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Energy Aware Competition-Based Unequal Clustering Protocol for Wireless Sensor Networks

Rohit Gupta[1,*] and **Vinith Chauhan**[2]

[1] *Department of Electronics Engineering, Medi-Caps University, India*

[2] *Department of Electronics & Communication Engineering, Sardar Vallabhbhai Patel University of Agriculture and Technology, India*

Abstract: In wireless sensor networks, there is a limitation of energy resources. For the enhancement of the network's operational lifetime, energy resources need to be utilized efficiently. In this paper, the energy aware competition-based unequal clustering (EACUC) protocol is suggested where issues related to energy efficiency and energy holes are addressed. In the EACUC protocol, the competition radius is calculated with the help of two parameters, that is, distance from BS and residual energy, and also the cluster radius is further resized based on the node degree. The most appropriate nodes are identified as cluster heads in a competition radius after consideration of two vital parameters: residual energy and node degree. In the suggested EACUC protocol, to lessen the communication overheads, the cluster structure is kept for a set count of communication rounds. The results are simulated in MATLAB, and the performance of the suggested EACUC protocol is compared with four existing protocols: energy-efficient uneven clustering (EEUC), energy aware unequal clustering using fuzzy approach (EAUCF), unequal cluster radius based on node density (URBD), and energy aware unequal clustering algorithm (EAUCA). The results show that EACUC protocol enhances the network operational life by 11.12%, 22.98%, 30.96%, and 46.26% for scenario-1 (base station at center) and 10.63%, 16.41%, 28.21%, and 33.34% for scenario-2 (base station at the corner) compared to EAUCA, URBD, EAUCF, and EEUC, respectively. The outcomes permit the significant improvement in the network lifespan for the suggested EACUC protocol and guarantee consistent energy consumption in addition to resolving the energy hole issue.

Keywords: wireless sensor networks (WSN), energy hole, cluster head, network lifetime

1. Introduction

Wireless sensor networks (WSN) are designed as an independent and self-arranged wireless network that inspects conditions like temperature, sound, vibration, pressure, and motion and sends data to a sink via the network where the information can be noticed and analyzed [1]. The areas of application of WSN are military, agriculture, medical healthcare, industrial, environmental monitoring, etc. [2, 3]. The nodes in WSN are having finite energy due to which nodes have a finite lifetime. In many applications, the nodes are deputed to uneven environment or places where humans cannot easily reach; in those places, it is very tough to energize or replace the node's battery. So, some proper measurements need to be taken in order to utilize the node's energy effectively.

The inherent potential of nodes, where involvement by human beings is impossible, makes WSNs dominant in new areas of application, such as sediment transportation, monitoring of undersea pipelines, nuclear detection, and monitoring of snow avalanches [4]. Sensing nodes are the nodes whose function is to sense the environmental conditions, process them, and then forward the information to the remote location [5]. The node energy deteriorates due to these processes. As there is a restriction in the energy resources of the sensing nodes, the energy must be optimally used during the functioning of WSN [6]. The lifetime of the network can be enhanced by using an energy-efficient mechanism for data transfer. The energy-conscious definition seeks to skillfully identify the routes of the data traffic which will help to prolong the network's lifespan [7].

The nodes are scattered throughout the observing region in WSN; the surrounding region can be sensed by nodes, and this data is transmitted via single or multi-hop data transmission mechanisms to the destination (BS) [8]. Clustering is an essential method for reducing energy usage, thereby prolonging the lifetime of WSN. In clustering, all observational region nodes are formed into various small groups called clusters. Each cluster includes a cluster head (CH) and several cluster members (CMs) [9]. CH collects the highly correlated data with several CMs, accumulates it, and delivers the accumulated data to BS. Data accumulation eliminates duplication of data at the CH stage and reduces traffic costs [10].

The clustering strategy provides localized routing established within the cluster that minimizes routing table length for each node [11]. The periodicity of the cluster formation decides the nature of the clustered WSN (static or dynamic). The initial cluster configuration continues in a static network throughout the entire process, while cluster reformation occurs in the dynamic network

***Corresponding author:** Rohit Gupta, Department of Electronics Engineering, Medi-Caps University, India. Email: rohit.gupta@medicaps.ac.in

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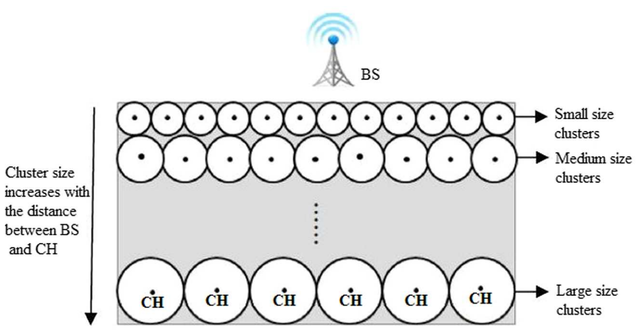
after each round. The clustering configuration increases the network efficiency, but it introduces an excess amount of communication overhead [12].

The energy is drained during different cluster traffic in clustered WSN. The intra-cluster traffic is the traffic between the members within a cluster, whereas inter-cluster traffic is the traffic CHs and BS [13]. The traffic information might be single or multi-hop, depending on the strategies used to send information. The information is directly sent to the destination nodes in single hop, whereas the information is transferred in multiple hops to the destination nodes via relay nodes (RNs) in case of multiple-hop traffic [14]. The power usage of the nodes in the course of transmission is dependent on the varying powers (second power corresponds to single hop, and fourth power corresponds to multiple hops) of the distance [15]. The distance of hop transmission through multiple hops is far lower than the single hop. In this way, it can be said that multiple-hop communication is more efficient than single hop. Thus, long-distance communication generates excessive energy, and communication with multiple hops provides greater energy conservation when it is compared with one-hop communication [16]. Multiple hop transmission is used where the area is quite large or with sensor nodes having low communication ranges [17].

The clustering approach deals with the variable size of the clusters (equal or unequal). The clusters have the same radius across the network in equal clustering; however, the radius varies uniformly in unequal clustering. The benefits of clustering include reduced energy usage with an increase in bandwidth, reduced delay, stable network topology, lessened overhead, and efficient load equilibrium [18]. The CHs near to BS handle large traffic due to intra-cluster traffic, data accumulation, and inter-cluster traffic. Network disruption and coverage issues have been generated in clusters closer to BS, which is called the energy hole problem [19].

Unequal clustering methods can be employed for the load balancing of CHs and to root out the energy hole problem. Figure 1 indicates the unequal WSN cluster architecture. Here, the cluster has a small size that is close to BS, and a big size cluster is away from CH.

Figure 1
Unequal clustering architecture in WSN



The cluster size relies on the CH to BS distance. The smaller size clusters are near to BS and have lower number of CMs in the particular cluster that reduces the intra-cluster traffic cost. There is less energy consumption by smaller clusters during intra-cluster traffic. Conversely, the larger clusters have more CMs and require more energy during intra-cluster traffic. Unequal clustering allows the use of the same energy by all CHs. Thus, unequal clustering eliminates the problem of the energy hole by efficiently balancing the load.

The contribution of the proposed energy aware competition-based unequal clustering (EACUC) protocol is stated as follows:

1) In this paper, EACUC is presented to deal with energy-conscious competitiveness challenges.
2) The issues related to energy proficiency and energy holes are addressed in the EACUC protocol. The unequal-sized clusters are created in which small clusters are nearer to BS and the size of cluster increases as stepped away from the BS.
3) The competition radius in the suggested EACUC is determined using two parameters: first, the distance between the node and the BS and, second, the leftover energy, the competition radius is further resized according to the node degree.
4) In the suggested EACUC protocol, the most appropriate nodes are identified as CHs after having competition among various nodes on the basis of two vital parameters: residual energy and node degree.
5) The suggested EACUC protocol effectively partitions the network in such a way that sensor nodes survive for a longer time, which enhances the operational life of the WSN.

Section 2 consists of the related work that several authors have done to create an energy-efficient routing protocol. Section 3 discusses the radio energy model taken into consideration. Section 4 includes the suggested work that has been suggested regarding the preparation phase, selecting CH, cluster formation, and communication between CHs and BS. Section 5 covers the simulation results and suggested scheme comparison with the current in-use protocols. Section 6 concludes the paper.

2. Related Work

Various researchers published their study on routing protocols dealing with energy efficiency based on clustering techniques in WSNs. The primary goal of a cluster-driven routing protocol is to minimize energy usage of sensing nodes efficiently through their involvement in multiple-hop communication into a cluster. A lot of distributed hierarchical cluster-based routing protocols were suggested such as low-energy adaptive clustering hierarchy (LEACH) [20], Power-Efficientin Sensor Information Systems (PEGASIS) [21], hybrid energy-efficient distribution (HEED) [22], and many more. LEACH is an innovative hierarchy of clusters forming in the whole network and randomly selecting CHs. CMs sense the information from their surroundings and send it to the CH. The CH transfers the accumulated data collected by CMs to the sink. The CHs rotate at random to equally divide the energy cost within the network. The network's overall energy usage is thus minimized, and the network lifespan significantly improves. The weakness of the LEACH protocol is a random CH's selection process; thus, it does not guarantee the optimum number of CHs. Another weakness of the LEACH protocol is that all nodes within the network have the same chance of being a CH, so the node having less residual energy and more residual energy has an equal chance of being a CH. Researchers propose a number of modifications to the LEACH protocol to overcome these shortcomings [23].

The HEED protocol suggested the integration of intra-cluster traffic and residual energy for the selection of CHs [22]. The likelihood of CHs is dependent on leftover energy, and the final decision is determined by intra-cluster traffic cost. The data is transferred by multiple hops to BS from CHs. Each node chooses the lower cost of transmission, so CHs use multiple hops rather than a single hop to send the accumulated data to the BS. Subsequent overheads affect HEED, as different iterations must be carried out to select the CHs.

A LEACH protocol for CH selection based on the GA (genetic algorithm) [20] optimizes the chance of a node becoming a CH. The sink gathers the information and calculates the best chance of nodes being selected as CHs. During operations, LEACH-GA adopts a centralized approach with many controls and advertising messages for transmission. This is a rather complex technique, and the computation time is very long. The new A-LEACH (amend leach) protocol [11] came into study, which selects the CH on the basis of weighted probability and the residual energy. Nodes having variable energy levels are heterogeneous in nature. This protocol gives the best clustering method for improving the lifespan of the network. An energy-efficient clustering approach (EECA) for a predetermined node deployment strategy was suggested [24]. Here, this technique needs two stages for the selection of CHs. In the first stage of the sensor node, the CH anchors are chosen based on the maximum residual energy after which, based on leftover energy and the distance from the CH anchor, CHs will be selected. The second stage includes a competition among the CH candidates to become CH by delayed broadcasting techniques. CHs are distributed according to the two-layer selective method used in EECA. The clustering technology called PR-LEACH [25] is used to balance the dissipation of energy in the LEACH Protocol. The selection of CH in PR-LEACH is based on the relation between the node's remaining energy and specified threshold limits. A sink calculates the threshold value, which is subsequently sent by selecting the CHs. Selected CHs then transmit to each member node of the cluster. The utilization of the inter-cluster multi-hop traffic is thus superior to the LEACH. This is a protocol that uses the multi-hop inter-cluster traffic.

Zhang et al. [26] suggested energy-efficient unequal clustering routing algorithm, which is a combination of unequal clustering and multi-hop routing algorithm. The residual energy and degree of the node are the key aspects of partitioning the network into unequal cluster sizes. Each CH selects the adjacent CH as the next relay node for inter-cluster traffic based on an Euclidean distance. The size of clusters that are outside the observation area is considerably large in the case of a large network, which enhances the communication cost tending to disperse high energy.

Zhu and Wei [27] presented a dual CH energy-efficient technique that splits energy and distance among different clusters. The vice-CH is selected to divide the CH load across each cluster. This vice-CH monitors traffic within the cluster and then transmits the accumulated data by means of multi-hop transmission. For selecting the CHs, multipurpose optimization procedures are used, and vice-CHs are chosen with energy and distance consideration.

The improved PEGASIS chain-based algorithm has been submitted by Wang et al. [28]. In order to prevent early mortality, a node protection mechanism is added, which defines a threshold function for nodes following the consideration of average energy in the nearby nodes. If the leftover energy of the node is less compared to the threshold amount, it is then not permitted to participate in data transfer, and only its own data are transmitted by this particular node. The range of the nodes is also modified with the distance from the BS in order to balance the energy consumption. Nodes far from the BS may transmit information over greater distances than those nearer to the BS.

Bagci and Yazici [29] suggested an energy aware unequal clustering using fuzzy approach (EAUCF) that minimizes the energy hole problem near the sink. The tentative competition radius of CHs is estimated by fuzzy logic. The battery residual power and the node separation to BS are used for evaluation purposes. The major objective of EAUCF is to minimize traffic load and low residual energy of CHs that are close to BS. The major disadvantage is excess overhead for the radius assessment process of CH, but one thing is to be notified that node density is out of consideration for estimating CH. Agbulu et al. [30] suggested a strategy where the concept of RNs is used, which depends on residual energy and the distance to the BS node. Nodes that are appointed as RNs have more energy and less average distance.

Hamidzadesh and Ghomanjani [31] suggested the study for unequal cluster radius based on node density (URBD) where the cluster radius relies on node separation from the BS and node density. The cluster size is updated for each node with the distance to BS, and subsequently, this number is updated according to the node density. A random value is produced by every node indicating the chance to become CH, and the node having the highest value in the particular radius is selected as CH. The node near to CH and having maximum residual energy will be counted as CH for the next round. The control messages are minimized using this CH selection process for the next round. Li et al. [32] suggested a methodology on energy-efficient uneven clustering (EEUC) for applications requiring regular data surveillance. The probabilistic approach is used by EEUC in deciding the number of CH-elected nodes, which are labeled as tentative CHs within the cluster. Elected CH has the highest residual energy within the competitive radius. A channel for data transmission from CHs to BS is then established, and RNs are selected. The main weakness of the EEUC is substantial overhead. Every round of the cluster setup process is carried out; consequently, each node must send/receive several messages throughout the CH selection process. This protocol can create a new energy hole when there are limited energy resources in the specified relay node.

Chauhan and Soni [33] suggested an energy aware unequal clustering algorithm (EAUCA) with multi-hop routing via low-degree RNs for WSNs to rectify energy holes and enhancement of network's lifespan. Here, the clusters are formed such that there are small clusters near BS and big clusters away from BS. The node's leftover energy and its separation from the BS determine the competitive radius that divides the network to uneven clusters. Two parameters, that is, node degree and the residual energy, are used to select the CH. The role of RN and CH is also decoupled in inter-cluster data transmission, which minimizes data traffic of the CH nodes.

The deployment issue for mobile sensing nodes in Unmanned Aerial Vehicle (UAV)-assisted for Secure Dedicated Communications Networks (SDCNs) is formulated in the study proposed by Yang et al. [34]. Subsequently, the problem formulation is converted into a coalition formation game utility maximization problem, whereby the coalitions' rules, ordering, actions, and stability are examined and demonstrated. Yang et al. [35] prioritize safeguarding the location information, identification of sensing terminals, and data freshness performance while simultaneously enhancing sensing data performance. The goal is to jointly minimize the Age of Information (AoI) metric and weighted privacy preservation budget in the single terminal scenario based on the artificial noise-based differential privacy and covert communication technologies. Table 1 shows the overall main outcomes and observations of various research papers that are related to WSNs.

Table 1
Main outcomes and observations of various related research papers

Sr. No.	Journal/author/year	Title	Main outcomes observations
1.	Intentional Journal of Machine Learning and Computing/Liu and Ravishankar/2011 [20]	LEACH-GA: Genetic algorithm-based energy-efficient adaptive clustering protocol for wireless sensor networks.	Authors proposed a GA-based LEACH protocol for CH selection by optimizing the probability of nodes to become a CH, and then the base station broadcasts a message in the network, which comprised of an optimal value of probability for creating the clusters. # CHs are randomly selected Residual energy of each node is not considered in the CH selection process.
2.	International Journal of Current Engineering and Technology/Vijayvargiya and Shrivastava/2012 [11]	An amend implementation on LEACH protocol based on energy hierarchy.	Authors developed a new protocol termed as A-LEACH (amend LEACH), which elects the CH on the basis of the probability of the weight value of the nodes along with their residual energy.
3.	Proceedings of 10th IEEE International Conference on Control and Automation/Yang et al./2013 [24]	An energy-efficient clustering algorithm for wireless sensor networks.	Here, this technique needs two stages for the selection of CHs. In the first stage of the sensor node, the CH anchors are chosen based on the maximum residual energy after which, based on leftover energy and the distance from the CH anchor, CHs will be selected. The second stage includes a competition among the CH candidates to become CH by delayed broadcasting techniques.
4.	Proceedings of 31st National Radio Science Conference, Ain Shams University, Egypt /Salim et al./2014 [25]	PR-LEACH: Approach for balancing energy dissipation of LEACH protocol for wireless sensor networks.	Here, the clustering technology called PR-LEACH is used to balance the dissipation of energy in the LEACH Protocol. The selection of CH in PR-LEACH is based on the relation between the node's remaining energy and specified threshold limits.
5.	Proceedings of IEEE 14th International Conference on High Performance Computing and Communication/Zhang et al./2012 [26]	Energy-efficient routing algorithm for WSNs via unequal clustering.	Here, the residual energy and degree of the node are the key aspects of partitioning the network into unequal cluster sizes. Each CH selects the adjacent CH as the next relay node for inter-cluster traffic based on a Euclidean distance.
6.	International Journal of Distributed Sensor Networks/Zhu and Wei/2019 [27]	An energy-efficient unequal clustering routing protocol for wireless sensor networks	Here, the author presented a dual cluster head energy-efficient technique that splits energy and distance among different clusters. The vice-CH is selected to divide the CH load across each cluster. This vice-CH monitors traffic within the cluster and then transmits the accumulated data by means of multi-hop transmission.
7.	Wireless Communications and Mobile Computing/Wang et al./2018 [28]	An enhanced PEGASIS algorithm with mobile sink support for wireless sensor networks.	In order to prevent early mortality, a node protection mechanism is added, which defines a threshold function for nodes following the consideration of average energy in the nearby nodes. The range of the nodes is also modified with the distance from BS in order to balance the energy consumption.
8.	Applied Soft Computing/Bagci and Yazici/2013 [29]	An energy aware fuzzy approach to unequal clustering in wireless sensor networks.	This approach minimizes the energy hole problem near the sink. The tentative competition radius of CHs is estimated using fuzzy logic. The major objective of EAUCF is to reduce traffic load and low residual energy for CHs close to the sink. The major disadvantage of EAUCF is the overhead excess in the radius assessment process of CH, and node density is not considered in the estimation of CH or the radius of CH competition.

(*Continued*)

Table 1
(*Continued*)

Sr. No.	Journal/author/year	Title	Main outcomes observations
9.	International Journal of Distributed Sensor Networks/Agbulu et al. /2020 [30]	A lifetime-enhancing cooperative data gathering and relaying algorithm for cluster-based wireless sensor networks.	Here, the author has suggested a strategy where the concept of relay nodes (RNs) is used which depends on residual energy and the distance to the BS node. Nodes that are appointed as RNs have more energy and less average distance.
10.	Wireless Personnal Communication/Hamidzadesh and Ghomanjani/2018 [31]	An unequal cluster-radius approach based on node density in clustering for wireless sensor networks.	In URBD, the maximum size of the cluster is predefined such that its radius compared to maximum range of nodes is always less. A random value is produced by every node indicating the chance to become CH, but the node having the higher value in the particular radius is elected as CH. The node closest to the present CH with the maximum residual energy is selected for the next rounds.
11.	IEEE International Conference on Mobile Adhoc and Sensor Systems Conference/Li et al./2005 [32]	An energy-efficient unequal clustering mechanism for wireless sensor networks.	EEUC uses the probabilistic approach in deciding the number of CHs, which are known as tentative CHs. Each tentative CH's competition radius is proportional to its distance from BS. The main weakness of the EEUC is substantial communication overhead. This protocol can create a new energy hole when there are limited energy resources in the specified relay node.
12.	Journal of Ambient Intelligence and Humanized Computing/Chauhan and Soni /2021 [33]	Energy aware unequal clustering algorithm with multi-hop routing via low-degree relay nodes for wireless sensor networks.	Here, the clusters are formed such that clusters closer to BS are smaller in size compared to the farthest ones. By calculating the node's remaining energy and its distance to the base station, the competitive radius to separate the network into unequal clusters is decided.
13.	IEEE Transactions on Green Communications and Networking/Yang et al./2022 [34]	Joint optimization of AoI, SINR, completeness, and energy in UAV-aided SDCNs: Coalition formation game and cooperative order.	The deployment issue for mobile sensing nodes in UAV-assisted SDCNs is formulated in the study
14.	IEEE Transactions on Mobile Computing/Yang et al./2024 [35]	Can we realize data freshness optimization for privacy preserving-mobile crowdsensing with artificial noise?	The goal is to jointly minimize the Age of Information (AoI) metric and weighted privacy preservation budget in the single terminal scenario based on the artificial noise-based differential privacy and covert communication technologies.

3. Energy Model

Figure 2 illustrates the radio energy model, which is almost the same as LEACH.

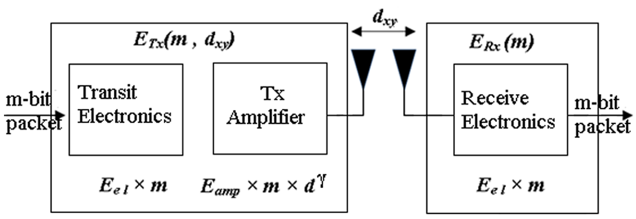
The energy needed to convey m-bit data across the distance d_{xy} between xth node and yth is

$$E_{Tx}(m, d_{xy}) = E_{Tx-el}(m) + E_{Tx-amp}(m, d_{xy})$$

$$E_{Tx}(m, d_{xy}) = mE_{el} + mE_{amp}d^{\gamma} = \begin{cases} mE_{el} + mE_{fs}d^2 if d_{xy} < \delta \\ mE_{el} + mE_{mp}d^4 if d_{xy} \geq \delta \end{cases} \quad (1)$$

E_{el} indicates the dissipated energy in the electronics section, and E_{amp} indicates the dissipated energy in amplifier circuit. E_{el} = 50 nJ per bit is taken into account, and γ denotes path loss exponent. Here, for propagation, two types of models are used, that is, free space (fs) models and multi-path (mp) models. The selection of models to be used depends upon the distance between the transmitting and receiving node and a threshold value δ. If threshold value is more than distance, then fs-model is used, and if threshold value is less than distance, then mp-model is used. In case of fs-model, the value of γ is 2, and E_{amp}= E_{fs} = 10 pJ/bit/m^2, while for mp-models, the value of γ is 4 and E_{amp} = E_{mp} = 0.0013 pJ/bit/m^4. The threshold value is calculated by the formula as given by Equation (2).

Figure 2
Radio energy model



$$\delta = \sqrt{\frac{E_{fs}}{E_{mp}}} \quad (2)$$

The energy used to receive m-bit data from the recipient is given by Equation (3).

$$E_{Rx}(m) = E_{Rx-el}(m) = m\,E_{el} \quad (3)$$

CH accumulates the data collected from their CMs. Data accumulation eliminates node redundancy that minimizes the traffic cost [10]. However, the less correlated data received from numerous CHs makes this approach ineffective. The energy consumption to contribute l number of m-bit data packet is given in Equation (4).

$$E_a = E_{da} * l * m \quad (4)$$

where E_{da} is the expended energy to aggregate a single bit.

4. Suggested Work

We assume that N number of sensing nodes are scattered in a random fashion over a square monitoring region during the suggested work. The i^{th} node is defined as s_i, and the node set for N nodes is given as $s = (s_1, s_2, \ldots\ldots s_N)$. In the suggested work, several assumptions are as follows:

1) The sinks and all the sensor nodes are inherently static, and sensor nodes are assumed as homogenous.
2) One sink is located at the center of the sensing region.
3) The received signal strength is used for the estimation of the distance between nodes.
4) Base station and common nodes can send the node condition information and network configuration information immediately at the setup phase.
5) Nodes can be operated both in active and sleep mode.
6) One identity number with a separate zone of identification is available for every node in a particular area. Within the chosen zone, the communication process for normal nodes is limited. The CHs are responsible for establishing inter-zone communication.
7) The communication between single hop and multi-hops is feasible depending on the distance from the sink.

The suggested EACUC protocol is fragmented into three phases: preparation, setup, and steady state.

4.1. Preparation phase

The N numbers of nodes are dispersed throughout the square field of observation. Firstly, BS transmits a specific power signal to the existing nodes so that each node can presume its separation from BS depending on the strength of the receiving signal. This not only gives the most crucial clustering information but also assists the node in adjusting its power level to connect to BS. Each node calculates its separation between the sink and neighboring nodes NN_j across predestined radii RAD. Collected information is shared with all the nodes. Each node individually calculates its node degree (ND_j) using Equation (5).

$$ND_j = \frac{NN_j}{\max(NN_1, NN_2, NN_3 \ldots\ldots NN_N)} \quad (5)$$

4.2. Setup phase

The setup phase comprises the selection mechanism of CHs, cluster formation, and the consequent hop selection process.

4.2.1. Selection of CH

At first, specific counts of tentative CHs ($T_{CH}s$) are selected randomly with a preset possibility (P_{th}). The nodes not chosen as $T_{CH}s$ will operate in idle mode or sleep mode. P_{th} denotes a critical design parameter to determine the quality of CH. The selecting procedure of CH drops with less $T_{CH}s$ in terms of energy efficiency, whereas unnecessary overheads are produced by more $T_{CH}s$. An optimum value of P_{th} should be considered for maintaining the quality of CHs and also reducing overhead message. The $T_{CH}s$ compete with each other to select the final CHs in cluster radii. The TCH node is calculated by each T_{CH} node. The CR varies with the distance of the node to BS and the residual energy of the node. Each T_{CH} uses Equation (6) to evaluate its CR_i.

$$CR_i = R_m \left[1 - \beta\left(\frac{d_{\max} - d(s_i, BS)}{d_{\max} - d_{\min}}\right) - (1-\beta)\left(1 - \frac{E_{r_i}}{E_{\max}}\right)\right] \quad (6)$$

where β is the design parameter whose range is in between (0, 1). For crowded and scattered networks, the optimum value of β is assessed in section 5. R_m is the maximum node range, which is considered as 60 m, and d_{max} and d_{min} indicate distance from BS to the closest and farthest nodes, respectively. $d(s_i, BS)$ indicates the separation between s_i node and BS. E_{r_i} is the node's residual energy, and E_{max} is the initial energy of node. Parameter β determines the extent to which these two factors affect the CR_i. According to Equation (6), if T_{CH} node is situated far away from BS, then its cluster radius (CR_i) will be more as compared to nearer ones. Thus, CHs in the vicinity of BS support the smaller cluster sizes; therefore, there will be more clusters in the surrounding area of BS. Hence, nodes closer to the BS can save a certain amount of energy during intra-cluster traffic, and it can be further utilized in the inter-cluster traffic. Other decisive parameter for (CR_i) is the residual energy of the node. If T_{CH} node has less residual energy, then its cluster radius (CR_i) will be less as compared to node having more residual energy. Due to the small cluster size, the T_{CH} node having less need to expend less energy to manage th operations of the cluster, thus allowing it to survive for a longer time period.

Since nodes are dispersed in a random fashion, a small cluster not necessarily have a less number of nodes, so the balance of energy usage cannot be properly implemented by utilizing the CR_i estimation using Equation (6). In the suggested EACUC protocol, cluster radius is further resized based on the node degree.

In the zone with more nodes, the numbers of CHs are distributed more, and in the area with fewer nodes, there are less CHs. In order to achieve the appropriate distribution of CHs, the CR_i is resized according to n_i. Here, n_i is the number of nodes whose distance from the i^{th} node is less compared to CR_i. In a circular area of CR_i radius, n_{av} is the average number of nodes and is given in Equation (7).

$$n_{av} = \left(\frac{\pi CR_i^2}{A}\right).N \quad (7)$$

where A is the area under observation and N is the number of sensor nodes in the observing area. If $n_i = n_{av}$, there will be no change in CR_i. If $n_i > n_{av}$, there are plenty of nodes around i^{th} node, so

CR_i is decreased to spread more CHs in the observing area. As CR_i decreases, n_i is decreased, and cluster size also reduces due to which the intra-cluster traffic costs. However, the network may have more CHs to cover all nodes due to the short cluster coverage. Figure 3 shows the original cluster size with a solid circle of radius CR_i and a resized cluster size with a dotted circle of radius CR'_i. The d_i ($CR'_i < d_i < CR_i$) is the distance from i^{th} node to a node that is in the circle whose outer radius is CR_i and the inner radius is CR'_i.

The distribution of d_i is

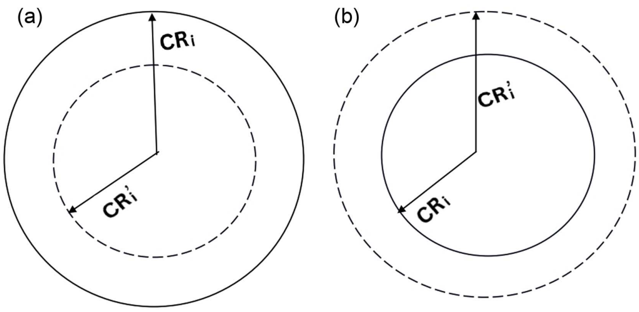
$$F(x) = P(d_i < x) = \frac{\pi \times (x^2 - CR_i'^2)}{\pi \times (CR_i^2 - CR_i'^2)} \tag{8}$$

where $CR'_i \leq x \leq CR_i$

The density function is

$$f(x) = \frac{2x}{CR_i^2 - CR_i'^2} \tag{9}$$

Figure 3
Resizing CR_i: (a) Decreasing and (b) increasing



The expectation of d_i is $E(d_i)$ and is given as follows:

$$E(d_i) = \int_{CR'_i}^{CR_i} x f(x) dx \tag{10}$$

$$= \frac{2}{3} \times \frac{CR_i^3 - CR_i'^3}{CR_i^2 - CR_i'^2} \tag{11}$$

The expectation of d_i^2 is $E(d_i^2)$ given as follows:

$$E(d_i^2) = \int_{CR'_i}^{CR_i} x^2 f(x) dx = \frac{CR_i^2 + CR_i'^2}{2} \tag{12}$$

The data length is assumed to be m bits. According to the energy model equation, the energy consumption of a node in the circle transmits m-bit data to the i^{th} node is given by Equation (13).

$$E_1 = m \times E_{el} + m \times E_{fs} \times \frac{CR_i^2 + CR_i'^2}{2} \tag{13}$$

If radius is reduced to CR'_i, a node might select another CH in the circle. It is assumed that the cluster radius of the newly elected CH is CR_i. The expectation of squared distance between nodes in the circle with the radius CR_i to the center is $CR_i^2/2$ according to Equation (12), so the expectation energy usage of transferring m bits information to new CH is given by Equation (14).

$$E_2 = m \times E_{el} + m \times E_{fs} \times \frac{CR_i^2}{2} \tag{14}$$

We assume that the node numbers in the circle are $n_i * (CR_i^2 - CR_i'^2)/CR_i^2$, so if the cluster radius decreases to CR'_i, the decreased energy consumption is given by Equation (15).

$$E_{dec} = m \times E_{fs} \times n_i \times \frac{CR_i^2 - CR_i'^2}{CR_i^2} \times \frac{CR_i'^2}{2} \tag{15}$$

Due to the small cluster size, there are plenty of CHs in the network, which are given as $n_i * (CR_i^2 - CR_i'^2)/CR_i^2$. If a CH sends a hand-shaking message and forwards data with the distance R_m, then the increased energy consumption is given by Equation (16).

$$E_{inc} = 2 \times (m \times E_{el} + m \times E_{fs} \times R_m^2) \times \frac{CR_i^2 - CR_i'^2}{CR_i^2} \tag{16}$$

Let $E_{dec} = E_{inc}$, from Equations (15) and (16), the revised cluster radius is given by Equation (17).

$$CR'_i = \sqrt{\frac{4 \times (E_{el} + E_{fs} \times R_m^2)}{E_{fs} \times n_i}} \tag{17}$$

If $n_i < n_{av}$, then there are less number of nodes around i^{th} node, so we raise CR_i to disperse less CHs across the region as shown in Figure 3(b). Now if the area of the cluster is increased, the sensing network might have less number of CHs, and its number is given as $n_i * (CR_i'^2 - CR_i^2)/CR_i^2$. If CH sends hand-shaking message and forwards data with the distance of R_m, the reduction in energy consumption is given by Equation (18).

$$E_{dec} = 2 \times (m \times E_{el} + m \times E_{fs} \times R_m^2) \times \frac{CR_i'^2 - CR_i^2}{CR_i^2} \tag{18}$$

Since the number of nodes in the circle is $n_i * (CR_i^2 - CR_i'^2)/CR_i^2$, so if the cluster size increases, the increased energy consumption is given by Equation (19).

$$E_{inc} = m \times E_{fs} \times n_i \times \frac{(CR_i^2 - CR_i'^2)}{CR_i^2} \times \frac{CR_i'^2}{2} \tag{19}$$

Let $E_{inc} = E_{dec}$,

From Equations (18) and (19), we get

$$CR'_i = \sqrt{\frac{4 \times (E_{el} + E_{fs} \times R_m^2)}{E_{fs} \times n_i}} \tag{20}$$

Initially, the radius of a cluster is computed by Equation (6) and then resized by considering the node's degree as calculated using Equations (17) and (20).

Now $T_{CH}s$ compete with each other to identify the most appropriate nodes as CHs. Compared to closer ones, the $T_{CH}s$ that are far from BS have greater CR'_i. The CHs that are near to BS accommodate small-sized clusters, so more clusters will be available around BS. The energy saved by the CHs that are nearer to the BS can be further used in inter-cluster traffic. Each T_{CH} candidate keeps record of number of its adjacent $T_{CH}s$ (ST_{CH}) node. The T_{CH} node SN_u is an adjacent node of SN_v, if SN_v is in $SN'_u sCR'_i$ or node SN_u is in

$SN'_v sCR'_i$. Each node is having a communication range denoted by R_m. SN_v node can therefore communicate with all its ST_{CH} members. Each T_{CH} then estimates a value function (P_{CH}) to assess the chance to become the CH as indicated in Equation (21). P_{CH} is dependent on the node's degree and present energy.

$$P_{CH} = \frac{E_{r_i} \times ND_i}{E_{avg} \times \sum_{N} ND_i}, E_{r_i} \geq E_{avg}(1-\gamma) \quad (21)$$

0, otherwise

where E_{r_i} = residual energy of i^{th} node.

E_{avg} = the network's average residual energy for the current cycle.
ND_i = ith node degree.
γ = design parameter whose value is in between (0, 1).

Equation (21) indicates that the tentative cluster head T_{CH} node with the highest node degree and residual energy has a higher P_{CH} value; therefore, T_{CH} that has high residual energy is thus positioned in the highly populated region and has a greater opportunity to become a final CH. The literature says that the CH available in the highly populated region is beneficial in reducing the cost of inter-cluster traffic and also acts as the central node. Each T_{CH} candidate sends a competition message (*CH_COMP_M*) after calculating P_{CH} which contains its identity, P_{CH} and CR'_i. There is a competition between every T_{CH} with the other $T_{CH}s$ node. Final CH is elected by T_{CH} node that acquires the highest P_{CH} value and then circulates a cluster head election message (*CH_ELECT_M*) to inform other adjacent $T_{CH}s$ nodes. Thereafter, other T_{CH} nodes of selected CH's ST_{CH} exit with the competition and notify by transmitting a set quit message (*QUIT_COMP_M*) to all members of their ST_{CH}. If the two T_{CH}s in ST_{CH} have a tie, the smaller ID node is chosen as CH. There is no more than one CH in CR'_i.

Let SN_u and SN_v nodes represent the tentative cluster heads T_{CH}s. SN_v is located in the CR'_i of SN_u, and both nodes are part of other T_{CH}'sSN_{CH}. If SN_u is identified as CH, then it sends its status to SN_v. Then SN_v behaves as a normal node after quitting from the competition and vice versa. The algorithm and flow chart for the CH selection mechanism are represented by Figures 4 and 5, respectively.

4.2.2. Cluster formation

After completion of the CHs identification process, inactive sensor nodes go to active mode. Thereafter, every CH broadcasts an advertising message *CH_Adv_M* across the entire monitoring region. Then, each ordinary sensor node connects with the nearest available CH and notifies to linked CH through a joining message *CLUSTER_JOIN_M*. In this way, clusters are formed; subsequently, CH decides the Time Division Multiple Access (TDMA) data scheduling format for all linked CMs by conveying this TDMA schedule to the entire respective member node.

4.2.3. Communication between CHs and BS

After gathering the data from their CMs, the CH transfers the data to BS. Before sending this data, it is first accumulated. The energy depletion of the sensor node primarily depends on the distance from the node to BS [36, 37]. In the suggested EACUC protocol, data packets can reach to BS in two different manners. The separation between CHs is estimated to determine the particular CH that is close to BS. Thereafter, the separation between sender CH and BS is approximated. If the separation distance from CH to BS is less in comparison to the distance between one CH to another CH, the data is straightforwardly sent to the BS; otherwise, the data is forwarded to the nearby available CH. The data traffic between CH and BS is single hop, while data traffic between CH and BS including other CHs is multi-hop.

Figure 4
Algorithm for CH selection mechanism

Start
φ = rand (0, 1)
if $\varphi < P_{th}$
Identified as tentative CH (T_{CH})
end if
if T_{CH}= True
every T_{CH} estimate its CR_i
if $n_u > n_{av}$
CR_u reduces to resized CR'_u
else if $n_u < n_{av}$
CR_u increases to resized CR'_u
else
unamended CR_u
end if
broadcast a message *CH_COMP_M* ($SN_u.id$, CR'_u, $SN_u.P_{th}$)
else
Exit
end if
at the reception of *CH_COMP_M* message from SN_v node
if d(SN_u, SN_v) < max(CR_u, CR_v)
include SN_v into set $SN_u.ST_{CH}$
end if
while reiteration the same till the CH competition time slot
expired **do**
if $SN_u.P_{th} > SN_v.P_{th}$; $\forall SN_v \in SN_u.ST_{CH}$
broadcast *CH_FINALSELECT_M* message that comprises $SN_u.id$
Exit
end if
at the reception of *CH_FINALSELECT_M message from* SN_v
if $SN_v \in SN_u.ST_{CH}$
broadcast *QUIT_COMP_M message* ($SN_u.id$)
Exit
end if
at the reception *QUIT_COMP_M* message from SN_u
if $SN_v \in SN_u.ST_{CH}$
remove SN_v from set $SN_u.ST_{CH}$
end if
end while

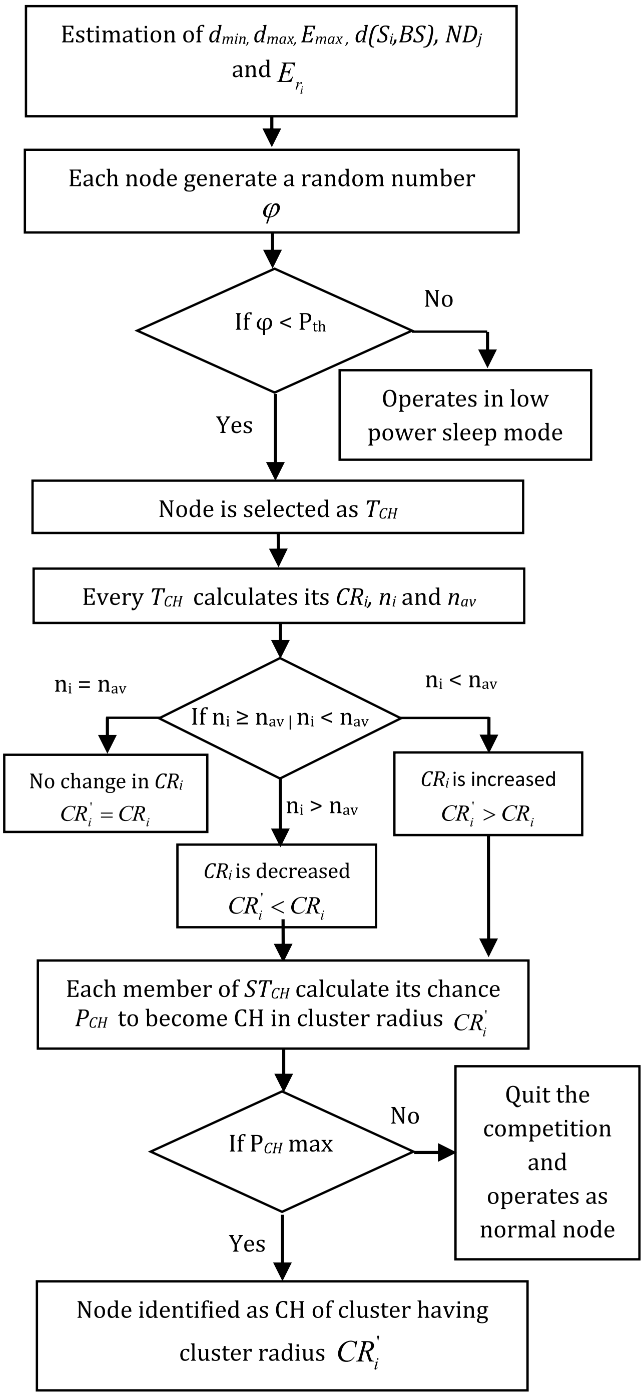
4.3. Steady-state phase

The data communication does occur during steady state. In the majority of clustered WSNs, the restructuring of clusters rolls up after every communication cycle, which in turn increases communication overheads. The process of re-clustering exhausts a substantial portion of the sensor node's energy. For the suggested EACUC protocol, communication overheads are reduced by retaining the cluster structure for a set number of communication rounds. This methodology ominously lessens the clustering overheads, which in turn also reduces the cost of intra-cluster traffic.

5. Simulation and Results

This section after simulation shows the outcome of the EACUC protocol observed in MATLAB, and its performance is compared with EEUC [32], EAUCF [29], URBD [31], and EAUCA [33]. The

Figure 5
Flow chart of CHs identification process in suggested EACUC protocol



findings are produced based on the network configuration parameters indicated in Table 2. The behavior of the EACUC protocol is analyzed with respect to the network life, the remaining energy, and the amount of data packets sent to BS.

The parameter for the evaluation of the energy performance of EACUC will be decided by the first node demise (FND), which is the node where its energy is totally drained off. The life of each node gives contribution for the operational lifespan of the network.

The information on the specific area of the observation region will never arrive to BS in the case of the node failure in that area. The route pathways are assembled during a round, and every node

Table 2
Network setup

Parameter	Value
Observing area	200x200 m^2
Node's count (N)	150
Node's initial energy	1J
E_{el}	50 nJ/bit
E_{fs}	10 pJ/bit/m^2
E_{mp}	0.0013 pJ/bit/m^4
E_{DA}	5 nJ/bit/signal
Threshold distance	87 m
Control packet	200 bits
Data packet	4000 bits
RAD	20 m

passes its information to BS. The round is said to be complete if all the nodes transfer their information to BS; otherwise, it is incomplete. Round is not the system's capacity in real time; rather, it shows the capability of nodes for data transmission. So round is a suitable parameter to analyze the lifespan of the WSN. The control message does not include useful user information data, and hence, useless information has to be sent during the exchange of the control message and therefore consumes energy. Many control messages are communicated during the process, such as Hello message, advertising message, CH request, detection of the neighboring node, members request, etc. There is no useful information in these messages, and also these messages consume much energy. The planned investigation will look at two possibilities that rely on the position of BS in the observation region. The BS is posted in the center of the observation region in scenario 1 and in the corner in scenario 2. In scenario 3, a key aspect of scalability of the WSNs is examined. Scalability is an important routing protocol design parameter. The routing protocol is scalable if the transformation in network topology will be adapted effectively such as variation in node count and observational region. The scalability measurement of the suggested EACUC is evaluated by changing the node density.

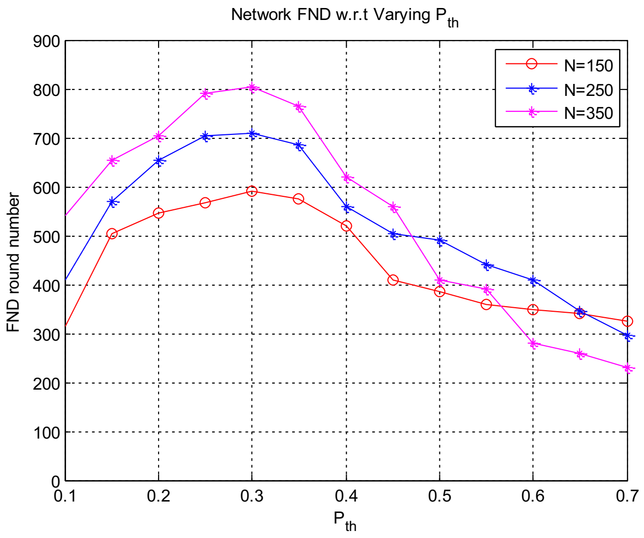
5.1. Parameter setting

P_{th}, R_m, and β are the different design parameters employed in the suggested EACUC protocol. This section also discusses the impact of such parameters on the operational life of the network and provides the assessment for the suggested network setup of the optimum value of these design parameters.

5.1.1. Impact of parameter P_{th}

At first, the impact of design parameter P_{th} on the network's operation life is analyzed. During the CH identification phase, a predefined threshold probability (P_{th}) is used to arbitrarily identify a set count of tentative CH candidates. The value of P_{th} is selected shrewdly as CH's quality, and the number of communication overheads depends on this parameter. More $T_{CH}s$ in the monitoring area will generate more communication overheads; however, less $T_{CH}s$ worsen the CH's quality. The impact of P_{th} is assessed for sparsely as well as densely node deployment in the observing area networks with 150, 250, and 350 sensor nodes. From Figure 6, it is clear that the optimum value of P_{th} is in between 0.24 and 0.34. To uphold

Figure 6
Impact of parameter P_{th}



CH's standard and keep communication overheads within the permitted range, a lower value of P_{th} is suitable for densely deployed node networks. In Figure 6, the higher values of P_{th} reduce the life of the network sharply in the densely deployed network because of massive communication overheads. As obtained from Figure 6, beyond $P_{th} = 0.3$, the network operational life declines quickly. The value of P_{th} is considered as 0.3 for the suggested network setup.

5.1.2. Impact of parameter β

This section analyzes the effect of the parameter β on the network operating lifespan. The value β in the monitoring area impacts the size of the cluster. For a set communication range of sensor nodes (R_m), competition radius CR_i depends on the distance between the sensor node to sink node $(d(s_i, BS))$ and its residual energy. β represents the degree to which distance and residual energy depend on the CR_i. The link between β and network operational life will be determined by changing its value between 0 and 1. When β is 0, the CR_i is estimated only by residual energy. If the value of β is increased beyond 0, then the influence of residual energy decreases conversely, and the influence of distance upsurges to decide the CR_i. At β = 0.5, the impact of both factors is the same on the CR_i, and beyond β =0.5, the influence of residual energy declines, and the contrariwise influence of the distance factor increases. At β =1, CR_i depends exclusively on the distance factor, and the influence of residual energy will become nil. Therefore, by varying parameter β, the dependency of distance and residual energy factors on the CR_i can be attuned. Figure 7 designates the impact of β on the network operational life, and it is indicated in Figure 7 that maximum network lifetime is achieved when the value of β is 0.7; henceforward in the suggested network setup, the value of β is considered as 0.7.

5.1.3. Influence of parameter R_m on network operational life

The influence of design parameter R_m on the network lifetime is evaluated in this section.

The R_m is the crucial parameter that affects the network operational life because R_m predominantly depends on cluster count and cluster's size. The network operating lifespan is assessed for a range of R_m and β values in Figure 8. The result designates that the suggested protocol performs best if the value of R_m lies within 60 and

Figure 7
Impact of factor β on network operational life

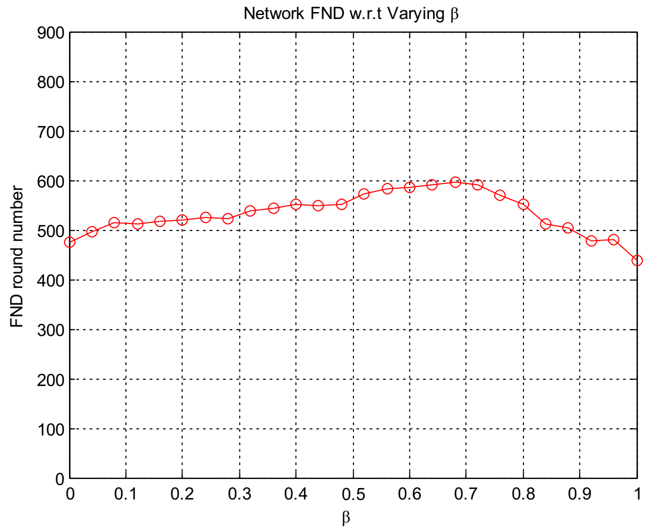
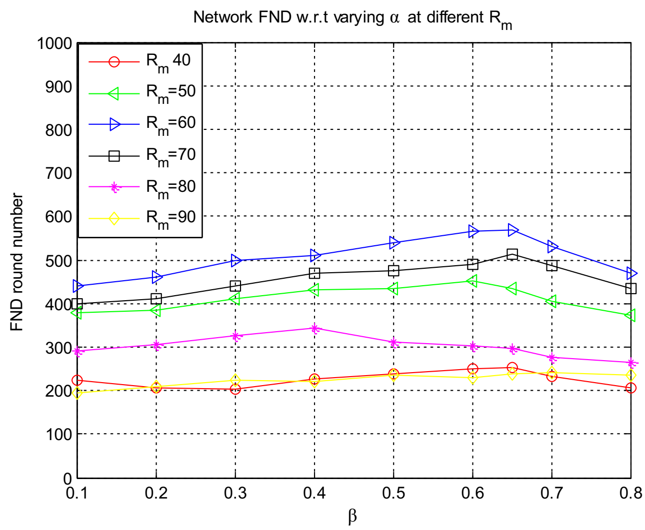


Figure 8
FND metric of suggested network setup for different R_m



70 m. In the suggested EACUC protocol's network setup, the value of R_m is considered 60 m.

5.2. Characteristics of CH

As claimed in section 4, the number of CHs identified depends on R_m and β. If R_m values increase, then the suggested EACUC protocol divides the observing area into fewer clusters, resulting in larger clusters that increase intra-cluster communication costs. Figure 9 designates the influence of R_m and β on the count of clusters within the network. In the suggested network setup, R_m is 60 m and β is 0.7. For these values of R_m and β, the average number of CHs is identified in the suggested EACUC protocol whose value is 9.

5.3. Network lifetime

The network operational lifetime of the suggested EACUC protocol is evaluated for different scenarios. In scenario-1, BS is

Figure 9
Count of clusters in the network for different R_m and β

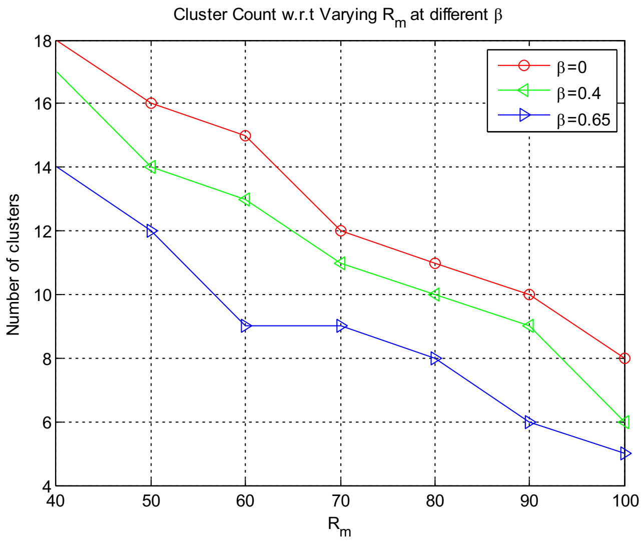
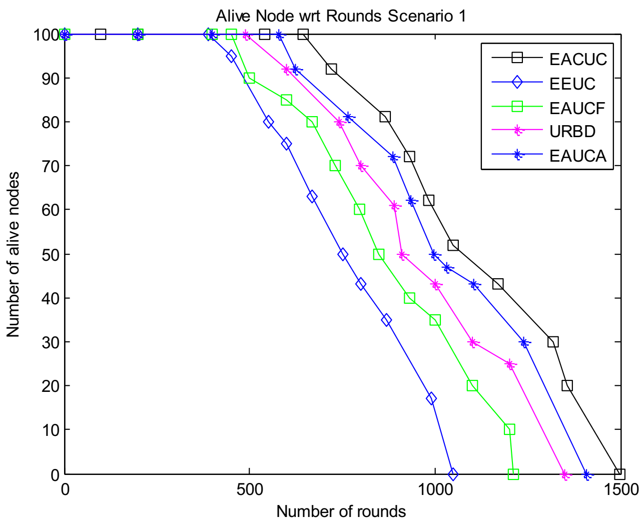


Figure 10
Alive nodes w.r.t. communication rounds for scenario-1



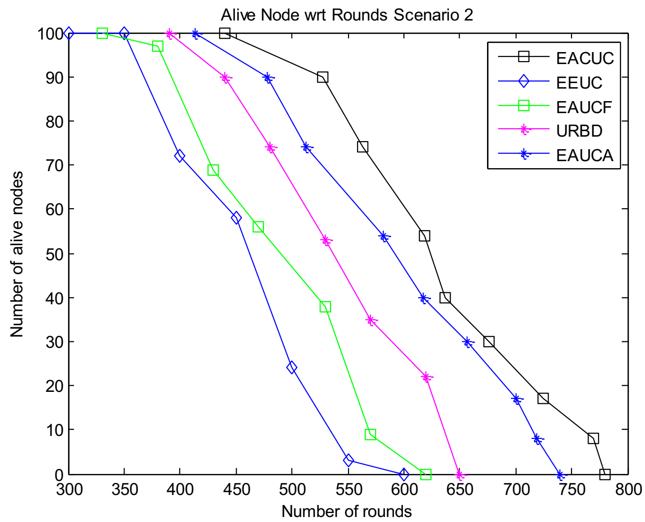
situated in the middle of the monitoring area. Figure 10 designates the alive nodes w.r.t communication rounds for suggested EACUC, EAUCA, URBD, EEUC, and EAUCF protocols. To recapitulate the simulation results, the communication round in which FND and HND as shown in Figure 10 are signposted in Table 3. The first sensor node entirely exhausts its energy at communication rounds 626, 561, 509, 478, and 428, for suggested EACUC, EAUCA, URBD, EAUCF, and EEUC, respectively.

The suggested EACUC protocol demonstrates 11.12%, 22.98%, 30.96%, and 46.26% enlargement in operational lifetime compared to EAUCA, URBD, EAUCF, and EEUC, respectively. The HND occurs at communication rounds 1008, 876, 811, and 753 for EAUCA, URBD, EAUCF, and EEUC, respectively, while HND occurs at communication round 1162 for the suggested EACUC. The results for the HND signpost that the suggested EACUC is far better than EAUCA, URBD, EAUCF, and EEUC by 15.29%, 32.64%, 43.27%, and 54.31%, respectively. The suggested EACUC protocol meritoriously allocates the network load among the sensor nodes that in turn enrich the network's operational lifespan.

Table 3
FND and HND metrics w.r.t. communication rounds for scenario-1

Protocol	FND	HND
Suggested EACUC	626	1162
EAUCA	561	1008
URBD	509	876
EAUCF	478	811
EEUC	428	753

Figure 11
Alive nodes w.r.t communication rounds for scenario-2



In scenario-2, the BS is positioned at the corner of the monitoring area, and the rest of the network simulation's remaining parameters are the same as considered in scenario-1. Figure 11 represents the network operational life, and Table 4 signposts the communication round where FND and HND for suggested EACUC, EAUCA, URBD, EAUCF, and EEUC. In case of the FND metric, the suggested EACUC is 10.63% better than EAUCA, 16.41% better than URBD, 28.21% better than EAUCF, and 33.34% better than EEUC. The suggested EACUC is superior to EAUCA, URBD, EAUCF, and EEUC by 10.31%, 15.77%, 22.43%, and 36.28%, respectively, in terms of HND metric.

Table 4
FND and HND metrics w.r.t. communication for scenario-2

Protocol	FND	HND
Suggested EACUC	468	631
EAUCA	423	572
URBD	402	545
EAUCF	365	495
EEUC	351	463

The results clearly show that the suggested EACUC protocol expands the operating life of the network. In addition to the network characteristics, BS location affects the projected performance of the protocol. Scenario-1 and 2 simulation results specify that the life of the network can be further increased by putting the BS in the

Figure 12
Average control messages generated in scenario-1

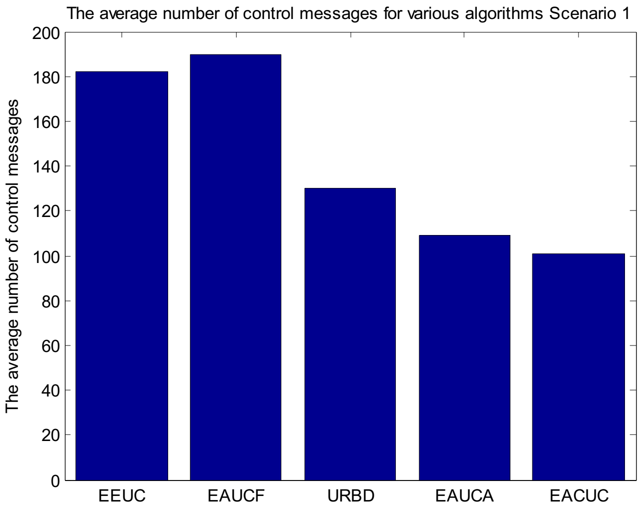
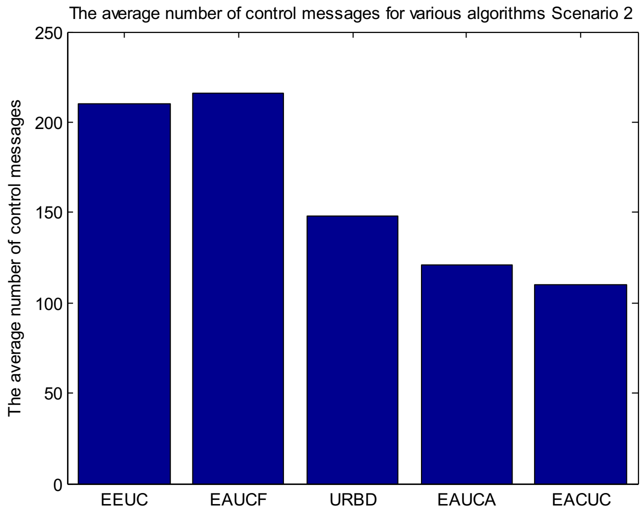


Figure 13
Average control messages generated in scenario-2



center of the monitoring region. In contrast, it is important to put the BS beyond the monitoring region in certain real-time application scenarios.

5.4. Control messages

The average control messages derived for implementing the suggested EACUC, EAUCA URBD, EAUCF, and EEUC during the communication process are shown in Figure 12 and Table 5 in scenario-1. All protocols are unequal clustering protocols, and there is conflict in every protocol between the sensor nodes in the cluster formation process and the CH identification process, which in turn increases the interchange of various types of control messages among the sensor nodes. The control messages generated by unequal clustering are always more than equal clustering protocols. The control messages produced in the EAUCA, URBD, EAUCF, EEUC, and suggested EACUC are 109, 130, 190,182, and 101, respectively. The cluster setup for a set count of communication rounds remains constant in the suggested EACUC. Control messages in the suggested EACUC protocol are effectively declined by the mechanism to retain a clustering setup for explicit communication rounds.

Table 5
Average control messages generated in scenario-1

Protocol	Number of average control messages
Suggested EACUC	101
EAUCA	110
URBD	131
EAUCF	189
EEUC	183

The average control messages generated in scenario-2 are indicated in Figure 13 and Table 6. The control messages produced in the suggested EACUC, EAUCA, URBD, EAUCF, and EEUC are 110, 122, 147, 217, and 211, respectively. The number of control messages generated in the suggested EACUC protocol is minimal among other clustering protocols.

Table 6
Average control messages generated in scenario-2

Protocol	Number of average control messages
Suggested EACUC	110
EAUCA	122
URBD	147
EAUCF	217
EEUC	211

5.5. Scalability evaluation

The scenario-3 investigates the scalability property of the WSN. The routing protocol is scalable if the variations in the network topology are adapted effectively such as variation in node count and observational region. The location of BS is positioned at the center of the observing region, and the rest of the design parameters remain the same as considered in scenario-1. The operational lifespan of the network is estimated for various node counts, that is, 200, 300, 400, and 500 sensor nodes. Table 7 designates the FND w.r.t. communication rounds. For suggested EACUC, the FND is at round 814, 869, 969, and 1118, if the nodes deployed in the monitoring region are 200, 300, 400, and 500, respectively.

Table 7
FND for different number of sensor nodes deployed in the monitoring area

	Number of Nodes			
Protocol	200	300	400	500
Suggested EACUC	814	869	969	1118
EAUCA	736	775	856	1025
URBD	658	708	837	979
EAUCF	644	683	792	889
EEUC	601	629	712	809

The results prove that the suggested EACUC still performs superior if the number of nodes is maximum in the network area; henceforth, the suggested EACUC exhibits the scalability property with the varying node count in the monitoring area.

6. Discussion

In spite of having several advantages of the proposed algorithm, there are some shortcomings, which are as follows:

Increased communication overhead: Inequality in cluster size determination and the need for frequent re-clustering in response to dynamic network conditions can result in higher communication overhead and higher energy consumption.
Scalability challenges: It gets harder to manage uneven clusters as a network gets bigger. In really large-scale deployments, the protocols could find it difficult to remain reliable and efficient.
Mobility support: A lot of protocols for unequal clustering are made for static networks. It can be difficult to modify these protocols for mobile nodes, which might cause problems with data transfer reliability and cluster stability.

7. Conclusion

This research proposes an energy-conscious competitiveness-based unequal clustering protocol (EACUC) for energy efficiency and energy hole issues. The competition radius in the suggested EACUC protocol is derived using node-to-BS distance and residual energy. In the suggested protocol, the cluster size varies exponentially; that is, there are small clusters near to the BS, whereas large clusters are formed away from the BS. This methodology indulged in the suggested EACUC protocol efficaciously and maintained the energy depletion across the network area. Additionally, the clustering structure is kept for a set number of rounds to minimize the message overheads. As a result, less energy is consumed by message overhead, and thus, the lifespan of WSN is extended. The results show that EACUC protocol enhances the network operational life by 11.12%, 22.98%, 30.96%, and 46.26% for scenario-1 and 10.63%, 16.41%, 28.21%, and 33.34% for scenario-2 than compared to EAUCA, URBD, EAUCF, and EEUC, respectively. The outcomes permit the significant improvement in the network lifespan for the suggested EACUC protocol and guarantee consistent energy consumption in addition to resolving the energy hole issue for all three scenarios. Furthermore, the results indicate that networks with a high node density can potentially benefit from the EACUC procedure. In the future, the suggested work can be expanded to heterogeneous sensor nodes in WSNs.

The proposed can also be deployed in real time. In precision agriculture applications, WSNs can track crop health, nutrient levels, and soil moisture. Effective data collection from geographically dispersed sensors is facilitated by unequal grouping. In smart buildings, WSNs are able to track temperature, occupancy, and energy usage. Data transmission frequency may be higher for sensors located near the base station or in high-traffic regions. A longer network lifetime can be achieved by using unequal clusters to spread the energy burden more fairly. WSNs keep an eye on industrial machinery to provide real-time process management and preventative maintenance. In geographically expansive industrial facilities, unequal clustering might be advantageous. Traffic movement and congestion are observed using sensors. Reliable and timely data transmission is necessary for urban environmental monitoring and surveillance sensor systems. In order to maintain continuous monitoring, unequal clustering aids in the management of the sensor network's energy resources.

In WSNs, unequal clustering procedures add a great deal of complexity in contrast to the more straightforward equal clustering. The reason for this is that complex routing protocols may need to be implemented to handle the uneven distribution of data among clusters. These protocols must also take into account the limited processing power and communication capabilities of sensor nodes. Finally, complex algorithms for choosing the best CH may need to take into account factors such as energy and distance.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Author Contribution Statement

Rohit Gupta: Conceptualization, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Vinith Chauhan:** Conceptualization, Methodology, Software, Validation, Resources, Data curation, Supervision, Project administration.

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