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ORIGINAL RESEARCH ARTICLE

Routing and clustering based energy optimization techniques in 5G networks for improving the performance and lifetime

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ABSTRACT

The 5G networks are the integral components of Wireless sensor networks also known as WSNs, providing critical data collection and monitoring capabilities. However, the limited energy resources of sensor nodes pose a significant challenge in maintaining the network's efficiency and longevity. To address this challenge, routing and clustering techniques have been extensively studied and employed to optimize energy consumption in WSNs. In the context of 5G networks, these techniques are tailored to improve the lifetime and overall performance of the network. Routing and clustering techniques in WSNs can be adapted and optimized for 5G networks to enhance energy efficiency and extend the network lifetime. The selection of specific techniques depends on the network characteristics, application requirements, and available resources. Ongoing research and development in this field aim to further enhance energy optimization techniques for the evolving needs of 5G networks. WSNs consist of numerous devices called sensor nodes which communicate with each other. Their main function is to sense the factors of the environment in which they have been deployed. The wireless communication techniques are utilized appropriately by the sensor nodes to communicate with each other. These techniques are governed by routing protocols based on the clustering process. Clustering is implemented using a new technique that is based on the social behavior of the network. Based on the above proposal, clusters are formed and these clusters are divided into two groups analogous to male and female herds. In the male group, the cluster head changes after every round of communication whereas in the female group, cluster heads continue until their energy is not drained. This results in improving the lifetime of networks resulting in a long time of communication as the nodes remain alive for a longer amount of time and clusters also continue for a longer period of time. In comparison with the existing techniques, this method based on Routing and Clustering based optimization gives better results in terms of lifetime, energy consumption, and the number of alive nodes. Also, energy consumption reduces substantially resulting in an optimal network.

Keywords: wireless sensor networks (WSNs); network lifetime; clustering; routing; live nodes; cluster head; energy consumption; optimization; energy conservation

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1. Introduction

Wireless sensor networks (WSNs) play a crucial role in 5G networks, as they provide data collection, monitoring, and control capabilities. However, due to the limited energy resources of the sensor nodes, optimizing energy consumption is essential to improve the lifetime and overall efficiency of the network. Routing and clustering techniques are commonly used to achieve energy optimization in WSNs. In the context of 5G networks, these techniques can be further tailored to address specific requirements and challenges[1].

1.1. Routing techniques

The routing and clustering techniques in WSNs can be adapted and optimized for 5G networks to enhance energy efficiency and extend the network lifetime. The selection of specific techniques depends on the network characteristics, application requirements, and available resources. Ongoing research and development in this field aim to further enhance energy optimization techniques for the evolving needs of 5G networks[2].

Energy-Aware Routing: Energy-aware routing algorithms aim to minimize the energy consumption of sensor nodes by considering the remaining energy levels and selecting energy-efficient paths for data transmission. Examples include the Minimum Energy Routing (MER) and the Energy-Efficient Shortest Path (EESP) algorithms[3].

Multi-Hop Routing: Multi-hop routing techniques enable data to be transmitted through intermediate nodes, reducing the energy consumption of individual nodes and extending the network lifetime. Popular algorithms include AODV and DSR[4].

1.2. Clustering techniques

LEACH: LEACH is a well-known clustering protocol that creates clusters of sensor nodes with a rotating cluster head. Cluster heads are responsible for aggregating and transmitting data, while the rest of the nodes can conserve energy by communicating only with their respective cluster heads[5].

HEED (Hybrid Energy-Efficient Distributed): HEED combines centralized and distributed clustering approaches. It uses a distributed algorithm to form clusters initially and then employs a centralized approach to elect cluster heads based on residual energy and distance to the base station[6].

PEGASIS: PEGASIS constructs a chain-based network topology, where each node communicates only with its nearest neighbors. The cluster head is dynamically selected, and data is aggregated and forwarded along the chain, minimizing the energy consumption of individual nodes[7].

1.3. Hybrid approaches

Some approaches combine routing and clustering techniques to achieve improved energy optimization. For example, a hybrid algorithm can utilize clustering for localized data aggregation and multi-hop routing for inter-cluster communication[8].

Machine learning techniques, such as reinforcement learning or clustering algorithms, can be integrated with traditional routing protocols to adaptively optimize energy consumption based on network conditions and traffic patterns[9].

WSNs consist of embedded devices called sensors, which are involved in the collection of data from the surrounding physical environment and transmit this data to the sink or base station. These nodes have limited capability and limited power. The batteries are prone to exhaust with time and since they cannot be recharged once distributed, they tend to die after some time[10]. Therefore, the only way to increase the lifetime of these networks, so that they can send data for a long amount of time, is the conservation of energy in sensor nodes by optimum use of the nodes. There are many optimized ways to conserve energy but nowadays technologists have shifted their focus toward nature-inspired algorithms[11]. This paper proposes to improve the network lifetime by reducing energy consumption. Integration of clustering and routing is a process that goes a long way in increasing the lifespan of a network. In this process, sensor nodes are assembled into small sets called clusters. From these clusters, the cluster heads are selected. Nodes with the highest energy are generally selected as Cluster heads. The data that is accumulated by all clusters is then transmitted to the cluster head which then transmits the data to the destination[12]. The selection of a Clusterhead is an important task. The selection of a proper route that remains for a long amount of time is also significant. Hence these two tasks are proposed in this paper which aims to increase the lifespan of the network. Bio-inspired techniques have a limited set of rules and can provide solutions to complex problems. The ability to adapt to variations of the medium and withstand external factors is helping in making the system a robust one. Many novel Bio-inspired techniques have been proposed and implemented by technologists and have proved to have provided very efficient and accurate results[13].

This paper presents an exploration of routing and clustering-based energy optimization techniques in wireless sensor networks for enhancing the lifetime of 5G networks. Routing techniques such as energy-aware routing and multi-hop routing are discussed, emphasizing their ability to minimize energy consumption by selecting efficient paths and enabling data transmission through intermediate nodes[14]. Furthermore, popular clustering techniques like LEACH, HEED, and PEGASIS are examined, showcasing their ability to create energy-efficient clusters, conserve energy through distributed communication, and leverage chain-based topologies[15].

The paper also highlights the significance of hybrid approaches that combine routing and clustering techniques to achieve even greater energy optimization in 5G networks. These hybrid approaches adaptively utilize clustering for localized data aggregation and multi-hop routing for inter-cluster communication, ensuring efficient energy utilization across the network[16]. Additionally, the integration of machine learning techniques and clustering algorithms is explored, showcasing their potential for adaptive energy optimization based on network conditions and traffic patterns[17].

The research and development in routing and clustering-based energy optimization performances for WSNs in the context of 5G networks aim to elongate network lifetime, enhance drive efficiency, and enable sustainable operation[18]. The findings presented in this paper contribute to the advancement of energy optimization techniques for WSNs and their application in 5G networks, ultimately facilitating the development of more efficient and long-lasting network infrastructures[19].

2. Literature review

Kaur et al., provides an overview of WSNs, including routing protocols, energy efficiency, and lifetime optimization techniques. Some authors propose a bio-inspired based routing technique that can be used to improve the efficiency of the routing technique[20]. This has been done by minimizing delay as well as reducing energy consumption. This method is inspired by the behavior of paddlefish and this technique has been aptly called Saddle goatfish routing protocol. Various cooperative behaviors are proposed in the natural hunting behavior that consists of different evolutionary activities and fitness is assumed to be one of the important parameters for the success of the behavior[21]. End-to-End Delay, Energy Consumption, and Packet Delivery Ratio are measured and compared in this technique[22].

Daneshvar et al.introduce the Low Energy Adaptive Clustering Hierarchy (LEACH) algorithm, which is a widely used clustering-based technique for energy optimization in wireless sensor networks[23]. According to the researchers, the process of clustering and Routing together is an efficient way to reduce energy consumption. This paper lies emphasis on the selection of a Cluster head and the methodology to select the cluster head uses a bio-inspired technique. For the selection of Cluster head, the factors considered are residual energy, load balancing capacity, and distance to the sink. This paper proposes to integrate the PSO and GSA algorithms for the clustering and Routing process[24]. The proposed algorithm uses the exploration capacity of GSA and the exploitation capability of PSO. The method when implemented shows that the energy consumption has been optimized, the premature convergence rate is avoided and a global optimum solution is obtained[25].

Majeed et al. present the Power-Efficient Gathering in Sensor Information Systems (PEGASIS) algorithm, which establishes a chain-based network topology to minimize energy consumption in wireless sensor networks. The energy consumption reduction technique is achieved by combining the clustering and Routing techniques but also uses a dual cluster head technique based on the Krill herd optimization technique Instead of choosing a random path, the method proposed chooses an optimized path by computing the path trust value krill herd maximization algorithm[26]. The collection of data by the cluster heads results in large consumption of energy. To reduce this energy loss, the authors propose a method called the centroids method. In this method the initial clustering is done by the pillar k means algorithm resulting in the placement of centroids away from distribution resulting in efficient clustering. After clustering the initial centroids act as aggregators. These functions both as aggregators and routers initially. This helps in increasing the lifetime of the network[27].

Manjeshwar and Agrawal, propose the TEEN routing protocol, which aims to optimize energy consumption and prolong network lifetime in wireless sensor networks. The authors finally discuss the different limitations of the algorithms and methods to overcome these limitations. These algorithms include the ACO algorithm, GA algorithm, cuckoo search algorithm, and other methods[28].

Zhang and Wang proposed a novel algorithm based on PSO and propose an improved bio-inspired clustering scheme called PSO-WZ. In the proposed technique, the Clusterheads are first initially decided randomly, and then non-CHs are assigned based on the division rule[29]. The division of the network is done based on two angles, one considering the non-CHs and secondly the network. The authors also propose a Gini coefficient to obtain the objective function. Here it selects as CH, the node with minimum consumption ratio, and non-CHs are assigned to the nearest CH so that the energy required for transmission shall be less[30]. The proposed algorithm helps in keeping more nodes alive and improves the lifetime of the network.

Yick et al. give a comprehensive survey paper that provides an in-depth analysis of various aspects of WSNs, including routing protocols, clustering algorithms, and energy optimization techniques. A hybrid algorithm has been proposed by combining the GA and PSO algorithms[31]. In this technique, the preliminary route is obtained by the GA technique, and optimization is obtained using the PSO algorithm. If some of the CHs are heavily loaded, their energy will be rapidly consumed. Hence it is necessary to balance the load for which a proper clustering and routing method must be implemented. Once clustering is implemented GA, PSO, and BFO techniques are used to find the optimum distance between destination and source[32].

Liu et al.focus specifically on energy-efficient routing algorithms in wireless sensor networks, discussing their advantages, challenges, and recent advancements. A clustering and routing technique based on Energy efficient PEGASIS protocol and Dragonfly algorithm has been proposed. In this technique, the nodes are distributed in an optimum manner using three different methods called the Random, the firefly, and the control methods. The nodes have the same energy with a unique ID[33].

Sharma and Tyagi provide an extensive review of routing protocols in wireless sensor networks, including energy-aware routing techniques, clustering-based algorithms, and their applications in different scenarios[34]. A new clustering algorithm is used to select the cluster heads for which the Grey Wolf optimizer (GWO) has been presented. The technique uses the same clustering in every subsequent round. This results in saving energy that may have been consumed due to reclustering. The clustering method divides the whole network into several clusters. To reduce the fast depletion of energy, a relay node is selected for each of the cluster heads. Only after 50% of energy is consumed in the cluster heads, the second clustering will take place with a new cluster head[35]. Until then the process continues with the same old cluster heads and clusters. Thu energy saving takes place because of the running of clusters for a longer amount of time.

Tang et al. focuses specifically on energy-aware routing protocols in wireless sensor networks, providing an overview of different approaches, their benefits, and their challenges[36]. PSO-based load balancing clustering algorithm is proposed, where the cluster heads are placed in an optimum manner. To overcome this, it is proposed to use a DE-based clustering algorithm that acts as a bridge between the parameters. One of them is lifetime maximization and the other is loading balancing. In this method, an additional node from an outside called gateway which shall act as a cluster head is introduced. All the nodes already in the networks get attached to these cluster heads introduced. For load balancing the PSO technique is used. This leads to improvement in the lifetime of WSNs[37].

Ahmed et al. give a comprehensive survey paper focusing on energy-efficient routing protocols in wireless sensor networks, discussing their classification, key features, and performance evaluation. Authors have proposed to form clusters using Fuzzy logic and then select the cluster heads[38]. The traditional Fuzzy logic has a limitation in that the rules and memberships have to be tuned manually. This results in more delay. Therefore, the authors propose that GA as it is a more powerful tool for stochastic search techniques and it can be implemented as a multiobjective function and can be used to obtain alternative solutions. Therefore for recomposition and reclustering, the authors have proposed a fuzzy-based GA technique. For finding the shortest path, the authors use the ACO algorithm. All these techniques have helped the authors not only improve the lifetime of WSNs but also with the proper load balancing of the network

These literature references provide a broad understanding of the routing and clustering-based energy optimization techniques in wireless sensor networks for improving the lifetime of 5G networks. They cover key algorithms, protocols, and surveys that are relevant to this research area, enabling a comprehensive review of existing techniques and insights for further exploration.

3. Proposed work

3.1. Clustering and routing

The clustering and routing process consists of two phases which are the cluster set-up phase and the data transmission phase. During the transmission process, the cluster heads aggregate data from the nodes in their respective clusters and then send it to the base station, directly or through a relay node.

3.2. Cluster head selection

The above-said process can be formulated as an optimization problem and mathematically expressed as,

$$\mathrm{Ft}_{\mathrm{CH}} = \alpha \times \mathrm{R}_{\mathrm{energy}}^{\mathrm{CH}} \tag{1}$$

where $\mathrm{R}_{\mathrm{energy}}^{\mathrm{CH}}$ is the ratio of the average energy of the Cluster heads to the average energy of normal sensor nodes in the current round. By maximizing $\mathrm{R}_{\mathrm{energy}}^{\mathrm{CH}}$ nodes with higher energy levels are selected as Cluster heads.

3.3. Relay node selection

If the base station is at a distance more than the threshold, then it is necessary to select a relay node and transmit the data through the relay node. The relay node in the proposed method is chosen based on the following two criteria. The first criteria are that the node with the highest residual energy should be selected and the second criteria are that the node nearest to the base station is selected among the nodes with higher residual energies.

If there are 't' potential relay nodes RN1, RN2, RN3 …………. RNt, between the Cluster head and Base station, then the equation for selection of Relay node may be expressed as:

$$\mathrm{Ft}_{\mathrm{RN}} = \beta \times \mathrm{R}_{\mathrm{energy}}^{\mathrm{RN}} + (1-\beta) \times \mathrm{R}_{\mathrm{location}}^{\mathrm{RN}} \tag{2}$$

where $\mathrm{R}_{\mathrm{energy}}^{\mathrm{RN}}$ is the ratio of average residual energy Relay nodes to average residual energy of Sensor nodes. Maximizing $\mathrm{R}_{\mathrm{energy}}^{\mathrm{RN}}$ results in the selection of a node with higher energy as a relay node. $\mathrm{R}_{\mathrm{location}}^{\mathrm{RN}}$ represents the location of the node which is nearest to the base station.

3.4. Energy consumption analysis

Let us assume that there are ‘n’ clusters and the number of nodes in every cluster is ‘m’. The energy consumed by a sensor node for signal transmission and reception plus the occasional sleep phases can be computed as follows:

$$E_{sn} = (1 - ps)[E_{tx}(l, d) + E_{rx}(l)] + p_s E_s \quad (3)$$

The data that is aggregated by the Cluster Head is then transmitted to the Cluster head nearer to the base station or directly to the base station. Depending on the distance between the cluster head and base station, the free space model or multipath model is selected.

Hence energy dissipated by the Cluster head is

$$E_{ch} = E_{tx}(l, d) + mE_{rx}(l) + ml(E_{da}) \quad (4)$$

where ‘m’ is the number of sensor nodes in a cluster. E_{da} is the energy dissipated per bit due to data aggregation. Therefore, energy dissipation within a Cluster is given as

$$E_{Cluster} = E_{ch} + mE_{sn} \quad (5)$$

Therefore, the total Energy consumed is given as

$$E_{total} = E_{Cluster} \times n \quad (6)$$

where ‘n’ is the number of Clusters.

4. Proposed methodology

The proposed technique will consist of the following steps:

1) The base station is assumed to be at the center of the clusters.
2) Then around 20 clusters are formed with each cluster consisting of 4 to 6 nodes.
3) Each cluster is marked sequentially as 1 to 20.
4) The energies of all the nodes are computed.
5) In all the clusters let the nodes with the highest energy in each cluster be the Cluster head.
6) The data is collected by the nodes and transmitted to the Cluster heads (CH). The CHs transmit the data to the Base Station (BS).
7) In case the distance between the cluster head and the base station is more than the threshold the cluster head in between the source cluster head and the base station is selected as an intermediate node for the transmission of data.
8) If there are more than two clusters in between, the cluster head with higher energy shall be selected as the intermediate cluster head and data will be communicated to the base station through this cluster head.
9) After the first communication is completed, the energies of the cluster heads come down and the energies may be another node is more than the cluster heads. In all odd-numbered clusters, the node with the second highest energies takes over as cluster heads analogous to male deers and the even-numbered clusters continue with the same cluster heads.
10) Again, communications take place and after every round, the cluster head changes in the odd-numbered clusters changes.
11) After a few rounds when the energy of the cluster head of the even-numbered clusters gets exhausted, that is it reaches its threshold, the node with the second highest energy takes over as cluster head and the process continues. This is analogous to the female clusters.
12) In this way communication takes place and data is transmitted from source to destination for a longer amount of time. Two different energy conservation techniques used in the two clusters are a unique point in this type of communication.

Altogether 100 nodes are spread over a square area of 300 m × 300 m size randomly. These nodes are prearranged with random energies. Initially, about 100 nodes are randomly distributed in a fixed area of 300 m × 300 m. Then clusters are formed with each about 4 to 6 nodes in each cluster. Every alternate cluster is assumed to be a female cluster. Numbering the clusters in such a way that all odd numbers of clusters shall be assumed as male clusters and every even number cluster shall be assumed as the female cluster. In the male clusters, the Rotation of cluster heads takes place in such a way that after every round of clustering the Cluster head changes. That means if one node with the highest strength is the cluster head, and after one round of communication, the energy of that cluster head diminishes and then the node with the second highest energy becomes the cluster head. This process takes place continuously in all odd-numbered clusters. These clusters are considered analogous to male clusters. Similarly, in even-numbered clusters, the cluster head with the highest energy is the cluster head and when the energy of this cluster head reaches its threshold, the node with the second highest energy takes over.

5. Results analysis

Simulation of this scenario with the proposed technique is implemented in NS2. Two ray ground propagation models are considered. For traffic patterns, the constant bit rate (CBR) of the always-on type of pattern is considered. The threshold is 0.2 mJ for every node Number of alive nodes; energy consumption and network lifetime are recorded. For traffic patterns, the constant bit rate (CBR) of the always-on type of pattern is considered. The threshold is 0.2 mJ for every node.

We are considering the variable number of nodes with the RWP mobility model and the pause period as 20 m/s. All the nodes in the network are prepared with 100 joules of energy battery initially and 250m as a fixed range of radio transmission. The MAC card, having data rates of 2 Mbps, is used which is an IEEE 802.11 MAC card. The transmitting and receiving power are set with a limit of 600mW and 300mW respectively. The simulation duration is kept as 1000s. Finally, the base node will generate a packet size of 512 bytes as a CBR traffic signal. We are going to take an average of 3 scenario performances in the simulation part. Three kinds of wireless nodes are considered for simulation,

1) A reputed node that follows the routing protocol specifications.
2) The nodes which drop the packets
3) Control packet modification nodes, which modify the packets.

All threshold values could be set at network initialization time. Hence, these values can be changed depending on the network's sensitivity and its application. The **Table 1**proposed parameers considered for the simulation process are given below.

Table 1. Parameters Considered for Simulation.

S. N.	Model constraints	Standards
1	Total nodes	100
2	Application area	300 m × 300m
3	Type of the channel	Wireless
4	Acceptance power	1 mw
5	Transferring power	2 mw
6	Package Size	1000 bits
7	Considered parameters	Total Alive Nodes, Energy Consumption, and Network Lifetime.
8	Initial node energy	100 J

The **Figures 1–3** below offer a graphical representation of performance comparisons between projected and existing techniques in terms of various parameters. **Figure 1** shows that the model proposed runs for 595 rounds for the longest time in comparison with the existing method. **Figure 2** shows that the nodes for the existing methods die earlier in comparison with the proposed one in terms of efficiency. The observation graph for **Figure 3** indicates that the recommended method consumes less power in comparison with the existing techniques. It shows that the projected work has a larger life span in comparison with existing techniques.

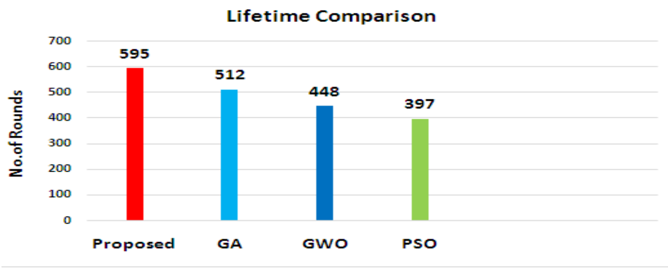

Figure 1. Comparison of lifetime.

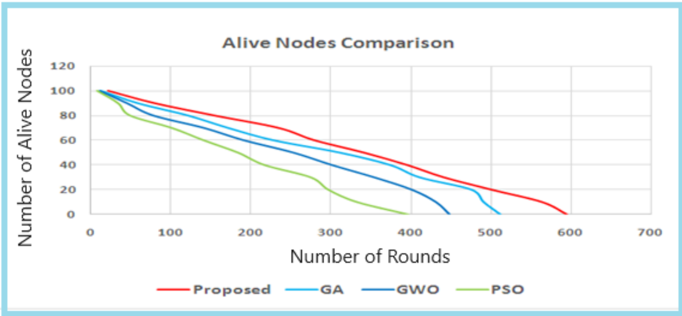

Figure 2. Comparison of alive node.

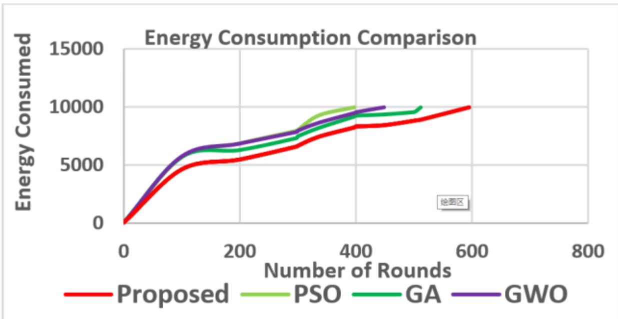

Figure 3. Comparison of energy consumption between proposed and existing methods.

6. Conclusion and future scope of the work

6.1. Conclusion

The research and development in routing and clustering-based energy optimization techniques for wireless sensor networks in the context of 5G networks are crucial for achieving sustainable and efficient network operations. The literature survey provides valuable insights into the advancements made in this area, including seminal algorithms, comprehensive surveys, and future directions. By leveraging these techniques and continuing research efforts, it is possible to improve the lifetime and energy efficiency of 5G networks, enabling their successful deployment in various applications and domains.

6.2. Future scope of the work

Routing and clustering-based energy optimization techniques play a crucial role in improving the lifetime and efficiency of 5G networks utilizing WSNs. The limited energy resources of sensor nodes necessitate intelligent strategies to minimize energy consumption and extend network longevity. Through the review of literature and research, it is evident that various routing and clustering techniques have been proposed and explored in this domain. Routing techniques such as energy-aware routing and multi-hop routing focus on selecting energy-efficient paths and enabling data transmission through intermediate nodes. These techniques consider factors like residual energy levels and aim to reduce the energy consumption of individual nodes. On the other hand, clustering techniques such as LEACH, HEED, and PEGASIS aim to create clusters of sensor nodes, with cluster heads responsible for data aggregation and transmission. By distributing communication and leveraging chain-based topologies, these clustering algorithms optimize energy utilization and prolong the network's lifetime.

Hybrid approaches that combine routing and clustering techniques have also been investigated. These approaches take advantage of the benefits of both routing and clustering to achieve enhanced energy optimization in 5G networks. They adaptively employ clustering for localized data aggregation and multi-hop routing for inter-cluster communication, ensuring efficient energy consumption across the network. Additionally, the integration of machine learning techniques and clustering algorithms holds promise for adaptive energy optimization based on real-time network conditions and traffic patterns.

Author contributions

Conceptualization, FR and RP; methodology, FR; software, FR; validation, FR, and RP formal analysis, FR; investigation, FR; resources, FR; data curation, FR; writing—original draft preparation, FR; writing—review and editing, FR; visualization, FR; supervision, FR; project administration, FR; funding acquisition, RP. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

Abbreviation

Sr. No.	Abbreviation	Definition
1	FtCH	The fitness functions of the Cluster Head.
2	R_{energy}^{CH}	The ratio of the average energy of the Cluster Heads to the average energy of normal sensor nodes in the current round
3	Alpha (α)	Proportionality factors
4	RN	Relay Nodes
5	T	Potential Relay Nodes between the CHs
6	Beta (β)	The term β is the Proportionality factors for the relay nodes
7	$\mathrm{Ft_{RN}}$	The fitness function of the Relay Nodes
8	$\mathrm{R_{energy}^{RN}}$	The ratio of average residual energy of the Relay nodes to average residual energy of the Sensor nodes.
9	$\mathrm{R_{location}^{RN}}$	The location of the node which is nearest to the base station
10	N	The number of clusters
11	M	The number of nodes in each Cluster
12	$\mathrm{p_s}$	Present Energy Status of the Node
13	$\mathrm{E_{tx}}$	Energy used for transmission
14	$\mathrm{E_{rx}}$	Energy used for transmission
15	$\mathrm{E_{da}}$	the energy dissipated per bit due to data aggregation
16	$\mathrm{E_{Cluster}}$	energy dissipation within a Cluster
17	$\mathrm{E_{total}}$	total Energy consumed
18	D	Distance between the Cluster Heads
19	l	Length of the Cluster

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