest path routing algorithm. Though the development is instinctive, as the mains-powered nodes are not battery-restricted, and the method might be problematic to incorporate in everyday circumstances with restricted accessibility of powered nodes.

12.11 DCHSM

In [35] the researcher suggested a Dynamic Cluster Head Selection Method (DCHSM), that analyses network power consumption balancing depending on heterogeneity of energy and redundant nodes. Using the Voronoi diagram, the zone to be tracked is partitioned into clusters, and the redundant nodes are nominated as first sort CH nodes. The existence of overlapping nodes does not disturb the coverage of network and more over their sensing role can be turned off to minimize the power utilization during the network operations. The CH selection method is based on "survival time estimation algorithm" which is used after the death of the redundant node's dependent on the ratio of the residual power and the average power of the existing network nodes. The suggested technique shows enhancement in the lifetime of the network and stable region however, the consideration of two unlike categories of techniques for CH nomination might boost the operational cost.

12.12 EECCCP

In [36] the author suggested Energy Efficient Concentric Circular Clustering Protocol (EECCCP) for tri-level energy in HWSN. The circular region is split into concentrated areas where ordinary nodes and super nodes are positioned simultaneously in the near and furthest areas of the BS. The advance nodes are organized in the area between the both regions. The normal and the super nodes transmit their data packets directly to the BS and the advance nodes adopts the clustering-based method. The CH selection is dependent on the node's residual power and average power of the network. [36] demonstrates enhancement, in terms of throughput and network lifetime. Nonetheless, the direct communication may not be a better choice for super nodes, which are distant from the BS, the chance of deterministic placement of nodes might not be accessible.

12.13 SEECP

Mittal et al. [37] developed Stable Energy Efficient Clustering Protocol (SEECP), a reactive routing protocol with threshold value based on nodes data transfer identical to [27]. A fixed set of CH is deterministically selected on the basis of the node's remaining power. It considers dual-hop CH to BS communication to diminish the trasnfer power of faraway CHs not lying within an appropriate range to the BS. [37] displays enhanced performance, in terms of stable region and power variance.

12.14 BEECP

In this article [38], a new approach for CH selection in HWSNs founded on biogeography-based optimization has been anticipated. BBO is a famous evolutionary algorithm used to resolve numerous composite real-world issues. BBO defined three key operators namely "elitism, migration, and mutation". In the investigated approach, "the fitness function" for BBO has been altered on the root of cluster size and the distribution of CHs in the network region. The density must be diminished in order to create compact clusters such that each node can transmit data to its respective CH with minimum distance while the distribution of CHs should be greater in order to effectively cover overall network zones.

12.15 P-SEP

Naranjo et al. [39] proposed Prolong-SEP (P-SEP), to extend the stability period of fog supported HWSN. P-SEP considers normal nodes to be randomly arranged and the advanced nodes to be placed at predefined location. It allows a fully distributed and appropriate selection of CHs depending on the sort -specific weighted probability of the node, taking into account the average power nodes int the current round, initial energy of advance nodes, etc. [39] shows enhancements in terms of stable region and data transfer rate. Though, the predefined assignment of the advanced node might not be feasible in some environments as it needs approachability of the application placement zone.

12.16 DSEP-FL

This paper [40] suggests a novel protocol DSEP-FL that expands D-SEP by means of the Fuzzy Logic method. Fuzzy logic takes real-time verdicts with the incorrect info. The BS picks the node as CH having higher energy by means of four parameters that are nodes energy level, distance from BS, the concentration of network nodes, and criticality w.r.t. the whole CH. This article investigates the DSEP protocol using DSEP-FL CH by taking into account four parameters such as energy, centrality, concentration, and distance to BS.

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12.17 FECR and FEAR

Borujeni et al. [41] propose FECR and FEAR protocol for fog-supported and two-level HWSN. The choice of CH is based on the role of likelihood taking into account the initial power and present power of the node. The CHs transmit their data to the adjacent fog node, which further processes and route the data collaboratively before transmitting it to the cloud. The methods show enhanced energy and network life-time.

12.18 DEECIC

DEECIC [42] balances energy utilization and transmission delay. In order to sustain connectivity and diminish lag from a network node to its CH, DEECIC enables dual-hop connectivity from individual node to its CH.

When two nodes are within the communication range of one another, they are assigned a peer and a node degree represent the entire number of peer's node displays a node concentration. It should be observed that there may still be some nodes that do not belong to any cluster after CH selection due to the random distribution of nodes. [42] enables the creation of clusters from un-clustered nodes and arbitrarily picks 4-byte integers as their ID.

For a particular group of CHs, they can establish the rest of the nodes into distinct clusters in order to decrease power ingesting and expand life time of the network. Compared to other nodes, CHs use more energy the number of CHs should be lessened as much as probable. Decreasing the number of clusters while preserving whole phenomena is precisely equal to increasing the typical cluster volume. Nevertheless, nodes installed in dense zones should be picked as CH because the failure of a network node from such areas would not interfere with the total coverage area of the due to the maximum coverage redundancy of the overlapped monitoring zones covered by the node's peers. In certain scenarios, distributed sensor nodes in dense areas or at the boundary of the network cannot communicate directly with CHs because of the restraint of cluster communication range. In [42], transmission amid a CH and a network node outside the communication radius of CH is attained through intermediate nodes.

12.19 WBCHN

WBCHN [43] is a distributed algorithm in HWSN focused on three issues: residual power, number of active peers and distance from BS. This algorithm estimates residual power in the network by using the approximation technique. In the subsequent round, each network node with power greater than average power utilization and predefined threshold energy, announces itself as a CH. Every node sends a group message to all its peers active in the subsequent round at the end of the round. Then each node sends each weight in the current round to their neighbors forecasting energy consumption. In order to forecast power ingesting, the number of active peers' nodes, it broadcast its announcements to its peers. Other network nodes link to a CH with the highest power utilization.

12.20 EHE-LEACH

EHELEACL [44] is an extension of [8] proposed in HWSN to maximize the node's lifetime. In [44] a predetermined threshold value is set for intra cluster and inter-cluster transmission. Nodes close to BS transmits to BS directly, and network nodes away from BS send their data to BS through cluster-based communication. In this article, a fixed threshold is adopted to divide the network. Low-threshold nodes send their data directly to BS, and nodes further back from the set threshold are clustered and their data is sent hierarchically to BS. This enhances the lifetime and stable region of the network. In nodes far away from the threshold, CHs are nominated randomly.

13. Open Issues

This article analyses the performance of some selected heterogeneous protocols in terms of, energy efficiency, cluster head selection parameter, data transmission, network lifetime, stable region and unstable region Though the existing protocols have successfully enhanced the network lifetime still there are open issues which need to be addressed.

13.1 Optimal Cluster Head Selection Per Round

The networks become unstable when the nodes tend to die and optimal CH selection criteria become void. Since energy consumption of the CHs is almost twice as compare to other nodes due extra number of CHs the energy consumption of the network is increased and the network life time is decreased.

13.2 Node Deployment

In heterogeneous clustering the nodes having more energy levels are selected as CH. Since HWSN are comprised of multi-tier nodes having different energy levels, random deployment of nodes is not feasible solution. However, the node deployment significance on the lifetime of the nodes in a randomly deployed network, has been mainly unaddressed in clustering protocols. Subsequently in clustering protocols long haul transmission is involved, the inappropriate deployment of the nodes will affect the network coverage, transmission rate and as well as lifetime of the overall network, making the nodes deployment vital problem in clustering protocols.

13.3 Cluster Communication Range

The cluster communication radius and the comparative CH closeness to the BS are vital problems that must be taken into account. Cluster Communication range is typically restricted and due to which a CH might not be able to connect with the BS, even if it is directly connected with the BS [42,43].

13.4 Cluster Head Formation Overhead

Cluster Member nodes have various parameters to join an suitable cluster i.e.,

- **Cluster Member Distance:**

The distance between the CM and its CH affects the power consumption of the network. The cluster member connects with the nearest CH based on the minimum distance. Due to random deployment, the location of the node may be located at a distance from the CH, so it will use more energy to convey its data to the CH as compared to other CMs.

- **Number of Hops:**

It depends on the network scenario to connect directly or indirectly with the CH based on the number of hops between them i.e., single or multiple hops. The number of hops between the CMs and CH affects the CH selection.

- **Cluster Size:**

The cluster size plays a critical role in the stability of the network and energy efficiency. If the cluster size is not optimal it could lead to serious energy issues. The cluster with the maximum number of CMs will lead to high energy ingesting [44].

- **Cluster Head Overhead:**

The CH selection process introduces additional overhead in the network which is also the source of energy depletion. The volume of CH overhead is dependent on the parameters related to the CH election, cluster formation and network complexity.

- **Cluster Head Distance:**

The CHs performs multiple tasks, it communicates with its cluster members and also with the BS. Since the cluster head is involved in long haul communication, its energy is depleted faster and the rate of energy depletion is higher the intra-cluster communication distance is maximum.

14. Conclusion

This article mainly provides the overview of overall clustering process in heterogeneous wireless sensor networks, cluster heads selection plays a vital role in the enhancement of the network lifetime, besides the cluster head selection parameters other parameters like Intra and inter-cluster communication, optimal number of cluster heads per round and data transmission should also be considered for the enhancement of network lifetime.

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