Innovative Computing Review (ICR)
Volume 6 Issue 1, Spring 2026
$ISSN_{(P)}$: 2791-0024, $ISSN_{(E)}$: 2791-0032
Homepage: https://journals.umt.edu.pk/index.php/ICR

Article QR

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DOI: https://doi.org/10.32350/icr.61.02

History: Received: January 23, 2026, Revised: February 25, 2026, Accepted: April 24, 2026, Published: June 25, 2026

Citation: K. I. Malik, H. Arooj, M. Yaqoob, “Stable election with sink mobility routing protocol, a stochastic model for clustering in wireless sensor network,” *Innov. Comput. Rev.*, vol. 6, no. 1, pp. 14-30, December. 2026, doi: https://doi.org/10.32350/icr.61.02.

Conflict of Interest: Author(s) declared no conflict of interest

A publication of
School of Systems and Technology
University of Management and Technology, Lahore, Pakistan

Stable Election with Sink Mobility Routing Protocol, a Stochastic Model for Clustering in Wireless Sensor Network

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ABSTRACT The best routing protocol is a requirement of any application that incorporates a Wireless Sensor Network (WSN) to determine the best path, minimize congestion, route optimization, minimum traffic delays, effective data transfer, and network stability. The current research aimed to discuss the design challenges of WSN and its architecture that might impact routing protocols. Furthermore, the study also discussed various routing protocols for WSN that could be divided into four categories. These include location-based, hierarchical, Quality of Service (QoS)-based, and data-centric. The study also presented the new routing protocol model for a heterogeneous randomly-deployed WSN named Stable Election with Sink Mobility (SESM). This routing protocol can work for such applications where the sink node is mobilized on a predefined path within the area of the network. Sensor nodes select Cluster Head (CH) by-election based on residual energy and probability of being selected. The proposed protocol results proved that there was an increase in network stability time, throughput, and network lifetime. The results were compared, and it outperformed the existing famous protocols, that is, Stable Election Protocol (SEP) and Low-Energy Adaptive Clustering Hierarchy (LEACH) protocols.

INDEX TERMS clustering, energy efficiency, heterogeneous, routing protocol, sink mobility, wireless sensor network

I. INTRODUCTION

The Wireless Sensor Network (WSN), which is based on ZigBee, is one of the IEEE 802.15.4 standard for Low-rate Wireless Personal Area Networks (LR-WPAN). WPAN is a personal area network that uses a low-power, short-range wireless network infrastructure, such as wireless USB, IrDA, Bluetooth, or ZigBee to communicate [1]. Relevant information from the environment is monitored by wireless sensor nodes and broadcasted to the sink node in WSN. Such sensors are small compact devices. These are low power and low cost devices with a minimum of four main components. These components include a processing unit, sensing unit, transceiver component, and a power source [2]. These sensing devices are becoming considerably smaller due to the advancement in microelectronics, VLSI, and Programmable System on Chip (PSoC) technology. Furthermore, these devices have increased the processing power and communication range [3]. Sensor networks are used in various fields, such as the combat, under ocean, privacy and security, crisis response, asset tracking, medical and health applications, traffic monitoring, thorium reactors, farming, surveillance system, biotechnological, variety of industries, telematics, agribusiness, gas detection, molecular, and processing plants [4].

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Often, numerous sensors are deployed either in a predetermined or random order in a region where there is a need to collect the data. These sensor nodes collaborate mutually, and regularly sense the surroundings. Sensors capture the data directly from the environment and send it to the sink node via a particular path after aggregation. Sensor nodes are deployed at a specified position in various scenarios, such as in the manufacturing industry, on the other hand, these are allowed for random deployments, such as a battlefield or underwater surveillance [5]. For randomly deployed sensor applications, such as combat fields, sensor nodes are dropped from the air. These sensing nodes are generally self-organized. The data is communicated from the sensor node to the sink node via intermediate nodes known as cluster heads, resulting in the construction of an ad-hoc network. Continuous changes in the topological structure of WSN are a crucial factor that affects routing protocols. Sensor nodes typically update their routing due to multiple factors, such as dried node battery, mobility, and pre- and post-deployment changes that occurred in the environment of deployed area [6].

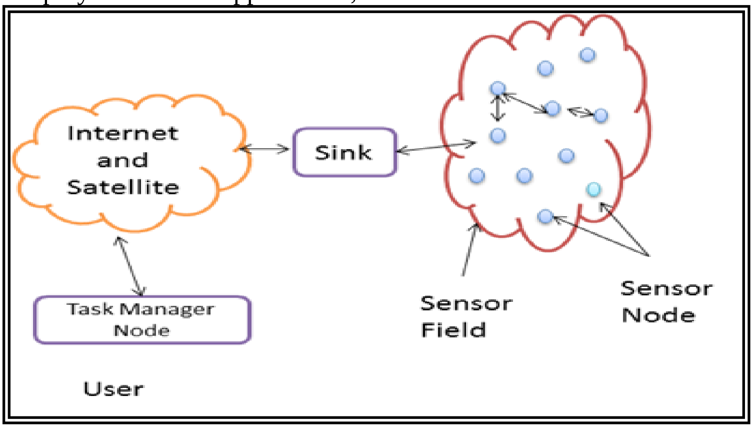

FIGURE 1. WSN Communication Flow

These sensor nodes are typically deployed in the field randomly, as shown in Fig. 1. Each sensor node gathers information from its surroundings and transfers it to the sink node. This data is then sent to the task manager by using the Internet or a communication satellite [7]. Several factors other than energy efficiency may have an impact on the WSN architecture, some of which are listed in Table 1.

Owing to limited network power, its lifetime is a major problem practically in every clustering approach. In traditional routing schemes, the Cluster Head (CH) selection method does not consider the energy levels of the sensor nodes adequately, leading to a reduced overall network lifetime [8]. In the current suggested methodology, the new technique for CH selection was discussed and evaluated on the basis of stochastic model that creates a positive effect over stability, network lifetime, and packet throughput. Thecurrent study presented the Stable Election with Sink Mobility (SESM) routing protocol for a heterogeneous WSN. The main idea was for applications, such as an underwater surveillance system or surveillance with a drone, where sensor nodes are randomly distributed around the environment. On the other hand, sink nodes are mobilized along a specified path to collect the data from sensor nodes in the vicinity. The presented approach used the probability function for CHs chosen on the highest residual energy and the likelihood of each node becoming a CH.

TABLE I

FACTORS THAT INFLUENCE THE ARCHITECTURE OF WS

Scalability	Scalability is a metric for determining the number of sensor nodes.
Topology	The topology of sensor networks is very dynamic and changes often.
Fault tolerance	On how much node failure, WSN network would still be able to survive and continue its working?
Hardware Constraints	The cost of a sensor/sink node determines the network's overall cast.

The study discusses the related work in Section 2, after that the proposed scheme for SESM is discussed in Section 3. Then, the next section discusses simulation, results, and comparative analysis with the existing techniques. The last section describes details regarding the conclusion and future directions.

II. LITERATURE REVIEW

Authors in [9] presented the LEACH protocol for clustered networks. They divided the clustering work into steady and set-up phases. In the set-up phase, all clusters were established, and their CHs were selected by neighbor nodes. While, the data was aggregated by CHs and subsequently sent to a Base Station (BS) during the steady phase. In LEACH, the CH changed randomly during every new set-up phase.

The research conducted by [10] discussed a mechanism for heterogeneous networks called the Stability Election Protocol (SEP). The sensor nodes were divided into two groups by the author: normal and advanced sensor nodes. The advanced nodes have some extra energy given at the start-up phase. SEP assigns a weighted probability to the normal and advanced nodes on the basis of residual energy.

Authors in [11] presented the Distributed Energy-Efficient Clustering (DEEC) protocol where CHs were chosen based on the network's average energy level and each node remaining energy. In DEEC protocol, the nodes with more energy in the start-up phase might have more chance to be chosen as a CH. Authors in [12] discussed the new variant of LEACH protocol with the name Time-based LEACH (TB-LEACH). By using the network simulator NS2, it was proved that TB-LEACH improves 20-30 % lifetime of the network.

An enhanced SEP technique was presented by [13], where a three-tier node design for the clustering technique is used to extend the efficient routing lifetime. Experiments were conducted on both types of homogeneous and heterogeneous sensor node environments, which showed a more promising result and improved the network lifetime. Another study conducted by [14] presented the new variant of SEP protocol with the name Zonal Stable SEP (Z-SEP). In the study, the sensor deployment area was divided into different zones. Some nodes directly sent their data to the base node and some chose the CH and communicated via their selected heads. They showed better results in terms of network stability as compared to the existing protocols.

The new concept of cross-layer LEACH protocol was proposed by [15]. In the study, an energy efficiency transmission scheme was presented by using the concept of utilizing the residual energy of nodes in CH selection. The study presented the concept of exploiting conversing dependencies across the application, MAC, physical layers, and cross-layer design that provided adaptive modulation. Their results were better than LEACH in terms of energy dissipation during CH selection.

The study [16] presented the distrusted algorithm approach for tolerance over node failure and improvement in energy efficiency. During data routing, a new CH is selected which carefully rearranges the path to the neighbor's node on failure. The study [17] presented Hamilton Energy Efficient Routing (HEER) protocol. During initializing of network, sensor nodes select their CH and with the help of a greedy algorithm, CH decides the Hamilton path of each node for data transmission. In this proposed methodology, no reformation of CH is required again and again, which saves energy. In MATLAB simulation, authors compare their results with LEAC, LEACH-EE, and PEGASIS protocols. The results show that HEER removes 90% of communication delays as compared to LEACH.

A cross-layer protocol that depends on the adaptive threshold for WSN was proposed by [18]. They utilized the idea of weighted probability to choose the CH. Furthermore, they conducted experiments on both proactive and reactive networks, improving the stability and network lifespan. A novel approach presented by [19], uses the technique of two cluster selections at a time in a specific region, called Dual-head Static Clustering Algorithm (DHSCA). CHs are selected based on the remaining energy level. One of them is used for data accumulation purposes, while the second is used for communication to BS. The concept of inter-cluster and intra-cluster communication was utilized in the methodology.

The study [20] discussed the issues of underwater sensor network routing protocols and presented a new scheme for Improved Energy Balance Routing (IEBR). In the study, the authors presented the design methodology in two phases. In the first phase, a mathematical model was established for each node's distance from its neighbor, and network was constructed. The looping problem was also addressed in data transmission. In the second phase during transmission, the energy difference of the neighbor node was measured regularly and the energy balance was achieved in this way. This concept enhances the overall network lifespan. In the study [21], authors presented the Multi-Threshold Long life Time Protocol (MTLLP) that reduces energy dissipation by approximately 70% as compared to LEACH and its other variants. Not just residual energy but the distance between each node and the CH was also taken into account. By using variance and average of these two concepts, a multi-threshold level was created which made them more accurate in choosing CHs.

The study [22] presented an extended version of LEACH, with an extended message passing (LEACH-XMP) approach introduced. It is a distributed algorithm that saves computational load for every node. LEACH-XMP improves the network life span. The study [23] proposed an algorithm based on information entropy which uses local information according to entropy value and selects the CH. In the study, the sensor node network was divided into a three-level hierarchy according to their energy level. Their results revealed that the suggested arrangement by the author outperformed in terms of network stability and lifespan. The study [24] proposed the new protocol, that is, Heterogeneous Network-Based Clustering (HNBC). This protocol is based on a probability model to select CHs. The study implemented the simulation in MATLAB and compared their work with different protocols. In their research, the major assessment factors were energy dissipating, network longevity, and throughput.

In the existing literature, various WSN routing protocols are discussed with many parameters. All of them could not be discussed here, however, Table 2 shows their comparison over features as follows:

TABLE II

WSN ROUTING PROTOCOLS, A COMPARATIVE VIEW

Protocol	Network Model	Power Manage	Multi-path	Data Fusion	Extend-able	Query based	Mobility	Network Lifetime
LEACH	Clustering	Max	✗	✗	Good	✗	Fixed BS	Best
APTEEN	Hybrid	Max	✗	✓	Good	✗	Fixed BS	Best
DD	Proactive / Flat	Limited	✓	✓	Limited	✓	Limited	Fine
RR	Hybrid / Flat	Not Support	✗	✓	Good	✓	Limited	Fine
SAR	Location	Max	✗	✓	Limited	✓	Limited	Fine
SPEED	Location	Low	✗	✗	Limited	✓	Limited	Best
MMSPEED	Location	Low	✓	✗	High	✓	Limited	Best
GAF	Location	Limited	✗	✗	Limited	✗	Limited	Fine
SPIN	Proactive / Flat	Limited	✓	✓	Limited	✓	Support	Fine
GEAR	Location	Limited	✗	✗	Limited	✗	Limited	Fine
TEEN	Reactive / Clustering	Max	✗	✓	Good	✗	Fixed BS	Best
PEGASIS	Reactive / Clustering	Max	✗	✓	Good	✗	Fixed BS	Good

Note. LEACH: Low-energy adaptive clustering hierarchy [25]. APTEEN: Adaptive Threshold Sensitive Energy Efficient Sensor Network [26]. RR: Rumor Routing [27]. PEGASIS: Power-Efficient Gathering in Sensor Information Systems [28]. DD: Directed Diffusion [29]. MMSPEAD: Multipath Multispeed [30]. SAR: Sequential Assignment Routing [31]. SPEED: Real-Time Routing Protocol for Sensor Networks [32]. GAF: Geographic Adaptive Fidelity [33]. SPIN: Sensor Protocol for Information via Negotiation [34]. GEAR: Geographic and Energy Aware Routing [35]. TEEN: Threshold sensitive Energy Efficient sensor Network [36]

III. METHODOLOGY

The network design of our proposed (SESM) routing protocol comprises one sink node and one hundred sensor nodes. In comparison to normal nodes, the sink is not an energy-limited node. A sink is a mobile node that rotates at a constant speed along a pre-set path. This protocol is designed for specific applications, such as drone cameras and underwater sensor networks, where sensor nodes are thrown or positioned at random. Surveillance is carried out using a sink node mounted on a drone or an Autonomous Underwater Vehicle (AUVs).

A. HETEROGENEOUS MODEL

Sensor nodes are placed at random, usually in places where their batteries cannot be recharged or replaced. The sensor nodes are diverse in terms of their initial energy level, while their position is static. Few of them are called normal nodes having normal energy, while others are advanced nodes having more energy. Advance nodes usually have more energy (α time more energy) than conventional nodes. They may also called as powerful nodes. If there are 'n' number of nodes, then the fragment of these nodes is 'm' that has more energy. With the Equation 1, normal nodes can be calculated.

$$Normal\ Nodes = (1 - \mathrm{m}) * n \qquad (1)$$

Suppose, there are n=100 nodes and 10% of nodes are advanced nodes. In this case, m=0.1. So, the total number of normal nodes is (1-0.1) x 100= 90 nodes. In most applications of WSN, sensor nodes are normally deployed in such areas where recharging or replacing batteries is difficult. In such applications, lifetime of the network is limited due to power constraints. In most protocols where clustering is used, all sensor nodes initially have same power resources. Consequently, their lifetime is limited. In SESM proposed scheme, a heterogeneous node is employed in terms of initial energy level, which extends the network's stability and, as a result, its network life as well. The stability period is the time interval between the initiation of the network and the death of the first node. After the first node dies till the end of the last node, this time period is called the unstable period. While, the lifetime of a network starts with network formation and ends with the death of the last node. It may be considered as a stable period plus an unstable period.

B. CLUSTERING HIERARCHY

In a hierarchically clustered network, clustering is maintained during each round of the network. During every round, few nodes as CHs are elected randomly so that the load is distributed in a well-balanced way among the network. The clustering hierarchy is maintained as in the LEACH algorithm. The communication process is divided into two stages: firstly, nodes submit their data to CH, where it is aggregated, filtered, and sent to the sink node. This operation is performed periodically as shown in Fig 2.

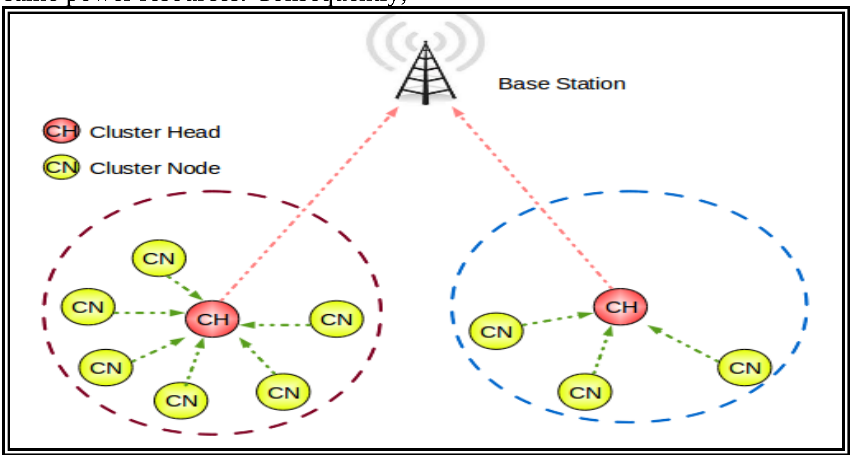

FIGURE 2. Node to CH and CH to Sink Transmission

Chances to Become CH: there is an optimal percentage Popt (determined a priori) in every round by considering the uniform distribution of nodes in the network field.

Initially, the probability to become a CH for a node is Popt. Averagely per epoch, there are n x Popt nodes that may become CHs. During one epoch, one node may be selected only once. This means if a node is selected in any round, then it would not be considered as a candidate for CH during the current epoch. While, all non-selected nodes are a member of the G set. During one epoch, a node that is a member of G (nodes ∈ G), its probability increases with every round of that epoch. The node that is a member of G selects the random number between zero and one (0, 1). A node's ability to become a CH during the round is determined based on this option. The threshold formula is then applied to the resulting random value. If generated number by the nodes is smaller than the threshold value, then that specific node would become the round's CH. The creation of this evaluating function for CH selection in clustering algorithms is a difficult undertaking since the threshold plays an important role in CH decision. The threshold function in our suggested methodology was based on starting energy of a node, calculated probability, epoch number, and node's remaining energy. In each iteration, every node passes through the clustering process, and only a few are chosen as CH. Nodes that are not chosen in one round are given another opportunity in subsequent rounds.

This random number is compared to threshold T (h), and if random number is smaller, this node would become a CH in the current round. This threshold limit is established as follows in the Equation 2:

$$T(h) = \begin{cases} \dfrac{P_{opt}}{1 - P_{opt}\left(r * mod\left(\dfrac{1}{P_{opt}}\right)\right)} & \text{if h ε G} \\ 0 & otherwise \end{cases} \quad (2)$$

where,

Popt is the specific probability value for node to become CH

‘r’ presents the round number started from 0.

G is the collection of all CHs that were not picked in the last 1/Popt rounds.

Round may be defined as a time interval during which all members of a cluster send their data to the head.

As probability of clustering is calculated with Equation 3:

$$\boldsymbol{P_{opt}} = \frac{\boldsymbol{K_{opt}}}{\boldsymbol{n}} \quad (3)$$

where,

K = number of clusters

K_{opt} is the optional number of constructed clusters.

Advance node may also become CH and their probability may be found through following Equation 4:

$$P(adv) = \frac{P_{opt}}{1 + (\alpha.m)} * (1 + \alpha) \quad (4)$$

where,

α is the amount of energy in advance node

m is the number of advance node

Put the value of Equation 4 in Equation 1

Threshold for advance nodes may be calculated as in Equation 5:

$$T(adv) = \begin{cases} \dfrac{Padv}{1 - Padv.\left(r * mod\left(\dfrac{1}{Padv}\right)\right)} \\ 0 \qquad\qquad\qquad\qquad Otherwise \end{cases} \quad (5)$$

When a CH is chosen, it sends out an advertising message to all nodes. Each node then decides about itself as per minimum distance as to which CH they belong to. CH then allocates a TDMA plan to sensor nodes for data transmission. The CH gathers data, then aggregates it, and sends it to the sink node. This phase is called the data transmission phase.

C. WORKING OF SESM

Figure 3 shows the flow chart of SESM operation. According to this diagram, after network formation and initializing energy of each node, the sink node updates its coordinates (x, y) in the region. After this, CH selection process is started and CH is chosen. Once the CH process is completed, nearby nodes join the CH in response to its advertisement message. Afterwards, CH allocates a TDMA schedule for data transmission. The CH collects, aggregates, and filters data packets before transmitting them to the sink node. After each epoch, the sink node updates its location again and new CHs are selected. The same operation is repeated till all epochs are complete

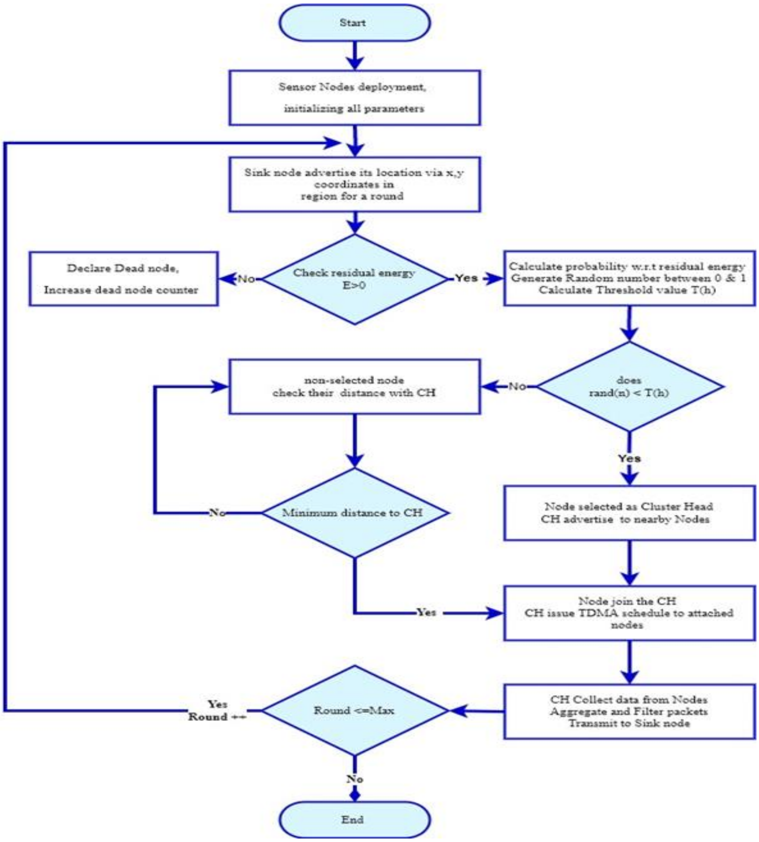

FIGURE 3. Flow Chart for SESM Algorithm

IV. SIMULATION AND RESULTS

The current study used MATLAB as a modelling tool for the proposed routing protocol SESM. The networking region with measurements of 100m x 100m was chosen for the simulation. In simulation, the study chose a total of 100 sensors, including normal and advanced nodes. In simulation, these normal and advanced nodes were randomly deployed in the 100m x 100m field. The sink node, on the other hand, moved in a field along a predetermined route. Table 3 depicts the simulation parameters.

TABLE III

SIMULATION PARAMETER

Parameter	Value
Field Dimension	100m x 100 m
Total Node (*n*)	100
Deployment nodes	Random
Movement of Sink Node	On predefined path
Normal Node, Initial Energy	Eo= 0.5 J
Transmission Packet Size	4000 bit
Electronics for Transmitter or Receiver	E_{elec} = 50nJ / bit
Energy Data Aggregation	E_{DA} = 5nJ/bit/report

In simulation field, randomly deployed nodes consist of normal nodes (90% of total sensor nodes) and advanced nodes (10% of total sensor nodes). As illustrated in Figure 4, these nodes are deployed between 0 and a maximum value of 100 on “X” and “Y” axes.

In figure 4, red star shows sink nodes, black stars show advanced sensor nodes, and blue circles show normal sensor nodes. Here it would be pretended that the sink node has no energy limitations. The sink node is mobile, rotating at a consistent speed along a predetermined x- and y-axis route. Resultantly, the distance between the sink node and every other node, including normal and an advanced node, changes with time. A simulated route of the sink node is depicted in Figure 5 (a) below. After each round, the location of the sink node is altered and elevated by one point.

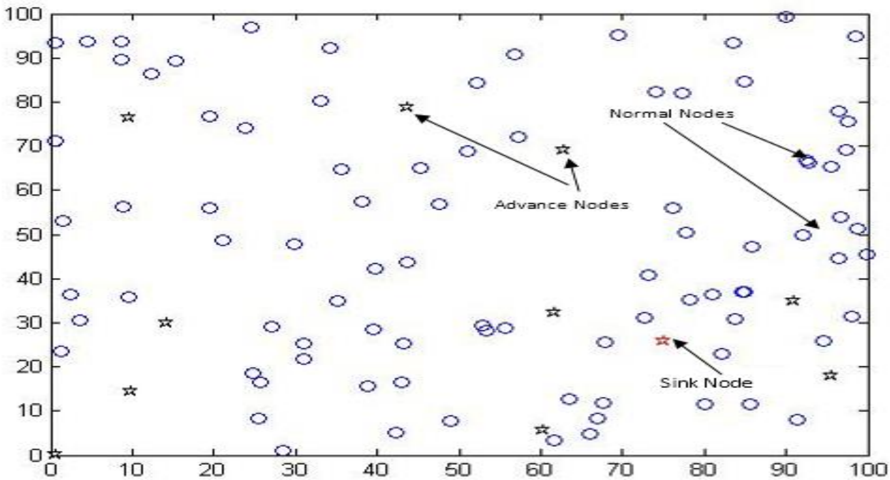

FIGURE 4. Randomly Deployed Sensor Network

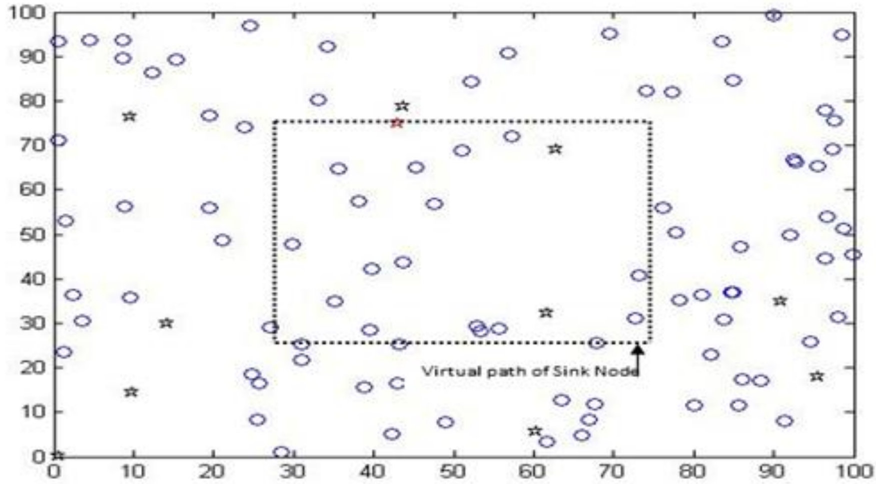

FIGURE 5(a). Virtual Path for Sink Node

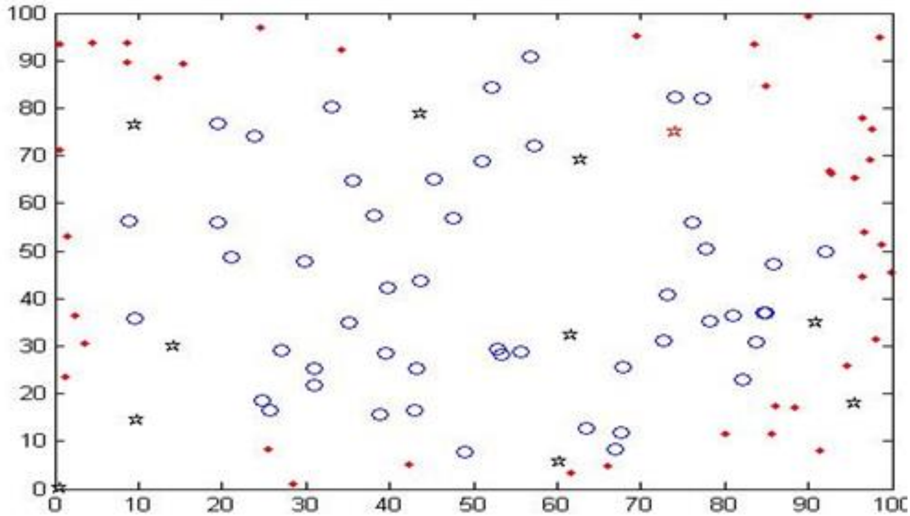

FIGURE 5(b). Dead Node Appearing after Some Epochs

After changing its position, sink node updates and publicizes its geographical coordinates in the region at the end of each round. In each round, few nearby nodes select their CH with stochastic model, and send their sensed data to CH as per TDMA provided schedule. Each dead node is shown in Figure 5 (b) below as a red dot. The number of dead nodes grows as the round passes.

The network's stable phase is defined as the time between the network's creation and the death of the first node. From the death of the first node through the death of the final node, the network is considered as an unstable period. The total lifetime of network can be calculated as in Equation 6:

$$Network\ Life\ time = Stable + unstable\ time \quad (6)$$

The proposed SESM protocol is specially designed to extend stability period of the network. Secondly, this protocol reacts comparatively better than LEACH and SEP during the unstable period. In SESM, stable period is increased with the comparison of LEACH and SEP. Total network lifetime also increased. The radio characteristics that are used during this simulation work can be reviewed through Table 4 below.

TABLE IV

RADIO CHARACTERISTICS OF PROPOSED MODEL

Operation	Energy Dissipated
Electronics Transceiver (Rx + TX)	E_{elec} = 50 nJ/bit
Aggregation	E_{DA} = 5nJ/bit/report
Tx Amplifier	E_{fs} = 10pJ/bit/m^2
If $d_{to\ BS}$ <= d_0	
Tx Amplifier If d_{toBS} >= d_0	E_{mp}=0.0013pJ/bit/m^4

The SESM protocol increases the stability of the network. As the stability period increases, the throughput of SESM becomes much better than SEP and LEACH. Overall lifetime of SESM is higher than SEP and LEACH. SESM is specially designed for some specific applications which are set-up to make collaborative monitoring tasks in a particular predefined area. SESM produces much better results than LEACH and SEP even though its sink node is mobile. Furthermore, during the network lifetime, distance between the sink node and sensor node continuously varies, which effects the energy consumption of sensor nodes considerably. For simulation, the m=0.1 was set. This means there are 10 advance nodes in 100 nodes that are randomly deployed in a 100x100 meter area. The study set α = 2, which means advance node has one time more energy than normal nodes.

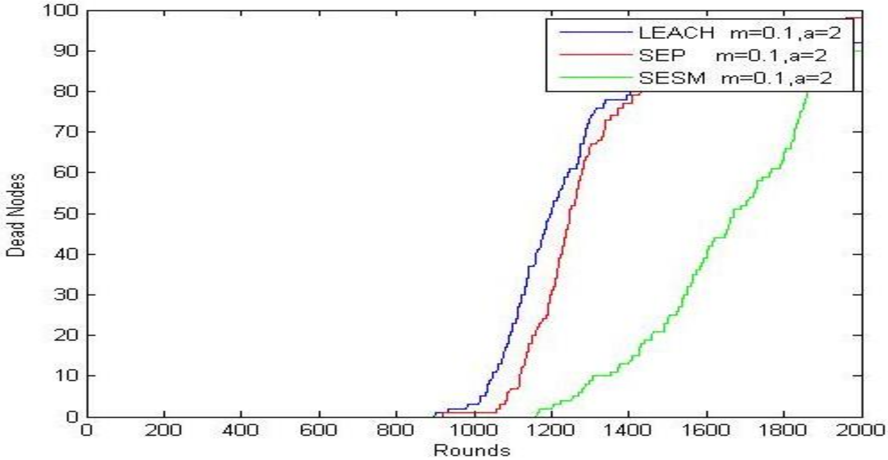

FIGURE 6. Comparison of SESM with LEACH and SEP in terms of Network Stability

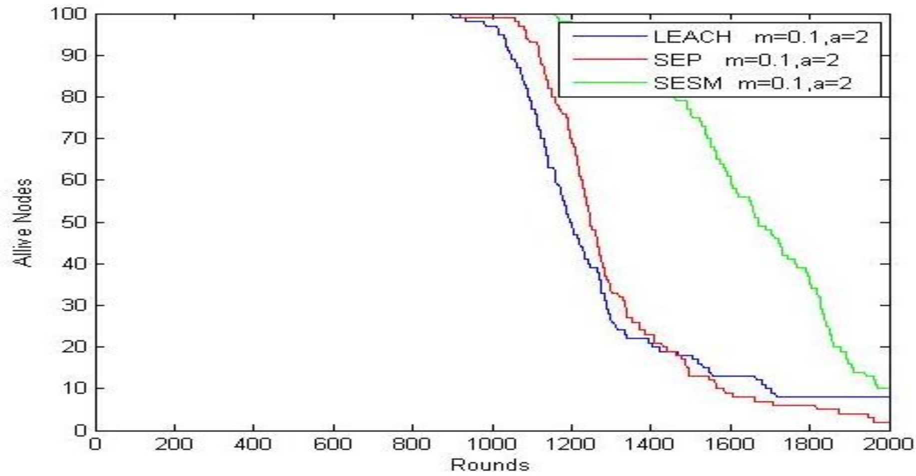

FIGURE 7. Comparison of SESM with LEACH and SEP in terms of Network Lifetime

Figure 6 shows the juxtaposition between SESM, SEP, and LEACH during their periods of stability. Here, the nodes are heterogeneous in power levels, the value of advanced nodes m= 0.1, and they have alpha time (α= 2) more power. Over these parameters, the stable region is increased. In SESM, the first dead node appears in round 1135, whilst in SEP it is in round 910 and in LEACH it appears in round 894. In comparison with SEP and LEACH, the stability period has improved by approximately 12%.

Figure 7 shows the analogy between SESM, SEP, and LEACH in relation to their network lifetime. Here, the nodes are heterogeneous in power levels, the value of advanced nodes m= 0.1, and they have alpha time (α= 2) more power. The overall network lifetime is enhanced. After the 2000th round, SESM has 10 active nodes out of a total of 100. Over the same parameter configuration, a total of 8 nodes were alive in SEP and a total of 3 nodes were alive in LEACH. Since there were more live nodes, the network was more reliable, which also improved the network lifetime. Secondly, after the death of the first node, the alive node graph rapidly diminished in SEP and LEACH, while in SESM, this graph declined slowly as compared to the other two protocols. In short, any SESM point graph seems more reliable since there are more vigorous nodes available in the network.

V. CONCLUSION

For heterogeneous environments in WSN, the study presented a novel routing protocol SESM. Sensor nodes in SESM were deployed randomly, heterogeneous in terms of energy level and static in region. On the other hand, the sink node was mobile and continuously moved on a predefined path. Sink node updated its location parameter in environment after each epoch. All sensor nodes selected their CHs. The CHs advertised their location coordinates to all other nodes linked to specific cluster. The CHs then issued their TDMA schedule. Sensor nodes transmitted their data according to this schedule, then CHs aggregated it and transferred it to the sink node. SESM was compared with two existing protocols, that is, SEP and

LEACH. SESM outperformed both LEACH and SEP in terms of network lifetime, stability, and throughput. Observations could be concluded as; SESM was specially designed for some specific applications where sink node was mobile, such as drone camera technology or underwater sensor network technology that consisted of underwater nodes and AUVs), which was set-up to make collaborative monitoring tasks in a particular predefined area. The SESM protocol increased the stable region in comparison with the other two protocols for heterogeneous clustering protocol. As the stability period increased, the throughput of SESM was much higher than SEP and LEACH routing protocols. Overall network lifetime of SESM was increased than LEACH and SEP. SESM outperformed LEACH and SEP in terms of the results. Here, the sink node was mobilized and distance among the sink and the sensor node was constantly changing. This had a significant impact on energy consumption of the entire network.

Author Contribution

Khawar Iqbal Malik: conceptualization, methodology, software, investigation, visualization, writing – original draft, project administration. **Hira Arooj:** methodology, formal analysis, validation, visualization, writing – review & editing. **Mateen Yaqoob:** validation, data curation, investigation, writing – review & editing.

Conflict of Interest

The authors of the manuscript have no financial or non-financial conflict of interest in the subject matter or materials discussed in this manuscript.

Data Availability Statement

Data supporting the findings of this study will be made available by the corresponding author upon request.

Funding Details

No funding has been received for this research.

Generative AI Disclosure Statement

The authors did not use any type of generative artificial intelligence software for this research.

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