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Energy-Efficient Routing for Greenhouse Monitoring using Heterogeneous Sensor Networks

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***Abstract*—A suitable environment for the growth of plants is the Greenhouse, that needs to be monitored by a continuous collection of data related to temperature, carbon dioxide concentration, humidity, illumination intensity using sensors, preferably in a wireless sensor network (WSN). Demand initiates various challenges for diversified applications of WSN in the field of IoT (Internet of Things). Network design in IoT based WSN faces challenges like limited energy capacity, hardware resources, and unreliable environment. Issues like cost and complexity can be limited by using sensors that are heterogeneous in nature. Since replacing or recharging of nodes in action is not possible, heterogeneity in terms of energy can overcome crucial issues like energy and lifetime. In this paper, an energy efficient routing process is discussed that considers three different sensor node categories namely normal, intermediate and advanced nodes. Also, the basic cluster head (CH) selection threshold value is modified considering important parameters like initial and residual energy with an optimum number of CHs in the network. When compared with routing algorithms like LEACH (Low Energy Adaptive Clustering Hierarchy) and SEP (Stable Election Protocol), the proposed model performs better for metrics like throughput, network stability and network lifetime for various scenarios.**

Keywords—Internet of Things, WSN, Energy-efficient routing, Heterogeneous Networks.

I. Introduction

The greenhouse is an enclosed structure covering a large area; designed especially for cultivation and protection of tender plants. In modern greenhouses, monitoring of certain parameters is required to maintain the productivity and quality of the plants against any climatic changes. The parameter ranges from humidity, temperature, light intensity, CO_2 concentration to soil moisture. Researchers have been focusing on designing an automated embedded wireless intelligent monitoring system for greenhouse [1]. The rapid growth of IoT technology has been successful in providing a platform for interconnecting virtually any physical device to the cloud. Measurement and control of critical factors affecting plant growth is an example of IoT based application in agriculture [2].

IoT is a revolution in the field of technology representing the future of communication and computing. However, to connect any device to the network or database, a cost-effective and simple system of object identification is crucial. WSN forms a network of autonomous devices called sensor nodes to collect data and link it to the intelligent system shown in Fig. 1. The nodes are deployed over the enclosed system to collect data related to various functionalities. After collection, the data is processed and communicated to the gateway and stored in the cloud. The user can now be able to monitor and alter any parameter that favors the plant behavior.

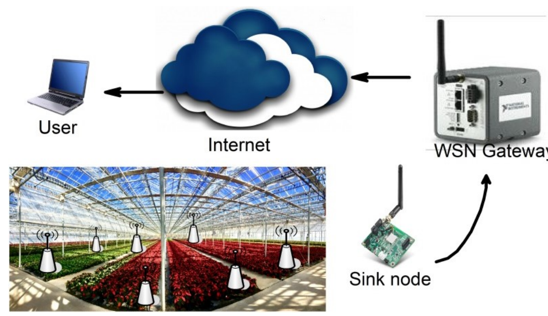

Fig. 1: Greenhouse monitoring using WSN

WSN-based IoT is a wireless network with benefits like convenient deployment, low cost and good scalability [3]. Wireless is preferred over wired networks due to its feasibility in installation in areas where cabling may not be possible. However, energy-efficient communication being one of the major concern in these battery operated sensors cannot be ignored. The clustering algorithm [4] is best suited for these energy-constrained networks to enhance the network lifetime. LEACH [5], a low energy adaptive clustering hierarchical is a common protocol used in homogeneous sensor networks. On the other hand, for networks with nodes of different energy level, the Stable Election Protocol [6] (SEP) is mostly used.

Classical clustering mechanism considers sensor nodes equipped with same initial energy level, due to which nodes die out randomly resulting in limiting the lifespan of the network [7]. Heterogeneity in the energy level of nodes eliminates this problem by distributing the load over the network. SEP algorithm can be applied for networks where nodes are divided into two categories based on energy level called normal and advanced nodes. For greenhouse monitoring, different types of sensors with unique specifications are required for accessing data related to various parameters. The battery power of nodes may not be similar leading to random death of nodes that shortens the lifetime eventually. The sensors also vary in their technical specifications, network sub-systems and computing devices [8]. Therefore, a heterogeneous routing algorithm becomes essential in maintaining energy and extending network lifetime.

In clustering algorithms, sensor nodes form clusters where a specially selected node called cluster head (CH) collects the data and forwards it to the sink node or base-station [9]. Proper selection of CH can lower the rate of cluster formation, thereby reducing the overhead in a sensor network. An efficient CH selection method is discussed in

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[10], where the CH position is rotated among nodes having higher residual energy than others. Factors like initial energy, residual energy and the optimal value of CH contribute in deciding the next CH.

In this article, the node clustering scheme is enhanced by modifying the threshold value of CH election suitable for a heterogeneous environment like a greenhouse. Since residual energy is one of the important criteria in the process of CH selection, the modified scheme is named as Residual-SEP (RSEP). According to the requirement in a large scale network, the sensor nodes are categorized into normal, intermediate and advanced nodes with respect to initial energy levels.

The normal sensors nodes are meant for sensing the environment and detect any changes in greenhouse parameters. The normal nodes forms cluster and are not allowed to take part in CH formation. Intermediate nodes have a power greater than the normal ones and are responsible for the collection of data from the member nodes. Advanced nodes are equipped with the highest power limit. They have a high-speed microprocessor and are operated with high bandwidth. These nodes are responsible for the processing of data, longer-term storage and also acts as a relay node for data transfer from CHs to the sink node. Advanced nodes form the second tier of CH, which indicates if all the intermediate nodes die out; the CH rotates within the advanced nodes. This set up helps in extending the network lifetime by distributing the load evenly in the field. The position of sink node or BS is fixed that dedicatedly looks for the designated channels to transfer packets coming from CH to the end user.

The paper aims to selecting the CH considering two important parameters like the residual energy of the individual node and the optimal number of CHs of the network. The primitive SEP routing method is modified with three level heterogeneity. The residual energy of each intermediate node is checked, and the one with the higher energy level in comparison to others has a higher probability for CH selection for the current round. The process continues till all the intermediate nodes die out. In the next phase, the residual energy of advanced nodes is checked for the election of next round cluster heads. This would prevent the network to die out too early thereby enhancing the network lifetime.

The paper organization is as follows: Section II provides the literature survey for the article. The proposed scheme and modified calculations for threshold value are discussed in Section III. Section IV shows the system settings and analyzes the simulation results. Finally, the article is concluded in Section V.

II. Related work

Sensors and actuators become necessary to monitor and control environmental factors in a greenhouse ecosystem. Proper routing of data is essential in those networks where sensors cannot send their data directly to the sink and have to rely on intermediate nodes to forward the data on its behalf. Sensor nodes in IoT based WSN are deployed over a large scale where intermediate devices like sink and gateway play a major role in delivering desired information to the user. Additionally, the classification of nodes into different categories distributes the load equally in the network [11].

Maintenance of WSN in a greenhouse is relatively easy and cheap as compared to other applications of WSN like health monitoring and military applications. The only extra cost builds up when nodes drain out the battery power completely that calls for an urgent replacement or charging [12]. Also energy consumption in WSN has a direct impact on network lifetime [13], which makes it a crucial issue that need to be handled properly. The lifetime of the battery can be extended to a larger time if an efficient power saving routing scheme is applied.

LEACH is the basic routing protocol to optimize energy and prolong the lifetime of the network [14]. The algorithm adopts a hierarchical clustering approach to distribute the energy evenly in the network. SEP is an enhancement of LEACH designed specifically for heterogeneous networks. Like the classical LEACH protocol, SEP algorithm has also been modified over time to provide better network performance when applied for real-time scenarios. A three-tier node system was introduced in [15], where nodes perform various functions like sensing the environment, processing the data and communicating the data to neighboring nodes. Extended SEP [16] discusses a topologically efficient algorithm considering three-tier nodes. However, the cluster heads can be elected from any node irrespective of its residual or initial energy.

Another modification of SEP for fog-supported WSN was presented in [17] that maintain a balanced energy dissipation to extend the lifetime of the network. Both types of nodes, whether normal or advanced have equal probabilities to be elected as CHs. Since the most eligible nodes become CHs, the node death rate is less as compared to other routing protocols. Threshold sensitive SEP (T-SEP) is a reactive protocol introduced in [18], where data is transmitted by sensors only when the explicit threshold is reached. Three level heterogeneous nodes were deployed to study the stability period and lifetime of the network.

Energy efficient heterogeneous clustering (EEHC) scheme that focusses on weighted election probabilities of each node [19]. The CH selection is done based on the residual energy in each node in the heterogeneous network. MATLAB results indicate enhanced network lifetime in comparison to LEACH. However, no result analysis is done with other heterogeneous algorithms. A hybrid routing scheme is discussed in [20] for a heterogeneous environment where sensor nodes follow different methods of data dissemination depending upon its position. The nodes nearer to BS send the nodes directly and those located far away send the packets via the relay node. Clustering of nodes is done on specific regions to save unnecessary power dissipation due to clustering and CH formation. The simulation result shows improved network performance in comparison to LEACH.

Clustering algorithm like LEACH and SEP selects cluster head in a probabilistic manner that does not consider any vital statistics such as residual energy or number of clusters in the network. This article intends to improve the primitive routing scheme with modifications for the betterment of network performance. The sensor nodes are categorized into three levels depending on the assigned function and the required energies. Since CHs plays an important role in enhancing network metrics, the election of the same should be done judiciously. The election of CH in the network plays an important role in extending the network lifespan. In this article, an energy efficient CH election is done by considering multiple parameters like initial and residual energy of each node with an optimal number of clusters in the network.

III. PROPOSED MODEL

The energy model used in [21] has been considered to study the behavior of the proposed model shown in Fig. 2. In this simplified radio model, the transmitter and receiver dissipate energy to run the radio electronics and power amplifier. The amount of energy a node dissipates depends on the bulk of data and the distance to be sent [22]. If the distance between sending and receiving nodes d is less than a reference distance d_0, then the energy consumed by a node is proportional to d^2. The proportionality factor changes to 4 otherwise.

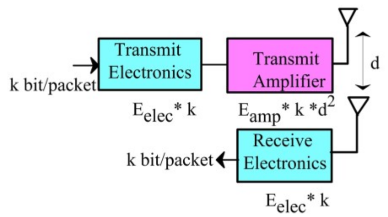


Fig. 2. Radio Communication Model

Hence the total energy consumed in transmitting a packet of k bits can be written as,

$$E_{Tx}(l,d) = \begin{cases} E_{elec} \times k + E_{fs} \times k \times d^2, d \le d_0 \\ E_{elec} \times k + E_{amp} \times k \times d^4, d > d_0 \end{cases} \quad (1)$$

$$\text{Where, } d_0 = \sqrt{E_{fs} / E_{mp}} \quad (2)$$

Similarly, to receive a packet of l bits, the energy consumed is given as,

$$E_{Rx}(l) = E_{Rx\_elec}(l) + lE_{elec} \quad (3)$$

Where, E_{elec} is the energy dissipated in running the transmitter and receiver section. It depends on factors like filter, modulation and coding techniques used. E_{amp} and E_{fs} are the amplifier parameters for multi-path fading model and free-space model respectively [23].

The sensor nodes are deployed randomly over the network. The position of nodes could not be altered after the deployment process culminates and senses the environment periodically to detect any parametric changes. The nodes are loaded with information related to their own location and position of the sink node. Also, it is assumed that at any instant of time, the node can estimate its remaining battery power. After deployment, sensors groups to form clusters based on proximity with a single cluster head in each cluster. The CH selection mechanism is similar to clustering algorithms such as LEACH and SEP, where a random node is generated in the range [0, 1]. If the number is less than $T(n)$, then the node is declared cluster head for the current round where,

$$T_n = \begin{cases} \dfrac{P}{1-P(r \bmod 1/P)}; \text{if } n \in G \\ 0; \; Otherwise \end{cases} \quad (4)$$

Where, G is the set of nodes that have not participated in CH selection process in the previous 1/ p rounds.

In a network of 'n' total nodes, 'a' is percentage of advanced nodes and 'b' is the percentage of intermediate nodes. The advanced nodes have 'α' extra energy and the intermediate nodes have 'β' extra energy such that $\beta=\alpha/2$. If E_0 is the initial energy given to normal nodes, then the advanced and intermediate nodes have $E_0(1+\alpha)$ and $E_0(1+\beta)$ energies respectively.

For normal nodes, the total energy E_n is written as:

$$E_N = nE_0(1-a-b), \text{ for normal nodes} \quad (5)$$

For intermediate nodes, the total energy E_I is given as:

$$E_I = nbE_0(1+\beta), \quad (6)$$

For advanced nodes, the total energy E_A is written as:

$$E_A = naE_0(1+\alpha), \quad (7)$$

Therefore, the overall energy of the network can be written as

$$\begin{aligned} &E_{Total} = nE_0(1-a-b) + nbE_0(1+\beta) + naE_0(1+\alpha) \\ &Hence, E_{Total} = nE_0(1+a\alpha+b\beta) \end{aligned} \quad (8)$$

A. Cluster-head Selection

Since energy is a crucial parameter in designing IoT based network, a routing scheme with energy efficient CH selection is introduced. The node that performs the functions of a CH for longer time duration will tend to exhaust its battery power prematurely. This calls for an optimized CH selection scheme that can extend the lifespan of the network. Since the network contains nodes of different energy level, the load of CHs can be made to rotate only among higher energy nodes. The normal nodes have the least energy and hence are responsible to sense the environment and communicate the data to CHs. For the initial rounds, only intermediate nodes are eligible for CH. With time when the intermediate nodes tend to die out; the CHs are elected from the group of advanced nodes. The two-tier CH election mechanism is done considering important parameters like residual energy and an optimum number of clusters in the network.

The threshold value for CH selection in each category of the node has been modified. $T(n_I)$ is the threshold for CH calculation for intermediate nodes and $T(n_A)$ is the threshold value for advanced nodes given by equation (9) and (11) respectively.

$$T(n_I) = \begin{cases} \dfrac{P_I}{1-P_I(r \bmod \dfrac{1}{P_P})} \times \dfrac{E_{r\_I}}{E_0(1+\beta)} \mathrm{k}_{opt}; \forall \text{ n } \in G_I \\ 0; \text{ Otherwise} \end{cases} \quad (9)$$

Where E_{r_I} is the residual energy of intermediate nodes, G_I is the set of intermediate nodes that have not been CH for the ($1/P_I$) rounds and P_I represents the probability of intermediate nodes to be elected as CH and given as:

$$P_I = \frac{P(1+\beta)}{1+a\alpha+b\beta} \quad (10)$$

$$T(n_A)=\begin{cases}\dfrac{P_A}{1-P_A(r \bmod \frac{1}{P_A})}\times\dfrac{E_{r\_A}}{E_0(1+\alpha)}\mathrm{k}_{opt};\forall \mathrm{n}\in G_A \\ 0;\ \text{Otherwise}\end{cases} \tag{11}$$

Where E_{r_A} is the residual energy of advanced nodes, G_A is the set of advanced nodes that have not been CH for the $(1/P_A)$ rounds and P_A represents the probability of advanced nodes to be elected as CH and given as:

$$P_{\mathrm{A}}=\frac{P(1+\alpha)}{1+a\alpha+b\beta} \tag{12}$$

Let the number of clusters in the network be 'm' and E_{r_I} and E_{r_A} are the residual energy level of the intermediate node and advanced nodes respectively. The optimal number of cluster k_{opt} can be rewritten as in [24].

$$k_{opt}=\sqrt{n/2\pi}\sqrt{\frac{E_{fs}}{E_{amp}d^4E_0(2m-1)(1+\beta)-mE_{DA}}}M \tag{13}$$

M represents the network diameter and d is the distance between sending and receiving node within the network.

B. System Operation

Once the CHs are elected, the network operation begins. The CH broadcasts an Energy REQ (request) message. The normal sensors measure their individual energy and transfer it to the CH with a Reply message. The CH receives all the Reply messages and compares the energy levels to select the highest E_{r_I} used in equation (9) for the new CH election. The new elected CH then broadcasts its ID to all the member nodes. The sensors then update the new ID information and communicate accordingly. The normal nodes meant for sensing the environment reports any change in the parameter to the CH if detected or switches to sleep modes otherwise.

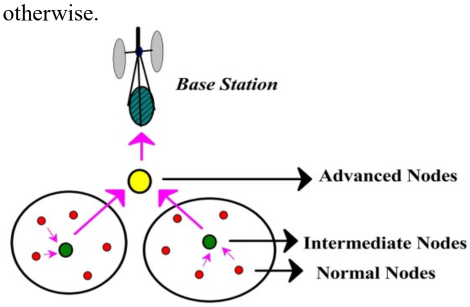


Fig. 3. The flow of data in the network

The sensing nodes transmit the data to respective CHs in the assigned TDMA (Time Division Multiple Access) slots. The heads then check for redundancy and process the data and transfer to the advanced nodes as shown in Fig. 3. In a large scale greenhouse, the distance between the sensor network and base station is explicitly outsized. Hence an intermediate node with high power is required to communicate the data over the large distance. Advanced nodes are equipped with the highest battery power and act as a relay between CHs and the base station. The process continues for the subsequent rounds until all the nodes of the network exhaust its energy.

IV. Simulation Result & Analysis

The section performs an evaluation of the proposed RSEP algorithm. 100 total sensor nodes are deployed in the greenhouse with 10 advanced nodes. The sink node is placed at the center of the network field. MATLAB simulation was carried out by varying the percentage of intermediate nodes for different cases of energies and the results are compared with LEACH and SEP algorithms. The standard parameters used for simulation are listed in Table 1.

TABLE I
SIMULATION PARAMETERS

Parameters	Value
Network diameter	100 meters^2
Total number of nodes (n)	100 nodes
Initial energy of normal node (E_0)	0.5 J
Energy dissipation: receiving (E_{amp})	0.0013 pJ/bit/m^4
Energy dissipation: free space model (E_{fs})	10 pJ/bit/m^2
Energy dissipation: power amplifier (E_{amp})	100 pJ/bit/m^2
Energy dissipation: aggregation (E_{DA})	5 nJ/bit
Packet size	4000 bits

We analyze important network parameters; i.e. stability period and throughput. Stability period is the time elapsed between the start of network operation until the death of the first node [15]. The throughput of a network is defined as the average number of successful data packets reception during communication from a sensing node to the base station. Both parameters are vital in evaluating the efficiency of the routing algorithm. The percentage of advanced nodes 'a' is kept constant at 0.1 and the value of 'b' is varied. The variation in percentage and energies of intermediate nodes helps to observe any change in network metrics.

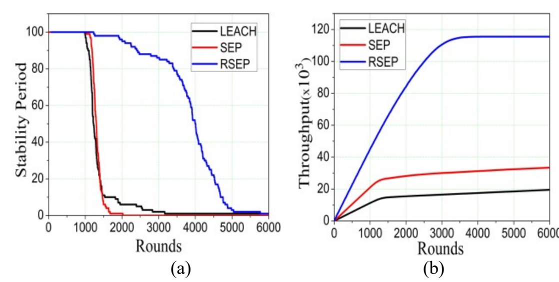
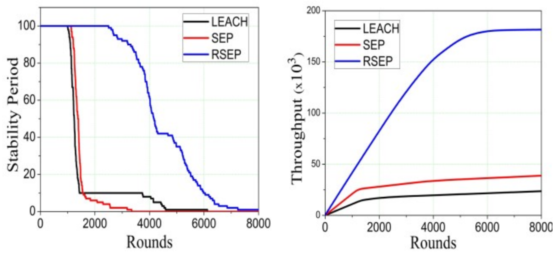


Fig. 4: (a) Stability Period (b) Throughput (β = 1, and b = 0.1)

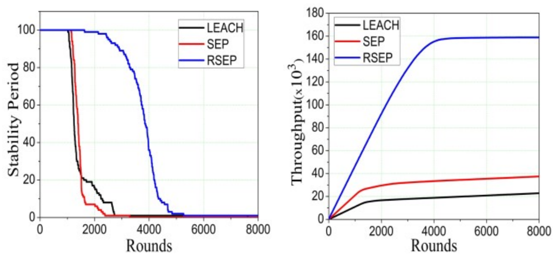
With 10 intermediate nodes in the network, as shown in Fig. 4(a), the first node dies (FND) out at 990 rounds in LEACH and almost 1030 rounds in SEP algorithm respectively. However, in RSEP the stability period is increased to 1230 rounds. This is major because of selecting the CH efficiently considering intermediate nodes only. The network lifetime is also increased up to 5000 rounds in the modified version of SEP. This indicates more packets are transmitted over the rounds. Fig. 4(b) suggests an increased throughput for RSEP as compared to LEACH and SEP by 80% and 50% respectively.



(a) (b)

Fig. 5: (a) Stability Period (b) Throughput (β = 2, and b = 0.1)

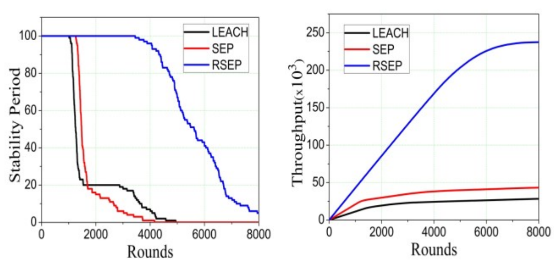
When the amount of energy supplied to intermediate nodes is increased twice that of normal nodes, an even better stability period and network lifetime is observed as shown in Fig. 5(a). The last node of SEP dies out at 3350 rounds and the first node of RSEP dies out at 2500 rounds. This clearly shows the efficiency of the proposed scheme in enhancing the network lifetime. Also, Fig.5(b) depicts the raised throughput for RSEP as compared to LEACH and SEP.



(a) (b)

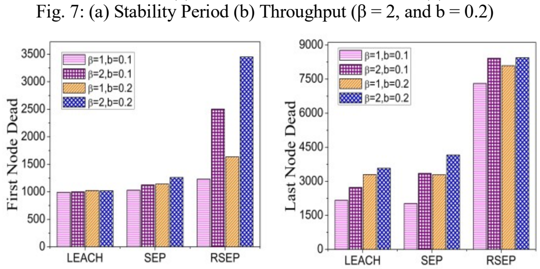
Fig. 6: (a) Stability Period (b) Throughput (β = 1, and b = 0.2)

Fig. 6 (a) and (b) shows the case when the number of intermediate nodes is increased to 20 percent. The stability period of RSEP is still greater than those of LEACH and SEP with FND at 1636 as compared to 1022 and 1140 rounds respectively. The network operation also extends up to 5000 rounds in RSEP resulting in improved throughput with minimal packet loss.



(a) (b)

Fig. 7: (a) Stability Period (b) Throughput (β = 2, and b = 0.2)



(a) (b)

Fig.8. Lifetime Metrics (a) FND (b) LND

To study the network behavior, the energy and number for the intermediate node are further increased. From Fig. 7(a), it can be studied that FND for RSEP occurs almost at the same time of LND (last node dead) for SEP. Although SEP considers two-level energy nodes, yet it distributes the responsibility of CH among both nodes equally. Hence there is a fair chance of repeated normal node selection for CH, resulting in the untimely death of the network. However, in the case of RSEP, the choice nodes opting for CH is fixed, which helps in sustaining the energy of the network for a longer period of time. The packet delivery ratio is also enhanced for RSEP by 50% as compared to SEP. The graph in Fig. 7(b) shows a fair rise in a number of successful data reception due to the transmission of packets for more number of rounds.

A brief analysis is done in Fig.8 to demonstrate the effect of the percentage of intermediate nodes and its energy on lifetime metrics like FND and LND. Figure 6(a) shows a clear rise in stability period for RSEP in comparison to LEACH and SEP because of proper CH selection using the modified threshold method. On a similar manner, the lifetime of the network for each case is also enhanced for RSEP. The proposed scheme chooses CH only from the intermediate nodes in the first tier, and from advanced nodes in the second tier. This enhances the lifetime of the network when compared with LEACH and SEP that rotates the CH randomly within all nodes.

V. Conclusion

Designing a WSN for IoT based application has to overcome number of problems when compared to normal ad-hoc sensor networks. Crucial issues like power and cost should be controlled wisely without altering its regular structure. One such case is deploying a sensor network for monitoring vital parameters in a greenhouse system to grow plants in regulated condition. This article presents a modular and scalable approach for even distribution of energy by considering a network with three categories of nodes. Each type of node performs a specific task based on its battery power. The CH selection method is also enhanced taking other parameters like initial and residual energy with an optimum number of the cluster in the network. The CH is chosen from higher energy nodes that help in maintaining the energy balance of the network. The simulation result shows better network performance when compared to LEACH and SEP routing methods.

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