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DE-SEP: Distance and Energy Aware Stable Election Routing Protocol for Heterogeneous Wireless Sensor Network

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ABSTRACT Sensing technology has undergone a revolution as a result of technological advancements, where the wireless sensor network (WSN) is considered as a major research area in recent times. WSN is made up of battery-powered multiple sensor nodes with limited energy, which eventually encourage the researchers in designing an energy efficient routing protocol to prolong the network lifetime. Hierarchical routing protocols can play an important role to improve the network's energy efficiency utilizing the threshold-based cluster head (CH) selection techniques. In this article, a cluster based proactive routing protocol named as Distance and Energy Aware Stable Election Routing Protocol (DE-SEP) is proposed to ensure optimum energy conservation. Here, both the energy and distance criteria are incorporated in CH selection to give priority for comparatively higher energy nodes and nearby nodes from base station (BS) to be selected as CH. Moreover, the proposed protocol imposes a limit on the number of CHs so that an optimum number of CHs can be utilized to avoid unnecessary cluster formation and reduce energy consumption. Simulation results show that DE-SEP outperforms the existing baseline protocols like P-SEP, M-SEP and SEP in terms of various performance matrices such as network lifetime, stability period, half lifetime, throughput, and normalized residual energy. In particular, the performance of DE-SEP protocol in terms of normalized residual energy is increased by a maximum of 5%, 41% and 41% in comparison to P-SEP, M-SEP and SEP respectively.

INDEX TERMS Heterogeneous sensor network, Network routing protocol, Clustering, Energy utilization.

I. INTRODUCTION

WSN comprises a large number of tiny sensor nodes that can be deployed in various applications like surveillance or target tracking, home and industrial automation, military and security purposes, habitat and environmental monitoring, traffic control, mobile-edge computing etc. [1] [2] [3]. Sensor nodes are used to sense the data from their sensing range and send it to the base station (BS) called as sink. The end users are connected to the sink for access of information over the internet. The sensor nodes and sink can be static or dynamic depending on the application for which the network is designed. The sensors are made with limited resources like small processors, sensing units, transceivers and batteries. Among these, the battery is considered to be a crucial component as it cannot be replaced or recharged in regular intervals if the deployment place is at a remote area for operation and maintenance. Hence, the energy utilization of sensor nodes is crucial to prolong the lifetime of WSNs [4]. To achieve this goal, an optimum design of routing protocol can play an important role and thus several energy efficient routing protocols have been proposed in recent years [5] [6].

One of the well investigated approaches is to group the sensor nodes in clusters for achieving an energy-efficient balanced routing [2] [7]. Here, each cluster is headed by a cluster head (CH) including one or more non-cluster head nodes called cluster members (CMs). Within the cluster, data is aggregated at CHs for further processing and finally sent to the sink. Clustering is useful to minimize the communication overheads that reduce the total energy consumption of the network. Therefore, the selection of CHs needs to be done intelligently in order to develop a balanced network maintaining an optimum utilization of available energy.

Besides this, WSNs can be categorized as either homogeneous or heterogeneous architecture [8]. In homogeneous sensor networks, all the nodes show similar

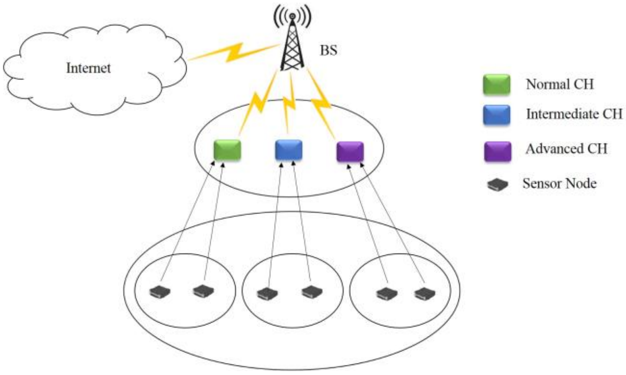


FIGURE 1. **Wireless Sensor Network architecture.**

characteristics in terms of connectivity range, energy, and computation capabilities, whereas in heterogeneous sensor networks, nodes are grouped by category depending on their design parameters. However, heterogeneous networks are getting more focused for the research community as it can provide improved performance without significantly increasing the cost [8]. A Network architecture of such cluster based heterogeneous WSN is shown in Fig. 1. A group of nodes called advanced nodes contain more energy compared to normal nodes. Besides the normal and advanced nodes, intermediate nodes are also available in the network model which contain energy between normal and advanced nodes.

Here, the routing protocols can be utilized for node clustering as well as selection of CH. Moreover, energy efficiency and balanced distribution of load for a network also depend on the routing protocol [9] [10]. Therefore, an energy efficient routing protocol can be utilized to select the optimum number of CHs and ensure the heterogeneity of sensor nodes. To meet such requirements, Low Energy Adaptive Clustering Hierarchy (LEACH) is considered to be a pioneer protocol, which focuses on the clustering of sensor nodes to improve energy efficiency [11]. However, LEACH is proposed for homogeneous WSN with a random selection of CH, and thus the protocol does not ensure the optimal choice of sensor node acts as CH. To extend the network stability period by maintaining the heterogeneity of sensor nodes and best selection of CHs, Stable Election Protocol (SEP) is proposed [12]. Moreover, such routing protocols can also be classified as proactive, in contrast to reactive protocols, to sense and transmit the data continuously.

In this article, a proactive routing protocol is proposed for heterogeneous WSN considering the three levels of energy heterogeneity. The proposed routing protocol considers the position of each node with respect to BS, the initial energy of each node and average energy of the network during CH selection. As a consequence, a node with higher energy and nearby to BS has more chances to be selected as CH. Here, the nearby CH consumes less energy during data transmission than distant CH, and therefore energy consumption is reduced. Moreover, the proposed protocol imposes a limit on the number of CHs so that an optimum number of CHs can be utilized to avoid unnecessary cluster formation and reduce the energy consumption

The rest of this paper is structured as follows: a short review of related research works is given in section II. Section III presents the system models that used for the proposed investigation. Section IV covers the proposed routing protocol for energy efficient WSN. The evaluation matrices and the corresponding results including a detailed comparison with exiting protocols are discussed in section V. Finally, the conclusion of this work with a future scope is highlighted in section VI.

II. RELATED WORKS

The purpose of the sensor node is to sense the accessible area, gather data and deliver it to the BS. Direct transmission is the easiest way for data transmission to BS, however, the nodes die out quickly in this process due to the unnecessary energy consumption. Therefore, data is transmitted to BS via intermediate nodes to reduce energy consumption. Clustering is considered a well investigated approach to do this crucial task. Here, the member nodes send data to CH, it aggregates the data, removes redundancy and finally, sends data to the BS. As a consequence, the overall energy consumption is said to be minimized since the network's energy usage is distributed uniformly [13].

LEACH is a cluster based hierarchical routing protocol [11]. In every $1/p$ round, every node will become a CH exactly once. Each node generates a random number inclusive of 0 and 1 to compare with a threshold T_n. If the random number is less than the threshold T_n, the node functions as a CH for the current round. Here, the threshold is formulated as follows:

$$T_n = \begin{cases} \dfrac{p}{1-p\times(r \bmod \frac{1}{p})} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

where, *r* is the current round and *G* is a set of nodes that have not been CHs in the last $1/p$ rounds.

CH broadcast a TDMA slot for the member nodes after the cluster creation stage. Sensing nodes send data during their allocated time slot. However, the initial version of LEACH was not effective considering the optimum distribution of available energy especially for large WSNs and thus, several advanced LEACH protocols are investigated like LEACH-DCHS [14], LEACH-DT [15], Improved LEACH [16], DE-LEACH [17]. In LEACH with Deterministic Cluster Head Selection (LEACH-DCHS), the selection criteria of a node to become CHs is computed using the remaining energy level of the node. Besides this, LEACH with Distance-based Threshold (LEACH-DT) deploys a distributed CH selection algorithm considering the distances among sensors and BS to achieve balanced energy consumption among sensors. Moreover, Improved LEACH includes energy and distance factor in the threshold formula including a multi-hop routing algorithm on the basis of hop count and remaining energy. Distance and Energy Aware LEACH (DE-LEACH) introduces an energy and distance factors in the threshold formula and the sensing area is divided into two parts considering the nodes' position and nodes' average distance relative to BS.

As the low power consumption and longer lifetime of the network are the key considerations for designing a WSN, the researchers have focused on the energy heterogeneity of sensor nodes to prolong the network stability. Therefore, a stable election protocol (SEP) is proposed considering the node's energy heterogeneity to extend the stability period of a sensor network [12]. It uses two levels of heterogeneity (i.e., advanced node and normal node), where the advanced nodes' initial energy level is higher than normal nodes. The proposed method is based on the weighted probability of each node for CH selection in accordance with their respective energy level. So, advanced nodes have more chances to be elected as CH due to their high energy level. In [18], Modified SEP (M-SEP) is proposed considering the two levels of heterogeneity. M-SEP includes the remaining energy of the node and average energy of the network in CH selection criteria. However, the proposed methodology is not able to maintain the network's aliveness efficiently. An Efficient Modified SEP (EM-SEP) is proposed to enhance the network's stability by ensuring the balanced distribution of available energy [19], however, the energy consumption does not reduce effectively to prolong the network lifetime. In [20], a Prolong SEP (P-SEP) is proposed to improve the aliveness of the network by utilizing the average remaining energy in threshold function.

Due to the variation of initial energy levels among sensor nodes, energy heterogeneity has a crucial impact on the lifetime of a network. Therefore, three levels of energy heterogeneity can control energy dissipation more smoothly than two levels of energy heterogeneity. Threshold Sensitive SEP (TSEP) [21] is a reactive protocol that uses three levels of heterogeneity (i.e., normal node, advanced node and super node), where the super nodes contain much higher initial energy than the advanced nodes. However, TSEP cannot save energy efficiently to guarantee the balanced distribution of load. Enhance Threshold Sensitive SEP (ETSSEP) [1] is a modified version of TSEP, where the proposed method considers the minimum number of clusters per round and the node's residual energy in the threshold function.

The residual energy and position of a node have a crucial role in the CH selection process, and thus if a node with low energy is selected as CH, it will die fast. In addition, distant CHs will consume more energy in comparison to nearby CHs during the data transmission, which accelerates the fast dissipation of energy. Therefore, nodes' position and energy should be considered in designing the routing protocol with CH selection process that will certainly help to enhance the network lifetime. Reference [22] shows an approach named distance-based SEP (DB-SEP) to improve the network lifetime and energy efficiency using two levels of heterogeneity, where the CHs are selected on the basis of nodes' initial energy as well as the distances between the nodes and BS. As the large number of CHs may increase the operational complexity of WSNs, a Cluster-head Restricted Energy Efficient Protocol (CREEP) is also proposed to overcome such limitation by imposing a limit on the total number of CHs [23]. The protocol also introduces the energy and distance factors in CH selection criteria to improve the network lifetime considering the two levels of nodes' initial energy. In some applications, there is a necessity to place the BS far away from the deployment area, where the existing routing protocols using the BS at the center position are not suitable. To overcome this challenge, a Gateway SEP (G-SEP) is proposed to reduce the extra energy consumption using a gateway node at the center of the network while the BS is installed outside of the field [24]. Here the protocol considers both the distance and average distance to the BS as well as residual energy of the advanced nodes in the CH selection process. Moreover, a distance based ETSSEP (DETSSEP) is also proposed to consider the average energy of the network, nodes' residual energy as well as the distance between nodes and BS for the calculation of threshold function [25]. The process also gives priority to near nodes over distant nodes with the highest available energy to be selected as CH. However, the DETSSEP is a reactive protocol that is not suitable for those applications where the data is required on a continuous basis. In [26], authors proposed a hybrid approach named distance aware residual energy-efficient SEP (DARE-SEP) for three level heterogeneous WSN. In DARE-SEP, CH is selected on the basis of residual energy of each node, distance of each node from BS and weights that gives the priority for nodes with higher energy and closer distance from BS. However, the system performance significantly depends on the optimum selection of weight values, which are not investigated thoroughly in the presented results.

Here, the proposed DE-SEP is a proactive routing protocol, which considers both the nodes' position and energy during the CH selection process by imposing a limit on the total number of CHs to prolong the network lifetime, throughput and stability period for heterogeneous WSN. The major contributions of this work are summarized as:

i. Proposes a routing protocol based on nodes' average energy and distance in the calculation of node's probability and threshold to prolong the network lifetime.

ii. The use of average energy in CH selection process reduces the chance of a low energy node to become CH, which eventually improve the network stability period.

iii. The proposed protocol selects the optimum number of CHs to reduce the extra energy costs by avoiding unnecessary cluster formation. This CH selection approach achieves a balanced distribution of load.

iv. Exploits the three levels of heterogeneity in nodes' energy during CH selection to achieve balanced energy consumption.

v. The proposed protocol shows significant performance improvement in terms of network lifetime, throughput, and energy consumption compared to other existing routing protocols.

III. SYSTEM MODELS

Different models are employed for implementing the proposed routing protocol such as the energy model, energy dissipation model and network model. A brief detail of each model presents in the following section.

A. ENERGY MODEL

WSN includes different types of heterogeneity such as energy heterogeneity, computational heterogeneity and link heterogeneity. Among them, energy heterogeneity is considered to be the most significant to ensure optimum performance of the network. In this article, we have addressed three levels of energy heterogeneity such as normal node, intermediate node and advanced node. Intermediate nodes' initial energy is between the normal and advanced nodes' initial energy. Let, m and b be the percentage of advanced nodes and intermediate nodes respectively. Advanced nodes' energy level is α times more than the normal nodes' energy level and intermediate nodes' energy level is β times more than the normal nodes' energy level. Here, the β is related with α using $\beta = \alpha/2$. If the initial energy of normal, intermediate and advanced nodes is represented as E_N, E_I and E_A, the energy relationship can be expressed by,

$$E_N = E_0 \tag{2}$$

$$E_I = E_0(1 + \beta) \tag{3}$$

$$E_A = E_0(1 + \alpha) \tag{4}$$

B. ENERGY DISSIPATION MODEL

Data transmission and reception are two basic operations in WSN. Conventionally, the data transmission process consumes more energy than the data reception [7]. The energy dissipation model that is used in this work is shown in Fig. 2. Here, energy costs during k-bit data transmission over distance d can be expressed by [11] [12].

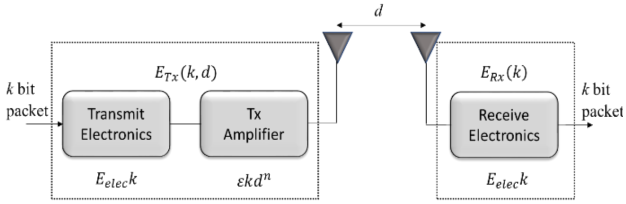


FIGURE 2. **Energy dissipation model.**

$$E_{Tx}(k,d) \triangleq \begin{cases} k\left(E_{elec} + \varepsilon_{fs} d^2\right), & \text{if } d \le d_0 \\ k\left(E_{elec} + \varepsilon_{mp} d^4\right), & \text{if } d > d_0 \end{cases} \tag{5}$$

where, d_0 is the reference distance and $d_0 \triangleq \sqrt{\varepsilon_{fs}/\varepsilon_{mp}}$. E_{elec} is the per bit energy costs to run the transmitter or receiver circuit, ε_{fs} and ε_{mp} are the amplification parameters of the transmitter for free space and multipath fading models respectively.

Moreover, energy costs during k-bit data reception can be represented by,

$$E_{Rx}(k) \triangleq kE_{elec} \tag{6}$$

C. NETWORK MODEL

We assume that n sensors are placed in an area of M size and the sensors are static. Each sensor is considered to be aware of the identifications and locations of other sensors. It is also assumed that the advanced nodes' locations are predefined, whereas the normal and intermediate nodes are deployed randomly. Each node sends data to nearby CH to aggregate the data. The distance between the BS and nodes is $d_s \ge d_s^r$,where d_s^r is a preset range (i.e., d_s^r = 10m) [20]. Hence, one node has a probability p of becoming CH, where $1/p$ is the clustered sensor network's epoch and the total probability in one round is np. Moreover, a node cannot become a CH multiple times in the same round.

IV. THE PROPOSED PROTOCOL

The proposed routing protocol for a three-level of the heterogeneous environment is presented in this section. To select cluster heads, the proposed protocol takes into account the initial energy of each node, average energy of alive nodes, average distance of BS from each alive node and distance between each node and BS.

A. NODES' WEIGHTED PROBABILITIES

Let p be the nodes' selection probability that affects the normal, intermediate and advanced nodes' selection as a CH in the r^{th} round. P_N, P_I and P_A denote weighted probabilities of normal, intermediate and advanced nodes respectively. The weight is determined by the initial energy of normal nodes and the average energy of alive nodes. This weight ensures a high probability for nodes that have more energy. The weighted probabilities of normal, intermediate and advanced nodes can be expressed by,

$$P_N = \frac{P * E_{avg}(r)}{(1+\alpha m+\beta b)E_0} \tag{7}$$

$$P_I = \frac{P(1+\beta)E_{avg}(r)}{(1+\alpha m+\beta b)E_0} \tag{8}$$

$$P_A = \frac{P(1+\alpha)E_{avg}(r)}{(1+\alpha m+\beta b)E_0} \tag{9}$$

where $E_{avg}(r)$ is the average energy of alive nodes that can be represented by

$$E_{avg}(r) = \frac{1}{N}\sum_{j=1}^{N} E_{N_j}(r)\,, \qquad \text{if } E_{N_j}(r) > 0, \tag{10}$$

where N is the number of alive nodes and equal to n before first node death, $E_{N_j}(r)$ is the energy of node N_j in rth round.

B. THRESHOLDS CRITERIA FOR CH SELECTION

Let, T_N, T_I and T_A denote the threshold for normal, intermediate and advanced nodes in rth round respectively. Each node generates a random number inclusive of 0 and 1.

Algorithm I DE-SEP based routing

CH_set: Set of CH
CH_count: CH counter
CH_max: Maximum allowed CH which is equal to q% of the alive nodes
N_{rand}: Random number
Non_CH: Set of non-CH or member nodes

```
begin
Build sensor network.
for $r$ = 1 to $r_{max}$ do
  CH_set = 0;
  CH_count = 0;
  Calculate $P_N$, $P_I$, $P_A$, $E_{avg}(r)$ by using Eq. (7)-(10);
    for $i$ = 1 to $n$ do
      if (CH_count ≥ CH_max) then
        break
      end if
      Calculate $T_N$, $T_I$, $T_A$ by using Eq. (11)-(16);
      Calculate $\overline{E}_{Ni}(r)$, $D_i$, $D_{avg}$ by using Eq. (17)-(19);
      if ($N_{rand} \le T_N$ & $E_{N_i}(r) > 0$ & $G'_r > 0$) then
        Normal node $N_i$ is selected as CH;
        CH_set = CH_set ∪ {$N_i$};
        CH_count = CH_count + 1;
        Calculate $E_{Tx}(k,d)$, $E_{Rx}(k)$ by using Eq. (5)-(6) and Update $E_{N_i}(r)$;
      end if
      if ($N_{rand} \le T_I$ & $E_{N_i}(r) > 0$ & $G''_r > 0$) then
        Intermediate node $N_i$ is selected as CH;
        CH_set = CH_set ∪ {$N_i$};
        CH_count = CH_count + 1;
        Calculate $E_{Tx}(k,d)$, $E_{Rx}(k)$ by using Eq. (5)-(6) and Update $E_{N_i}(r)$;
      end if
      if ($N_{rand} \le T_A$ & $E_{N_i}(r) > 0$ & $G'''_r > 0$) then
        Advanced node $N_i$ is selected as CH;
        CH_set = CH_set ∪ {$N_i$};
        CH_count = CH_count + 1;
        Calculate $E_{Tx}(k,d)$, $E_{Rx}(k)$ by using Eq. (5)-(6) and Update $E_{N_i}(r)$;
      end if
    end for
    for $i$ = 1 to $n$ do
      if ({$N_i$} ∈ non_CH & $E_{N_i}(r) > 0$) then
        Calculate $d_{toBS}$, $d_{toCH}$, $d_{min}$ by using Eq. (20)-(22);
        Calculate $E_{Tx}(k,d)$ by using Eq. (5) and Update $E_{N_i}(r)$;
      end if
    end for
  end for
  end
```

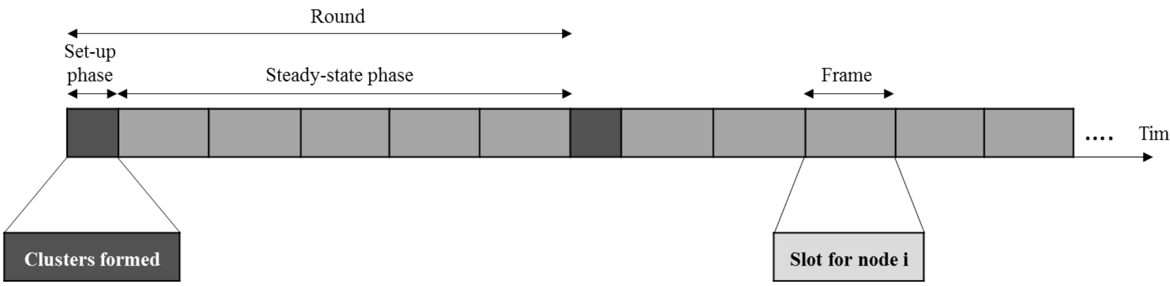


FIGURE 3. **Implementation Phases of Routing Protocol [18] [20].**

If the generated number is less than the threshold, the node will be selected as probable CH. The network area is divided into two sectors based on the distance of a node from BS. Both distance and energy factors are incorporated in the threshold formula. Hence, the distance factor gives more priority to near nodes over distant nodes to be selected as CH. As a consequence, distant nodes are protected from rapid drain out of energy. Moreover, the threshold condition of advanced nodes is calculated in such a way that such nodes can get highest priority to become CHs, which improves the network lifetime as those nodes have highest energy level compared to others nodes.

If $D_i < D_{avg}$,

$$T_N = \begin{cases} \frac{P_N}{1 - P_N(r \bmod \frac{1}{P_N})} \times \bar{E}_{Ni}(r) \times \frac{D_{avg}}{D_i}, & \text{if } N_i \in G_r' \\ 0 & \text{otherwise} \end{cases} \qquad (11)$$

$$T_I = \begin{cases} \frac{P_I}{1 - P_I(r \bmod \frac{1}{P_I})} \times \bar{E}_{Ni}(r) \times \frac{D_{avg}}{D_i}, & \text{if } N_i \in G_r'' \\ 0 & \text{otherwise} \end{cases} \qquad (12)$$

$$T_A = \begin{cases} \frac{P_A}{1 - P_A(r \bmod \frac{1}{P_A})} \times \frac{1}{\bar{E}_{Ni}(r)} \times \frac{D_{avg}}{D_i}, & \text{if } N_i \in G_r''' \\ 0 & \text{otherwise} \end{cases} \qquad (13)$$

If $D_i \geq D_{avg}$,

$$T_N = \begin{cases} \frac{P_N}{1 - P_N(r \bmod \frac{1}{P_N})} \times \bar{E}_{Ni}(r), & \text{if } N_i \in G_r' \\ 0 & \text{otherwise} \end{cases} \qquad (14)$$

$$T_I = \begin{cases} \frac{P_I}{1 - P_I(r \bmod \frac{1}{P_I})} \times \bar{E}_{Ni}(r), & \text{if } N_i \in G_r'' \\ 0 & \text{otherwise} \end{cases} \qquad (15)$$

$$T_A = \begin{cases} \frac{P_A}{1 - P_A(r \bmod \frac{1}{P_A})} \times \frac{1}{\bar{E}_{Ni}(r)}, & \text{if } N_i \in G_r''' \\ 0 & \text{otherwise} \end{cases} \qquad (16)$$

Where, G_r' is a set of normal nodes that have not been CH in the last $1/P_N$ rounds, G_r'' is a set of intermediate nodes that have not been CH in the last $1/P_I$ rounds and G_r''' is a set of advanced nodes that have not been CH in the last $1/P_A$ rounds. D_{avg} is the average distance of BS from each alive node and D_i is the distance of i^{th} node from BS. $\bar{E}_{Ni}(r)$ denotes the average energy of alive nodes (N is the number of alive nodes and $N = n$ until the first node dead) starting from 1^{st} node to i^{th} node in the r^{th} round and continues up to the N^{th} node in that round. $\bar{E}_{Ni}(r)$ can be represented by

$$\bar{E}_{Ni}(r) = \frac{1}{N}\sum_{j=1}^{i} E_{N_j}(r), \quad \text{if } E_{N_j}(r) > 0, \qquad (17)$$

$$D_i = \sqrt{(X_i - X_{BS})^2 + (Y_i - Y_{BS})^2} \qquad (18)$$

$$D_{avg} = \frac{1}{N}\sum_{i=1}^{N} D_i \qquad (19)$$

Here, (X_i, Y_i) and (X_{BS}, Y_{BS}) are the coordinates of i^{th} node and BS respectively.

Now, we denote the distance between member nodes and BS by d_{toBS} and the distance between the member node and its nearest CH by d_{toCH}. We determine the minimum distance between d_{toBS} and d_{toCH} to save energy during data transmission. Member nodes directly transmit data to BS if d_{toBS} is less than d_{toCH} otherwise, data is transmitted to BS via CH.

$$d_{toBS} = \sqrt{(X_j - X_{BS})^2 + (Y_j - Y_{BS})^2} \qquad (20)$$

$$d_{toCH} = \sqrt{(X_j - X_{CH})^2 + (Y_j - Y_{CH})^2} \qquad (21)$$

$$\text{and } d_{min} = \min(d_{toBS}, d_{toCH}) \qquad (22)$$

Here, (X_j, Y_j) and (X_{CH}, Y_{CH}) are the coordinates of the member node and CH respectively. Particularly, we find the distance between member nodes and BS using Eq. (20). Eq. (21) computes the distance between the member node and its nearest CH. Ultimately, Eq. (22) selects the lowest value between the Eq. (20) and Eq. (21) for member nodes and further, necessary to calculate the energy according to section III(B). Algorithm I includes all the steps corresponding to the proposed protocol.

C. IMPLEMENTATION PHASES OF DE-SEP

Each round of the DE-SEP consists of two-time phases i.e., set-up phase and steady-state, which are basically the same basic strategies of original protocols LEACH [11] or SEP [12] as shown in Fig. 3. The set-up phase starts with the process of selecting a node that acts as a CH based on the threshold setting Eq. (11)-(16). The CHs will broadcast an

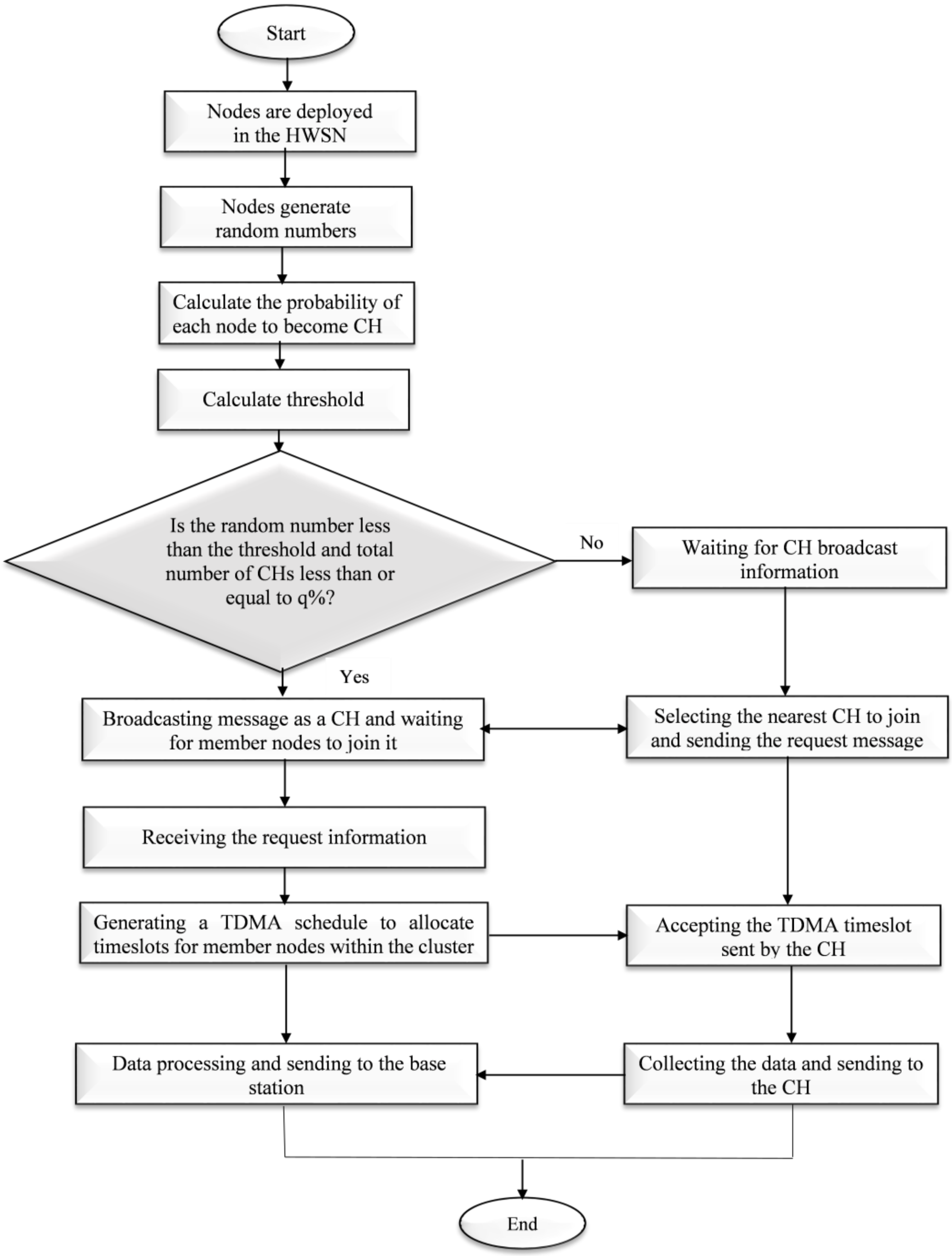


FIGURE 4. **Flowchart of DE-SEP.**

advertisement message to member nodes using the CSMA MAC protocol. All the member nodes start to search their nearby CH for building the cluster based on the received signal strength of the advertisement message. At the end of the setup phase, each member node again notifies the CH about its presence in the cluster using the CSMA MAC protocol. After receiving the request message from the member node, the CH allocates a TDMA schedule to member nodes based on the number of nodes in the cluster. In the steady state phase, each member node sends data to CH during its allocated timeslot, and thus avoid collision among data. After completing the data transmission from all the nodes, CH performs the data aggregation, removes redundancy and compresses data to a feasible extent for better utilization of bandwidth. The detail of the proposed protocol is presented using a flowchart as shown in Fig. 4.

V. SIMULATION AND RESULT ANALYSIS

This section presents the performance results of the proposed DE-SEP protocol and also, compared with the existing routing protocols such as SEP, M-SEP, P-SEP. The performance of the proposed routing protocol is evaluated

Table I PARAMETER SETTINGS

Parameters	Value
Network size, M	100m × 100m
Number of sensor nodes, n	100
Packet length, k	4000bits
Initial energy of normal node, E_0	0.5J
Transmitter/receiver electronics energy, E_{elec}	50nJ/bit
Data aggregation energy, E_{DA}	5nJ/bit
Energy dissipation for multipath model, ε_{mp}	0.0013pJ/bit/m^4
Energy dissipation for free space model, ε_{fs}	10pJ/bit/m^2
Optimal probability, p	0.1
Additional energy factor between normal and advanced nodes, α	2

using a number of performance matrices, namely network lifetime, stability period, half lifetime, throughput, and normalized residual energy. The network lifetime is the time period between the start of network operation and the death of the last sensor node. This measurement is a key performance matric as it closely relates to WSN's energy efficiency as well as the system's reliability. Moreover, the total number of rounds completed before the death of the first node is called the stability period and the total number of rounds completed before the death of the half node is called half lifetime. In addition, throughput represents the number of transmitted packets from CHs to BS and normalized residual energy per round exposes the state of the total energy of nodes after each round.

A. SIMULATION SETUP

The Network is constructed and performances are evaluated in a MATLAB based simulation model. The network size is 100m × 100m with 100 heterogeneous sensor nodes. A stationary BS is placed at the center of the network with unlimited energy. Table I shows the network parameters that are used in the simulation model.

B. OPTIMAL CH SELECTION

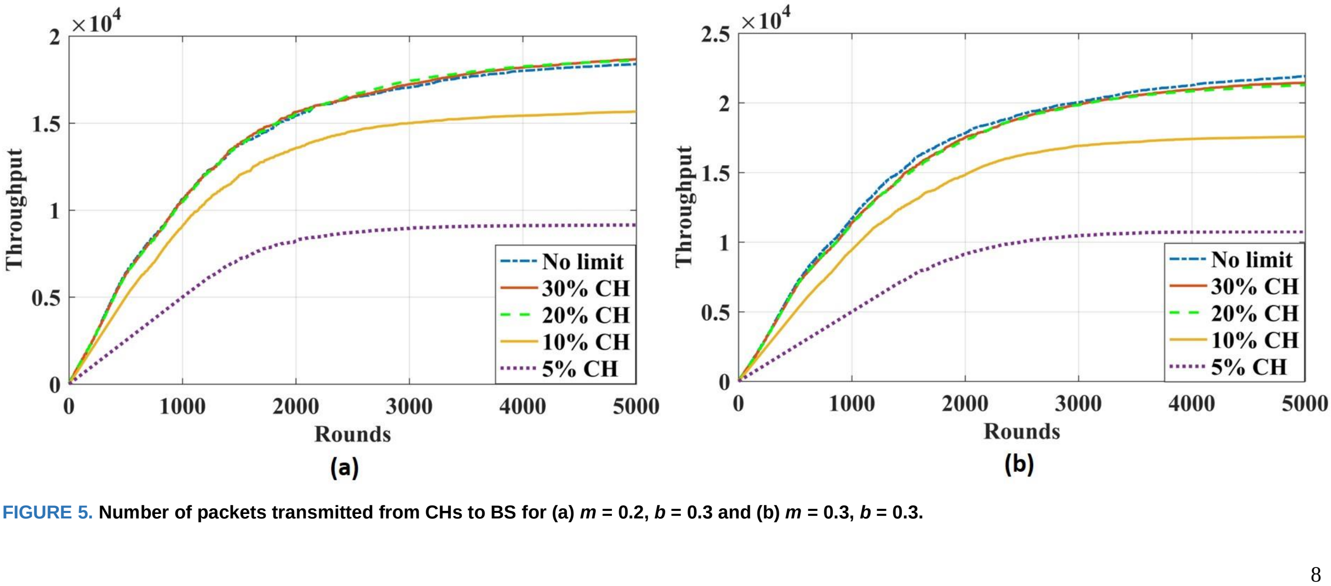
Total number of alive nodes are computed in each round, where the maximum q% of the alive nodes are allowed to be selected as CH per round. All the nodes in the network that meet the threshold criteria are treated as 'probable CH'. Among the 'probable CHs', maximum q% of the alive nodes are assigned to the 'final CH set'. Note that such restriction on the number of CHs significantly affects the performance parameters such as stability period, half node death, throughput and normalized residual energy. Tables II and III show the stability period and half lifetime in rounds for m = 0.2 & b = 0.3 and m = 0.3 & b = 0.3 respectively. For both cases, the number of CHs is restricted from 5 % to 30 % including the "no limit" conditions. The results show that the stability period increases with the increased number of CHs and such a tendency continues up to 20% of the alive nodes selected as CHs. In particular, the maximum value of the stability period is 1533 rounds and 1616 rounds for m = 0.2 & b = 0.3 and m = 0.3 & b = 0.3 respectively. However, the stability period decreases when the limit reaches 30%

Table II STABILITY PERIOD AND HALF LIFETIME FOR m = 0.2, b = 0.3

Limit on number of CH	Stability period	Half lifetime
No limit	1208	2791
30%	1447	2465
20%	1533	2338
10%	1331	2270
5%	506	2200

Table III STABILITY PERIOD AND HALF LIFETIME FOR m = 0.3, b = 0.3

Limit on number of CH	Stability period	Half lifetime
No limit	1160	2655
30%	1549	2347
20%	1616	2420
10%	1445	2325
5%	554	2174



(a) (b)

FIGURE 5. **Number of packets transmitted from CHs to BS for (a) m = 0.2, b = 0.3 and (b) m = 0.3, b = 0.3.**

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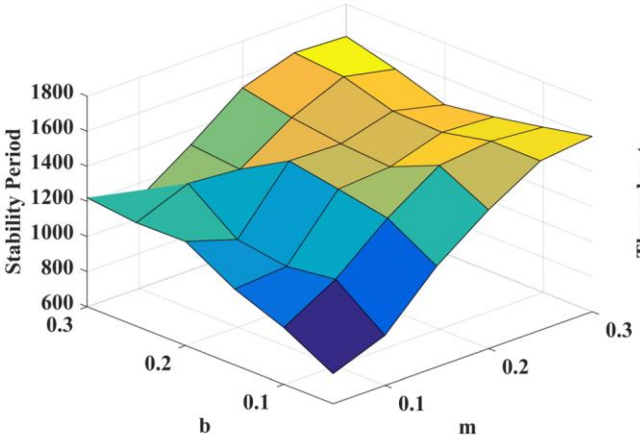

FIGURE 6. Variation of stability period with *m* and *b*

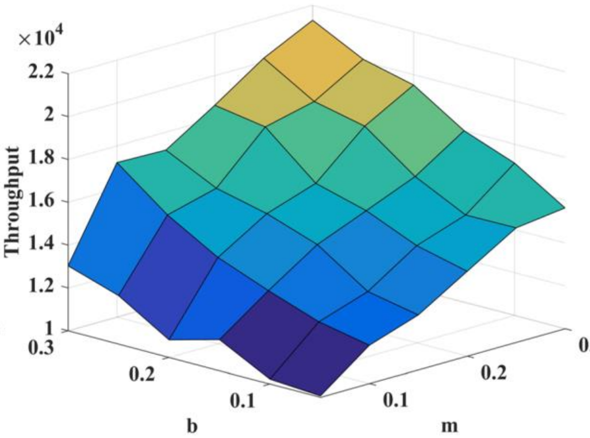

FIGURE 7. Variation of throughput with *m* and *b*

including 'no limit' condition. On the other hand, the half lifetime is maximum for 'no limit' in CHs selection and continues to decrease after imposing restrictions on the number of CHs.

Beside this, throughput performance of the system is also measured for m = 0.2, b = 0.3 and m = 0.3, b = 0.3 with respect to CHs limit in percentage as shown in Fig. 5. If the number of CHs decreases, packet transmission from CH to BS also decreases as represented by Fig. 5. The system shows maximum throughput for "no limit" in CHs selection and minimum for 5% alive nodes selected as CHs. The results clearly indicate that the throughput is almost the same for "no limit", 30% and 20% of alive nodes selected as CHs. Therefore, a performance trade-off is observed between the stability period and throughput. The number of CHs should be restricted to achieve a larger stability period, whereas "no limit" in CHs selection is required for better throughput. Overall, we found that 20% of alive nodes selected as CHs can be treated as optimum value to maximize the stability period as well as throughput and thus, such selection of CHs are used for subsequent performance analysis.

C. EFFECT OF m AND b

Increasing the value of m and b refers to adding more advanced and intermediate nodes to the network respectively. Advanced node's energy level is higher than intermediate node, so m has a more significant impact on the network's performance compared to b. The stability period and throughput for various values of m and b are depicted in Fig. 6 and Fig. 7 respectively. Both the stability period and throughput improve with increasing values of m and b due to the rising energy level of nodes. Moreover, variation of m influences more on stability period and throughput in comparison to variation of b due to the presence of high energy in advanced nodes compared to intermediate nodes.

D. PERFORMANCE COMPARISONS

Fig. 8 and Fig. 9 depict a comparison of DE-SEP, P-SEP, M-SEP and SEP in terms of network lifetime and the number of dead nodes relative to the number of rounds. To analyze the performance of DE-SEP, the value of m is varied, where the value of b maintains constant to 0.3. Fig. 8(a) and Fig. 9(a) show that the first node of DE-SEP dies at 1533 rounds, while these values are 1188, 1242 and 1235 rounds in case of P-SEP, M-SEP and SEP respectively for m = 0.2. Moreover, Fig. 8(b) and Fig. 9(b) show that the first node of DE-SEP, P-SEP, M-SEP and SEP dies at 1616, 1375, 1306 and 1298 respectively for m = 0.3 indicating the better proposed routing scheme.

Besides this, the performance of stability period and half lifetime for DE-SEP show better results compared to P-SEP, M-SEP and SEP as shown in Fig. 10 and Fig. 11. In particular, Fig. 10 presents that the stability period of DE-SEP is about 29%, 23% and 24% better than P-SEP, M-SEP and SEP respectively for m = 0.2. In case of m = 0.3, the stability period improves by 18%, 24% and 25% compared to P-SEP, M-SEP and SEP respectively. Moreover, Fig. 11 also indicates the performance improvement in half lifetime for DE-SEP about 16%, 60% and 61% compared to P-SEP, M-SEP and SEP respectively in case of m = 0.2. For m = 0.3, DE-SEP still shows better results in half lifetime by about 15%, 54% and 53% compared to P-SEP, M-SEP and SEP respectively. The above results clearly justify that the nodes die slowly in DE-SEP compared to other protocols, and thus prolong the aliveness of the network. Nodes' average energy and distance from the BS are considered in the proposed DE-SEP during CHs selection, and thus it facilitates to obtain balanced energy consumption among sensor nodes and prolong the lifetime of the network.

Moreover, Fig. 12 shows the throughput performance of all the protocols, where the number of transmitted packets from CHs to BS per round are measured. Throughput for DE-SEP is higher than P-SEP and M-SEP but less than SEP. In the proposed protocol DE-SEP, node's average energy is used for both the probability and threshold calculation, which ensure that node with low energy cannot become CH. Therefore, there are optimum number of CHs are generated

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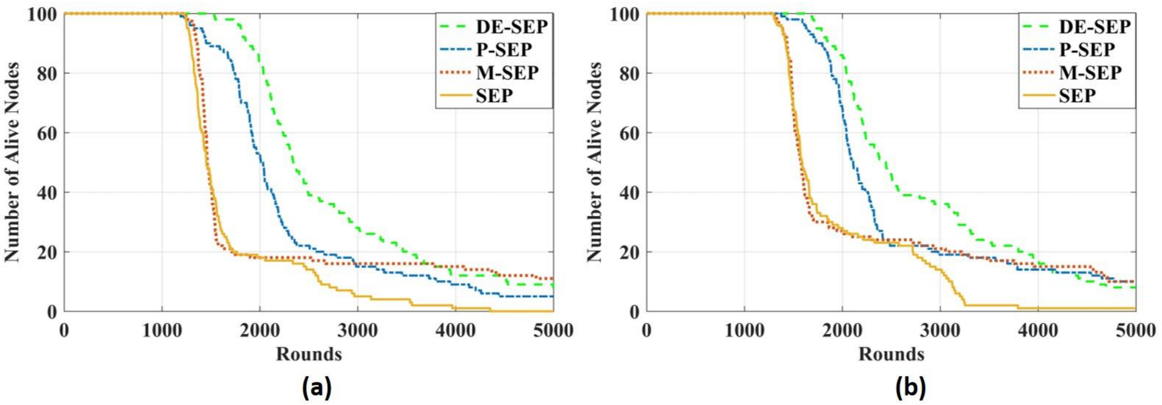


FIGURE 8. Network lifetime for (a) m = 0.2, b = 0.3 and (b) m = 0.3, b = 0.3.

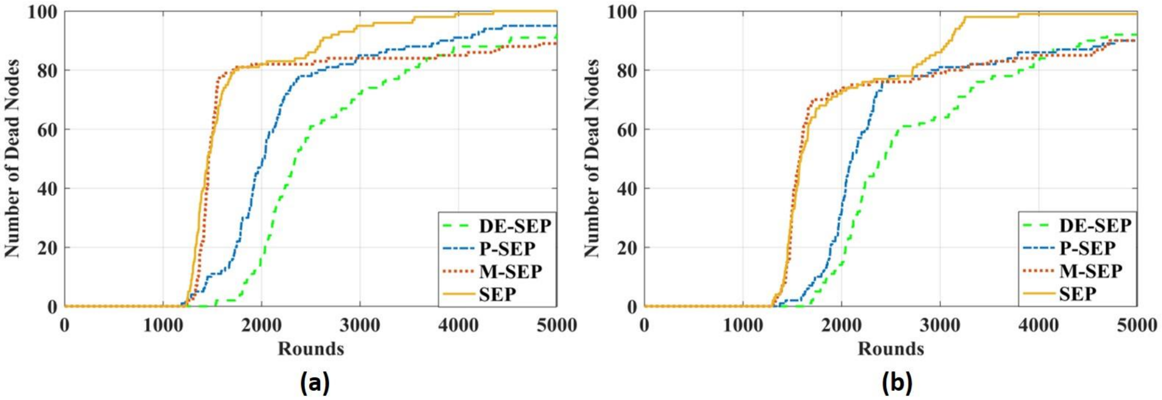


FIGURE 9. Dead Nodes per round for (a) m = 0.2, b = 0.3 and (b) m = 0.3, b = 0.3.

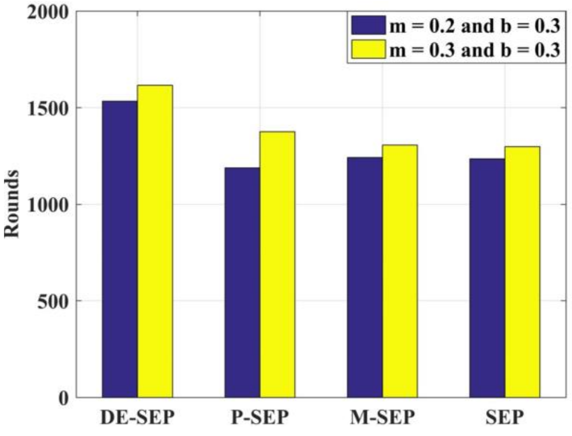


FIGURE 10. Stability period.

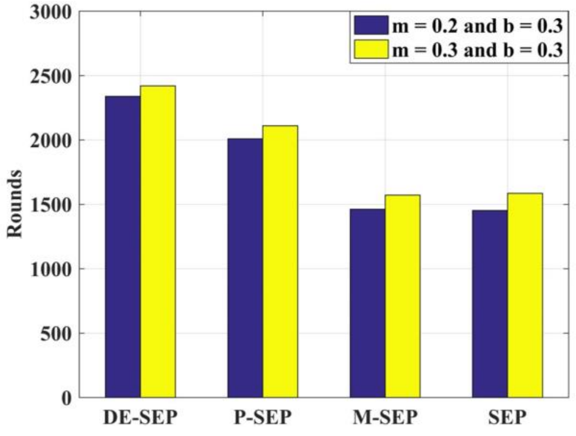
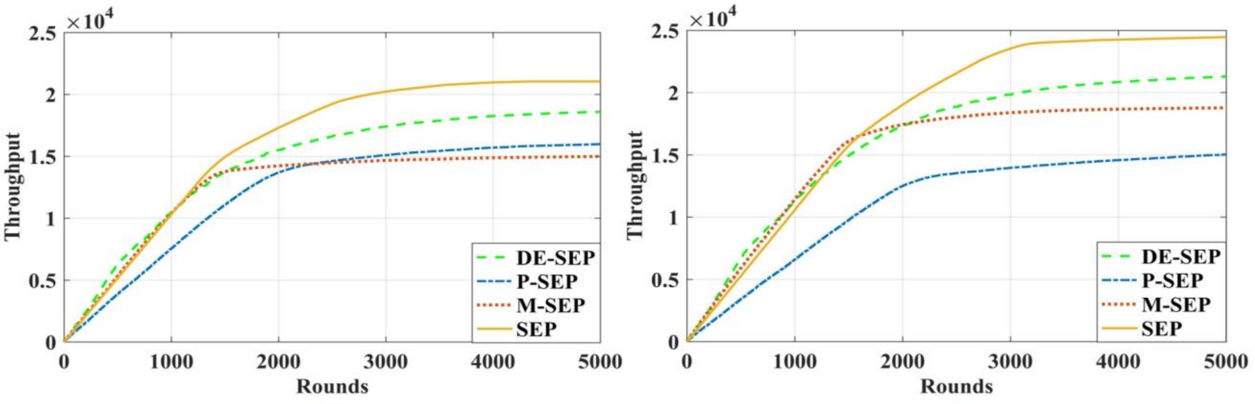


FIGURE 11. Half node death (half lifetime).

in the network that significantly improve the network's stability period. However, as the data aggregation part is mostly processed by CHs, the overall throughput is decreased. On the other hand, SEP does not consider the node's average energy in the threshold condition. The selection is based on node's initial energy and thus, there is a high chance that node having low energy also become CH. This approach increases the number of CHs, which eventually help to improve the throughput. However, the network stability period is reduced due to the presence of many CHs having a low residual energy and die in short time after some rounds. Fig. 12(a) presents that the throughput for DE-SEP, P-SEP, M-SEP and SEP are 18606, 15989, 14992 and 21052 data packets respectively in case of m = 0.2, which eventually show the good data transmission performance using DE-SEP. Further, Fig. 12(b) also shows that the throughput using DE-SEP is 21293 data packets, whereas the existing protocols of P-SEP, M-SEP and SEP have the transmission of 15026, 18771 and 24457 data packets respectively in case of m = 0.3. Here, the throughput

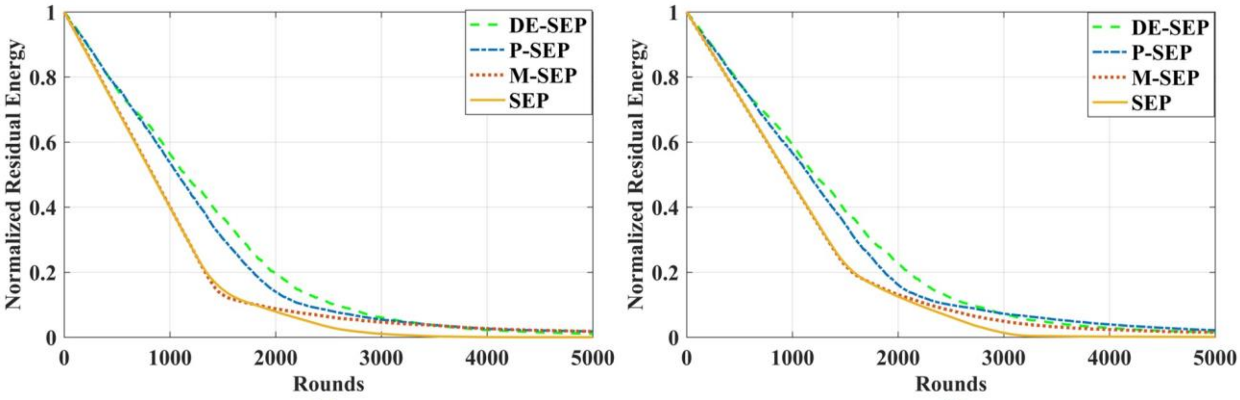


(a) (b)

FIGURE 12. **Number of packets transmitted from CHs to BS for different protocols in case of (a) m = 0.2, b = 0.3 and (b) m = 0.3, b = 0.3.**

Table IV COMPARISON OF DE-SEP WITH EXISTING PROTOCOLS

Protocol	Stability period			Half lifetime			Throughput	
	m = 0.2 b = 0.3	m = 0.3 b = 0.3		m = 0.2 b = 0.3	m = 0.3 b = 0.3		m = 0.2 b = 0.3	m = 0.3 b = 0.3
DE-SEP	1533	1616		2338	2420		18606	21293
P-SEP	1188	1375		2009	2110		15989	15026
M-SEP	1242	1306		1461	1571		14992	18771
SEP	1235	1298		1451	1585		21052	24457



(a) (b)

FIGURE 13. **Normalized residual energy of the network for (a) m = 0.2, b = 0.3 and (b) m = 0.3, b = 0.3.**

improvement for higher value of m results from the presence of more advanced nodes in the network with higher energy.

The summary of the above discussion based on Fig. 8 to 12 is presented in Table IV using the performance matrices of stability period, half lifetime, and throughput. Table IV clearly indicates that the proposed DE-SEP outperforms existing protocols in terms of all the evaluation parameters in either combination of m and b.

Moreover, Fig. 13 shows the normalized residual energy of the network per round, where the proposed protocol shows improved performance compared to existing protocols. In particular, the normalized residual energy of DE-SEP at the 1000th round is 5%, 41% and 41% more than P-SEP, M-SEP and SEP respectively in case of m = 0.2 as shown in Fig. 13 (a). Further, Fig. 13(b) shows that the normalized residual energy of DE-SEP is increased by 5%, 25% and 24% compared to P-SEP, M-SEP and SEP respectively at 1000th round in case of m = 0.3. The presented results confirm that the proposed DE-SEP consumes less energy compared to other protocols. This improved performance in energy

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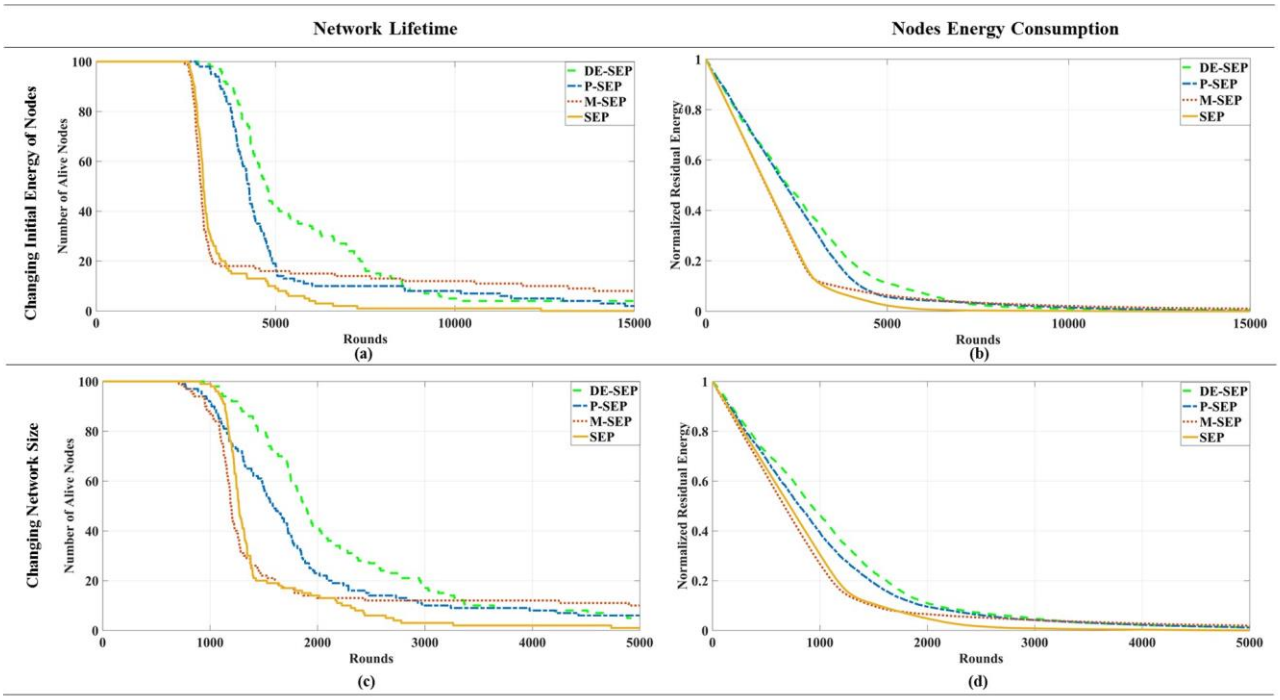

FIGURE 14. **Comparison of different network scenarios.**

consumption is mainly generated due to providing more priority in near nodes over distant nodes to be selected as CH, and thus the process ensures efficient use of available energy during the data transmission by maintaining the heterogeneity of the sensor network.

E. DIFFERENT SCENARIOS

Two different scenarios are considered for further analysis using DE-SEP and compared to P-SEP, M-SEP, SEP for m = 0.2 and b = 0.3. The performance of the protocols is evaluated in terms of the number of alive nodes, stability period, half lifetime and normalized residual energy. The network scenarios considered are as follows:

1) CHANGING INITIAL ENERGY OF NODES

Nodes' initial energy is an important factor in WSN as these nodes are power limited and cannot be recharged or replaced once they are deployed in the network. In this scenario, nodes' initial energy (E_0) changes from 0.5J to 1J and observe the performance of the proposed protocol compared to the existing protocols. The change of nodes' initial energy directly affects the network lifetime and nodes' energy consumption as shown in 14(a), 14(b). In the case of number of alive nodes, first node for DE-SEP dies at 2846 rounds, whereas these values are 2790, 2469 and 2583 for P-SEP, M-SEP and SEP respectively as shown in Fig. 14(a). The results show that the proposed DE-SEP consumes minimum energy compared to other protocols even with the change of nodes' initial energy as also appeared in Fig. 14(b). Overall, the DE-SEP performs better compared to existing protocols when initial the energy of the nodes is increased.

2) CHANGING NETWORK SIZE

In this scenario, the performance of DE-SEP is analyzed and compared to existing routing protocols by changing the network size (M) from $100m \times 100m$ to $200m \times 200m$, while keeping other parameters fixed. The change of network size affects the performance of the protocol in terms of network lifetime and nodes' energy consumption as shown in Fig. 14(c), 14(d). The performance results degrade due to the increase of network size for all the protocols compared to its original size. In particular, Fig, 14(c) shows that the first node death occurs at round 941, 732, 709 and 910 for DE-SEP, P-SEP, M-SEP and SEP respectively, whereas these values were 1533, 1188, 1242 and 1235 in earlier network size i.e., $100m \times 100m$. For the nodes' energy consumption, the SEP consumes highest energy while DE-SEP consumes lowest energy compared to other protocols as shown in Fig. 14(d). The presented results confirms that the proposed DE-SEP still performs better compared to other protocols even the network size is increased.

The summary of the results for different scenarios are presented using the performance matrices of stability period and half lifetime as shown in Table V. As mentioned before, there are two scenarios are considered, firstly, the change of nodes' initial energy (E_0) from 0.5J to 1J and secondly, the change of network size (M) from $100m \times 100m$ to $200m \times 200m$. For both cases, only the target parameter is varied while the other settings of the network keep constant. The results show that the network performance improves with the increase of the node's initial energy. In particular, the

Table V COMPARISON OF DIFFERENT NETWORK SCENARIO

Protocol	Stability period			Half lifetime		
	$M = 100^2$ $E_o = 0.5$J	$M = 100^2$ $E_o = 1$J	$M = 200^2$ $E_o = 0.5$J	$M = 100^2$ $E_o = 0.5$J	$M = 100^2$ $E_o = 1$J	$M = 200^2$ $E_o = 0.5$J
DE-SEP	1533	2846	941	2338	4761	1873
P-SEP	1188	2790	732	2009	4259	1582
M-SEP	1242	2469	709	1461	2910	1194
SEP	1235	2583	910	1451	2989	1267

stability period increases from 1533 rounds to 2846 rounds for DE-SEP with the increase of initial energy. Moreover, the half lifetime also improves with the increase of nodes' initial energy. The other existing protocols i.e., P-SEP, M-SEP and SEP also show better performance with the presence of added value of initial energy. Therefore, it can be concluded that the network shows improved performance due to the additional energy of each node and the proposed DE-SEP shows the best performance among all the existing protocols. Besides this, the increase of network size degrades the system performance as shown in Table V. In particular, the DE-SEP shows that the stability period decreases from 1533 rounds to 941 rounds and half lifetime decreases from 2338 rounds to 1873 rounds. The other existing protocols i.e., P-SEP, M-SEP and SEP also show similar performance for the case of changing network size. This degradation in system performance is mainly caused due to the increase of distance between member nodes and CHs as well as CHs and BS, which eventually accelerate the nodes' energy consumption to reduce their lifetime.

VI. CONCLUSIONS AND FUTURE WORK

Here, an energy efficient hierarchical routing protocol for heterogeneous WSN is proposed using three levels of energy heterogeneity in sensor nodes. The proposed DE-SEP utilizes both the energy and distance criteria in CHs selection process, where the closer node from BS gives more priority to become CH for effective utilization of available energy and ensures a longer lifetime. The demonstrated results show that the proposed DE-SEP performs significantly better than the state-of-the-art protocols like P-SEP, M-SEP, SEP in terms of network lifetime, stability period, normalized residual energy and throughput. In the future, we would like to change the proposed routing protocol considering the mobile sensor nodes as well as mobile sink nodes at a constant speed.

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