# Maximizing the Lifetime of Wireless Sensor Networks with Mobile Sink

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***Abstract*—The key parameter that plays a major role in designing a protocol for WSNs is energy efficiency, which is the scarcest resource of sensor nodes and determines their lifetime of sensor nodes. Prolonging the lifetime of sensor networks depends on efficient management of the sensing node of energy.**

**The protocol proposed in this study is a modified routing protocol based on the LEACH protocol, which distributes cluster heads. It also proposes sink mobilization to overcome problems that exist in the case of static sinks. However, controlling the movement of the sink to achieve the most efficient data gathering, both to guarantee the quality of service and to reduce energy consumption, is an important issue in maximizing network lifetime.**

**The novelty of our proposed approach over other mobile-sink-based LEACH-modified protocols is that we assume that the mobile sink traverses along the Y-axis of the sensing area and is relocated at the start of each round by computing the optimal tentative sink node position considering both the geographical distance from the sensors to the sink and the transmission load of the sensors.**

**A comparative analysis based on the standard best-practice benchmarking metrics was performed. The findings of this study clearly demonstrate that the proposed approach outperforms the LEACH protocol in maximizing WSNs lifetime.**

***Keywords*—mobile sink, clustering algorithm, wireless sensor network**

## I. INTRODUCTION

Sensor networks have recently gained significant attention from the scientific research community and have become a leading area of research. A Wireless Sensor Network (WSN) is a collection of nodes with sensors in a communication network. The sensor nodes are randomly distributed in an area to serve various purposes, including remote or real-time applications and monitoring environmental conditions [1–4]. Energy usage is one of the most essential considerations is energy usage. WSN use energy to receive, transmit, and process the data. The more efficient the power usage in a wireless sensor network, the longer the service lifetime. The service lifetime of each node of a WSNs is relevant to the entire network because of resource limits, battery power, and the energy consumption of the network is the core of wireless sensor network research. Generally, the energy and power limitations of WSN nodes are regarded as decisive factors in node lifetime [5–9].

An effective scheme to extend the lifetime of a WSN is to use the concept of grouping nodes, or the so-called clustering method. Clustering is the process of combining sensor nodes in a network to form tiny disjoint clusters, each of which has a leader known as the cluster head (CH), and the other nodes in a cluster are known as member nodes (MN). In general, the node with the highest residual energy is chosen as the CH. The sensor node detects the information in the surroundings and communicates it to the CHs. The CHs collect data from all the sensor nodes, combine them, and send them to the sink/base station. Data aggregation by cluster heads minimizes the traffic at the sink and hence reduces the energy consumption of WSNs by using an effective clustering routing protocol [10, 11]. Generally, a clustered architecture results in a simpler and more stable topology, less overhead, and reduced flooding and collision. Fig. 1 shows a typical wireless sensor network logical hierarchy diagram.

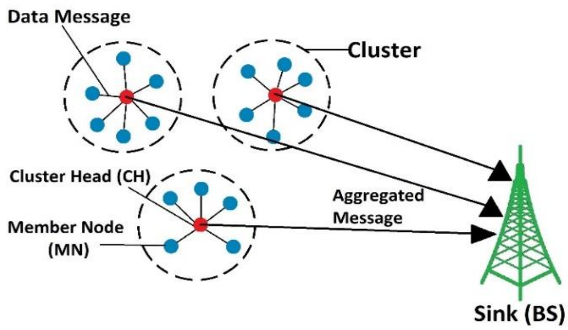


Figure 1. Typical WSN logical hierarchy diagram [2].

One routing protocol for WSN that uses the cluster method is the low-energy adaptive clustering hierarchy (LEACH) protocol [12, 13]. Although the LEACH of milestone significance in the clustering routing protocol determines the CHs based on the probability of each node, it is possible to select the adjacent CH. A CH that is not distributed in the network affects energy wastage.

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The proposed protocol is a modified routing protocol based on the LEACH protocol, which distributes cluster heads. Furthermore, this study also proposes the use of a mobile sink or base station, which is relocated at the start of a round to prolong the lifetime of the sensor network.

## II. Related Work

In recent years, many researchers have proposed different types of clustering protocols for WSNs. Siam and El-Jaafreh *et al.* [14] proposed an effective network-clustering method to enhance wireless network survivability. They determined that the greatest benefit of clustering the network on which they concentrated was a reduction in distances between sending and receiving stations, which lowered the transmission energy. This decrease in energy resulted in an improvement in the lifetime of the network.

Pal and Singh *et al.* [15] showed that clustering techniques extend the longevity of a load-balanced network. To ensure load balancing, the clustering algorithm rotates the function of the cluster head among the nodes. Hence, the process of selecting the cluster head is crucial for clustering algorithms. They described a genetic-algorithm-based cluster head selection method for centralized clustering algorithms, which resulted in a more load-balanced network than the classic clustering algorithm. The simulation results demonstrated that the proposed technique identifies the best cluster heads and has a longer network lifespan than traditional clustering algorithms, such as LEACH.

Chitra *et al.* [16] proposed a routing model called energy-efficient clustering (ENEFC), based on a hierarchical routing scheme. Simulations and analyses demonstrated that multilevel hierarchical ENEFC efficiently minimized and stabilized energy consumption across all sensor nodes, thus increasing the network's lifetime.

Mehfuz *et al.* [17] proposed the LEACH-Fuzzy Clustering (LEACH-FC) protocol and implemented fuzzy-logic-based cluster head selection and cluster creation. They used a centralized strategy rather than a distributed one to choose the CHs and form a cluster. They also used fuzzy logic to select the vice cluster head, which is a centralized technique. The suggested technique was shown to be successful in balancing the energy load at each sensor node, thereby improving WSN reliability. The LEACH-FC protocol outperformed the previously proposed algorithms in terms of increasing the lifetime of the network and minimizing the energy consumption.

Mabrouk *et al.* [18] presented an improved energy-efficient cluster head (CH) identification technique for WSN. Because they modified the CH selection process in LEACH, they suggested it as protocol enhancement. The choice of CH is made by balancing the cost of communication and the remaining energy. To avoid delivering duplicate information, they also identified the vice of each CH. The simulation findings clarified how well their approach may improve LEACH in terms of minimizing power consumption and maximizing network lifetime.

Gan *et al.* [19] suggested an energy-efficient clustering method that combines interval type-2 fuzzy logic and a dual super-cluster head (IT2FL-DSCH) mechanism to reduce and balance sensor node energy consumption. Taking into account the four fuzzy factors, namely cluster heads' (CHs') battery power, CHs' centrality, base station's (BS's) mobility, and distance between CHs and BS In terms of sensor node energy savings, network stability, and network longevity, the MATLAB simulation results demonstrate that this protocol outperforms low-energy adaptive clustering hierarchy (LEACH) and others.

Tanwar *et al.* [20] implemented a mobile base station or relay node to enhance the lifetime of a wireless sensor network in cognitive radio-based clustering for an opportunistic shared spectrum.

Minani [21] suggested a study for maximizing the lifetime of wireless sensor networks using the same parameters as those used in our research. A brief comparison is provided below:

| **Features** | **Our Proposed** | **Minani, F. [16]** |
|---|---|---|
| Round numbers | 500 | 500 |
| Alive nodes number | 100 | 80 |
| Dead nodes number | 0 | 20 |

## III. Methodology

A mathematical formulation of the network model and energy consumption model is presented, as well as simulation tools developed completely, including an original code, and implemented in MATLAB R2019b under ideal simulation conditions owing to the limitations of the real-time environment.

### *A. Network Model*

The network model used in this study was the WSN model, in which 100 homogeneous sensors were randomly distributed in a square area of 100×100 meter. It is assumed that: (1) each node has a unique ID number, a fixed position, with an initial energy of one joule, and the node energy cannot be supplemented. (2) The sink/base station can only be located at certain sites along a predefined path of 0 – 50 m on the Y-axis. (3) The idealized simulation environment did not consider the influence of natural factors such as temperature, humidity, light, and wind on the sensor nodes.

### *B. Energy Consumption Model*

This paper describes the energy consumption model proposed in [22], namely, the first-order radio-energy model considering both the free space model and multipath fading channel model, to analyze energy dissipation due to the actual transmission distance between the cluster head and sink node, as shown in Fig. 2.

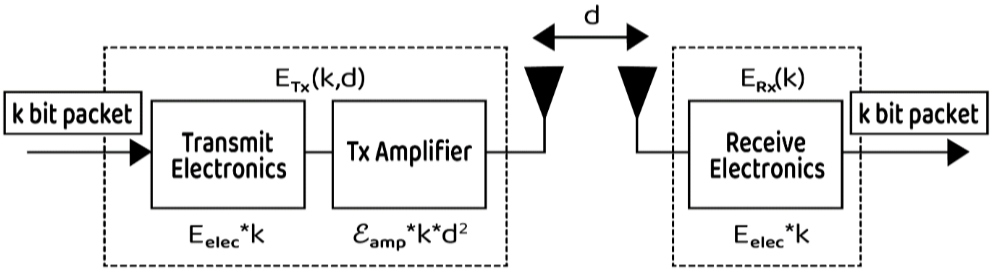


Figure 2. First order radio-energy dissipation model.

The transmission energy required for the transmission of a k-bit packet carried to a distance (d) between the transmitter and receiver radio in J/bit is $E_{Tx}(K, d)$.

$$E_{Tx}(K,d) = \begin{cases} K * E_{elec} + K * \varepsilon_{fs} * d^2 & , \ d \leq d_0 \\ K * E_{elec} + K * \varepsilon_{amp} * d^4 & , \ d > d_0 \end{cases} \quad (1)$$

where,

$E_{elec}$ is the amount of energy used by the circuit electronics to operate the transmitter and receiver (J/bit).

$\mathcal{E}_{fs}$ and $\mathcal{E}_{amp}$: This depends on the distance between the transmitter and receiver and the model of the transmitter amplifier used.

$d_0$: denotes the threshold distance in meters (m).

When d exceeded $d_0$, the multipath channel model ($d^{\lambda}=d^4$) was used. Otherwise, the dissipated energy was measured using the free-space channel model ($d^{\lambda}=d^2$), where $\lambda$ is the path loss constant.

The energy required to receive information from the k-bit packet in J/bit is expressed as follows:

$$E_{Rx}(K) = K \times E_{elec} \quad (2)$$

In Eqs. (1, 2), $E_{elec}$ is the energy consumed per bit by the transmitting or receiving circuits, and d is the distance between the transmitter and receiver. In (2), when $d \leqslant d_0$, we use the free space model and $\mathcal{E}_{fs}$ acts as the energy factor per bit. Otherwise, the multipath fading channel model is used, and $\mathcal{E}_{amp}$ acts as the energy factor per bit. Furthermore, $d_0$ was used as the distance threshold. As long as it is input as an independent variable into the free-space model and the multipath fading channel model to establish an equation, the following expression can be obtained:

$$d_0 = \sqrt{\frac{\mathcal{E}_{fs}}{\mathcal{E}_{amp}}} \quad (3)$$

In each round of data transmission, the cluster member nodes are responsible for sensing the information and transmitting it to the CH of the corresponding cluster.

The calculation formula for the energy consumed by transmitting $k$-bit information is defined as:

$$E_{non-CH} = e.E_{elec} + e.\varepsilon_{fs} d^2{}_{to\ CH} \quad (4)$$

where $d_{to\ CH}$: is the distance from the cluster member node to the cluster head. The cluster head receives information from the cluster member nodes in the cluster and transmits all merged information to the sink/base station. The energy consumed in the process is defined as

$$E_{CH} = \left(\frac{n}{m} - 1\right).e.E_{elec} + \frac{n}{m}.e.E_{DA} + e.E_{elec} + \begin{cases} e\varepsilon_{fs} d^2{}_{to\ BS}, & d_{to\ BS} < d_0 \\ e\varepsilon_{mp} d^4{}_{to\ BS}, & d_{to\ BS} \geq d_0 \end{cases} \quad (5)$$

where $n$ is the number of surviving nodes, $m$ is the number of clusters, $E_{DA}$ is the energy consumed by the cluster head to process each bit of information, and $d_{toBS}$ is the distance between cluster head and the base station. Therefore, the energy consumed consists of receiving, processing, and transmitting energy consumption.

### C. Descriptions of the Proposed Algorithm

The basis for determining cluster head in the LEACH protocol is a predetermined probability value and a random value from the threshold; hence, it is possible to select adjacent cluster heads. A cluster head that is not distributed in the network will impact energy wastage and may form inactive nodes outside all cluster head ranges, further impacting energy usage. However, the LEACH protocol aims to increase the lifetime of WSNs by lowering the energy consumption required to create and maintain cluster heads by maintaining a balance of weights among all nodes. This is important because each node has limited energy, and each node tries to use an energy load that is almost the same; hence, the lifetime of the entire WSN increases.

This study proposes a modified routing protocol based on the LEACH protocol and distributes cluster heads. The cluster heads are chosen during the setup phase by selecting a random number between 0 and 1. If the number is less than a specified threshold, the node will become a cluster head. The optimal number of cluster heads is 5% of the total number of network nodes [23]. Hence, in our case, 5% of the 100 sensor nodes are the desired percentage of those becoming a cluster head, which ich is equal to five cluster heads. Cluster members are normal nodes that are connected by a principle adjacent to the appropriate cluster head nodes. Normal nodes collect data from their environment and send it directly to the head node of the cluster. The node then broadcasts a cluster head advertisement message to its neighbors, and the normal nodes respond by sending a join message to the CH with the strongest signal received. After the network is divided into clusters, each CH generates and distributes TDMA time slots to the members of its cluster, and a CDMA code is chosen to send the sensed data to the BS.

The Steady-state Phase begins with each sensor node sensing the environment and transmitting the data to its CH. The CH node receives sensed data from all its group members, aggregates it, removes redundancy, and forwards it to the sink/BS. The network status was reset to the setup, and a new round was started [24]. To save energy, the duration of the steady-state phase (10 s) should be much greater than that required in the setup phase (4 s) [25].

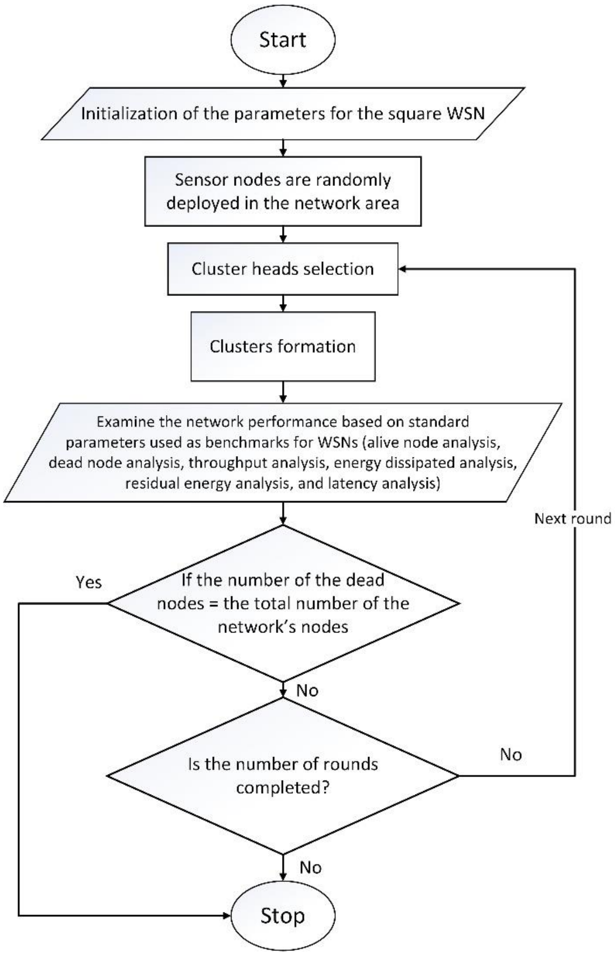


Figure 3. The proposed algorithm flowchart.

This study also proposes the deployment of a mobile sink or base station traverses along the Y-axis of the sensing area and is relocated at the start of each round by computing the optimal tentative sink node position considering both the geographical distance from sensors to sink and transmission load of sensors as well. After calculating the energy consumption of all nodes, the mobile sink selects the cluster head according to the node residual energy. Then, cluster formation is executed, and the network determines whether the data transform cycle can still be carried out. If the power in every node is below the threshold, the simulation round is stopped even if the number of rounds is not completed. Otherwise, the simulation rounds continued until the end of the specified number of rounds.

Fig. 3 describes the simulation flowchart carried out in this study, with the aim of providing better energy efficiency by considering the efficiency parameters from the perspective of network lifetime and energy dissipation.

## IV. Results and Analysis

A comparison is drawn between the performance analysis of the proposed algorithm and LEACH using MATLAB R2019b. In the network, 100 nodes were randomly distributed in a 100mX100m area with a mobile sink. The performance assessment is done in terms of standard parameters used as benchmarks for WSNs, namely, number of alive nodes: quantity of nodes that have not yet exhausted their energy power below the threshold value; number of dead nodes: number of nodes that have exhausted their energy power below the threshold value; throughput: quantity of packets per byte received by source per unit time; total energy dissipated: total energy used by the nodes due to their different activities; residual energy in the network: the current value of energy in a node after receiving or transmitting routing packets; latency: time utilized for a message to be communicated across the network from source to destination, in other words, end-to-end delay. The maximum number of rounds used in the simulation was 2048. The simulation parameters are listed in Table I, and are the same as those used and published in the literature [21, 24].

TABLE I. Network Parameters

| **Parameters** | **Description** | **Value (unit)** |
|---|---|---|
| N | Number of nodes | 100 nodes |
| W | Width of the network | 100 m |
| L | Length of the network | 100 m |
| P | Desired percentage of cluster head | 0.05,i.e, no. of CHs=5 |
| num_rounds | Maximum number of simulated rounds | 2048 rounds |
| $E_i$ | Initial energy of each node | 1 J |
| $E_{trans}$ | Energy for transmitting 1 bit | 50×10-$^{9}$ J/bit |
| $E_{rec}$ | Energy for receiving 1 bit | $50\times10^{-9}$ J/bit |
| $E_{agg}$ | Data aggregation energy | $5\times10^{-9}$ J/bit |
| $E_{fs}$ | Energy of free space model amplifier | $10\times10^{-12}$ J/bit/m$^2$ |
| CHp1 | Packet size for cluster head per round | 4096 bits |
| Non_CHp1 | Packet size for normal node per round | 2048 bits |
| $T_{setup}$ | Set-up phase time | 4 seconds |
| $T_{ss}$ | Steady-state phase time | 10 seconds |
| $S_X$ | Sink position in the X-axis | 0 m |
| $S_Y$ | Sink position in the Y-axis | Travels along the predefined path 0 – 50 m |

Fig. 4 shows a comparative analysis of the live node of the proposed algorithm with LEACH. It is clear that our algorithm performs better than LEACH does. The LEACH algorithm has 76 nodes that are still alive after 2048 rounds, whereas the proposed algorithm has 80 nodes, that is, an enhancement in the network lifetime by 5.26%.

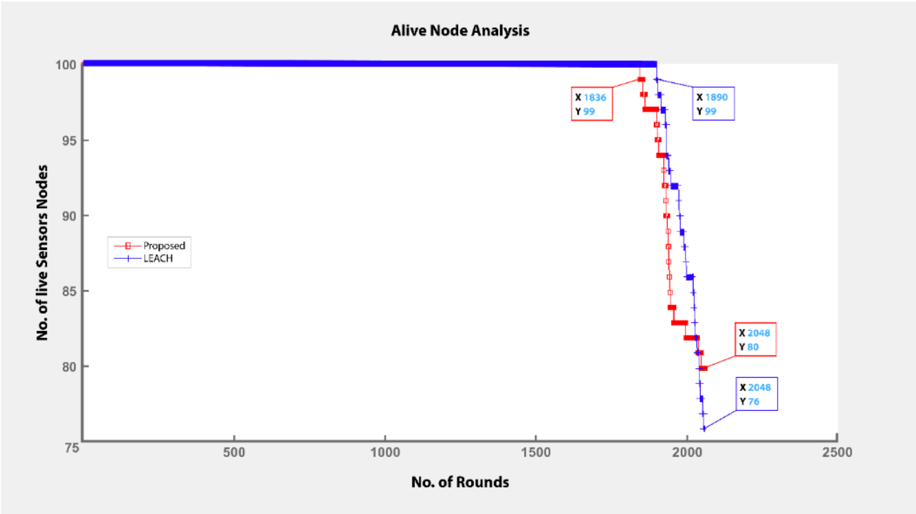


Figure 4. Alive node analysis over 2048 rounds.

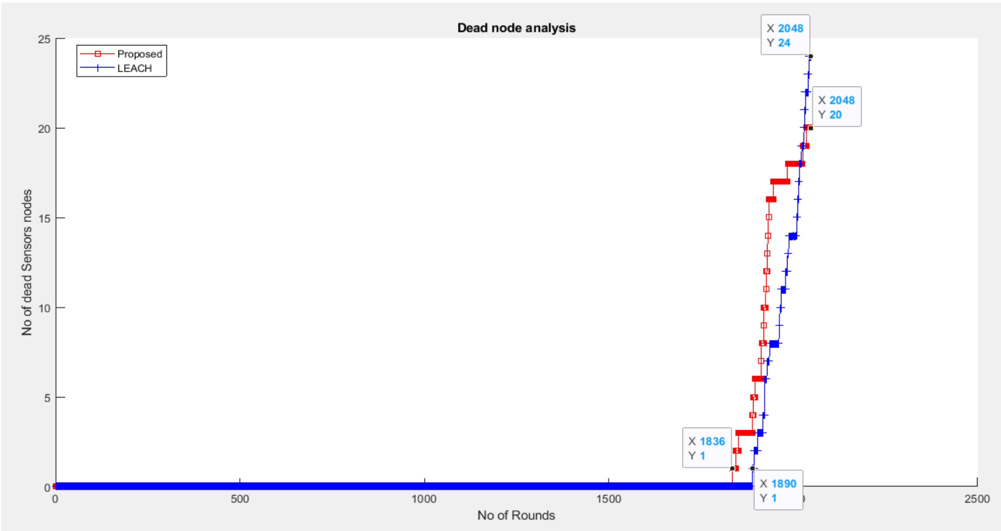


Figure 5. Dead node analysis over 2048 rounds.

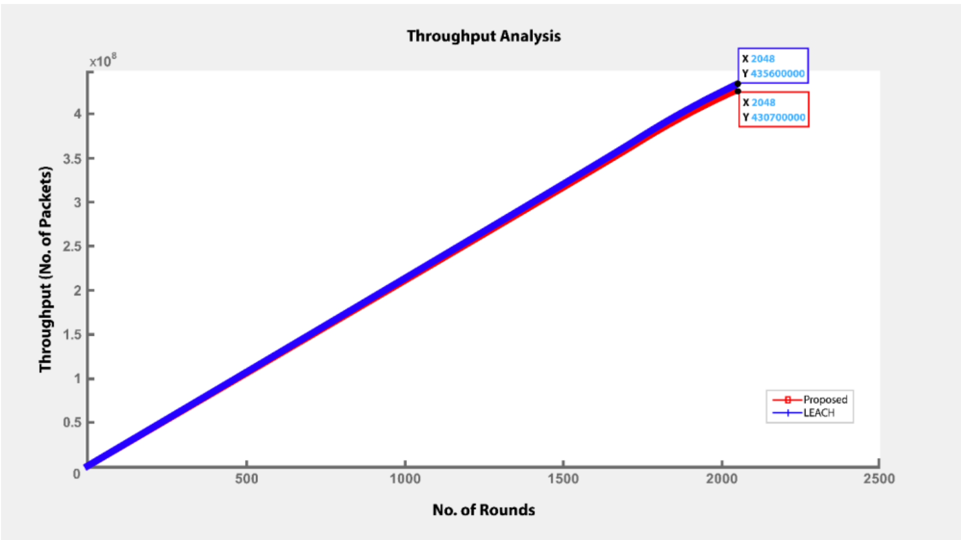


Figure 6. Throughput analysis over 2048 rounds.

Fig. 5 shows a comparative analysis of the dead node of the proposed algorithm with LEACH over 2048 rounds. Our proposed algorithm has four fewer dead nodes over rounds than LEACH and outperforms LEACH by 16.67%

fewer dead nodes, which is impressive because it means that the network is active for more rounds and thus has a longer lifetime.

Fig. 6 illustrates the throughput analysis for LEACH and the proposed algorithm. After 2048 rounds, the LEACH algorithm sends $4.356 \times 10^8$ packets to the BS, whereas the proposed algorithm sends $4.307 \times 10^8$ packets to the BS. However, the LEACH algorithm could deliver slightly more data packets to the BS compared to the proposed algorithm by sending $4.9 \times 10^6$ packets. Owing to the first dead node occurring in our proposed algorithm before LEACH, the election of CHs became unstable, which decreased the number of packets transmitted to the BS, resulting in a lower throughput for our proposed algorithm [26].

Fig. 7 shows the total energy dissipated over the rounds. The total energy dissipated in the network by LEACH algorithm is 96.05 J, while our proposed algorithm dissipated energy is 93.47 J, as shown in Fig. 7. Clearly, the proposed algorithm consumed less energy at the sensing nodes and saved 2.58 J more than the LEACH algorithm, and outperformed LEACH by 2.69%.

Fig. 8 shows a comparative analysis of the residual energy in the network of the proposed algorithm with LEACH. The LEACH algorithm has a residual energy of 3.96 J, which is lower than that of the proposed algorithm (6.53 J over 2048 rounds. Hence, it outperforms LEACH by 64.90%, thereby increasing the network lifetime.

Finally, Fig. 9 illustrates the end-to-end delay over rounds (latency). After completing 2048 rounds, LEACH algorithm took 0.22 seconds, which is a little bit less latency than the proposed algorithm which took 0.23 seconds. However, after 2100 rounds, the proposed algorithm outperformed LEACH by 4.55%.

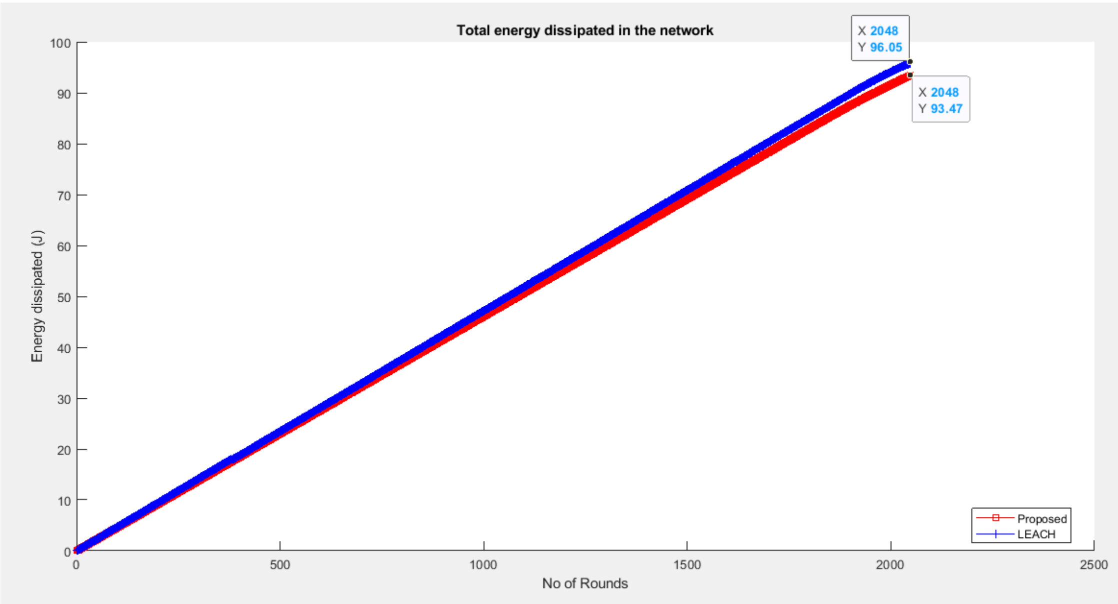


Figure 7. Total energy dissipated at 2048 rounds.

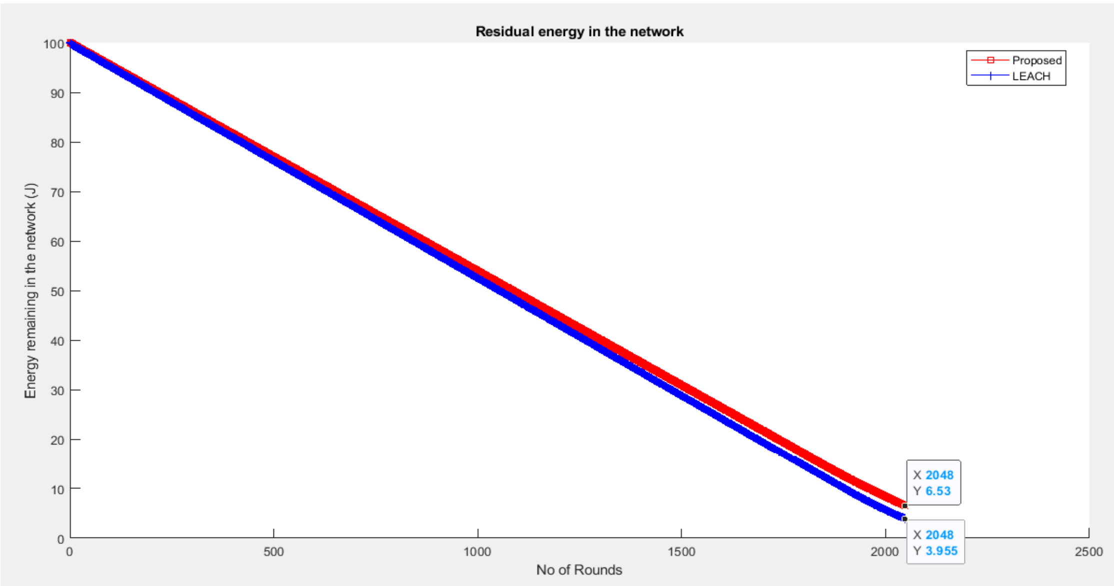


Figure 8. Residual energy in the network over 2048 rounds.

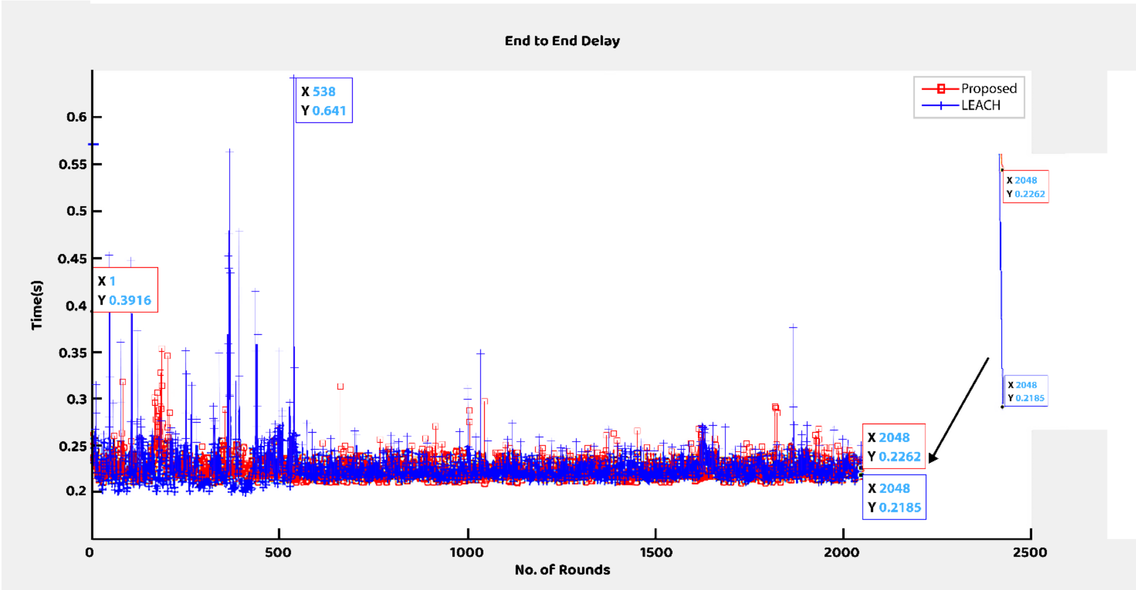


Figure 9. Latency analysis over 2048 rounds.

## V. Conclusion

The major aim of any wireless sensor network is to prolong the overall network lifetime as much as possible. Therefore, energy efficiency is a high-priority parameter for any sensor network, and thus, any efficient management needs to be focused on. Clustering is also an effective technique that can contribute to the entire network lifetime and energy efficiency of WSNs. In this paper, we present an energy-efficient protocol to prolong the WSN lifetime based on a modified LEACH routing protocol, as well as using a mobile sink or base station for data gathering in WSNs. The simulation model results show that the proposed algorithm is a significant improvement over LEACH, and can improve the overall network lifetime. The number of live nodes increased by 5.26%, the number of dead nodes decreased by 16.67%, the energy consumption decreased by 2.69%, the residual energy increased by 64.90%, and the latency time decreased by 4.55%.

## Conflict of Interest

The authors declare no conflict of interest.

## Author Contributions

Eljaafreh: formulating the research idea, supervising simulation experiments and editing the paper. Alsalahat: literature review, performing the experiments, presenting the results and writing the paper. All authors had approved the final version.

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