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Analysis of the impact of distance on cluster head election probability and threshold condition in heterogeneous networks

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Abstract. Large number of tiny nodes that are used in wireless sensor networks (WSNs) sense and collect data with the help of limited power source which are embedded in them. Routing of data is one of the main factor that decides network lifetime as data transmission process is an energy intensive process and the amount of energy exhausted is much higher than the energy consumed for computational process if the separation between nodes and sink is of notable distance. This analytical study is based on heterogeneous low energy adaptive clustering hierarchy (LEACH) and enhanced stable election protocol (SEP-E). This paper focusses on the analytical study of distance effect on heterogeneous network performance based on threshold condition and probability of cluster head (CH) selection to provide better idea about the dependence factor of proper cluster head selection and also analyses the effect of distance on CH selection process.

Keywords. Wireless sensor networks; energy; heterogeneous; stability; lifetime; threshold.

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1. Introduction

Wireless sensor network (WSN) is a type of ad-hoc wireless network mainly used to examine physical or environmental phenomena in an uncertain environment and its applications have been increasing rapidly in the recent years. WSN is used in different applications like military purposes, disaster management, traffic safety, emergency medical purposes, sensing environmental parameters like temperature, humidity, vibrations, etc. [1–3]. It is also used for forest fire detection, air pollution monitoring, landslide detection, commercial applications, etc. The advancement in technology has also added a unique feature in sensor network and leads to rapid growth of its position in the networking field. WSN consists of a large number of minute sensing and detecting devices called nodes (or sensor nodes) which are spread out in the particular area where the detection has to be done. These sensors have their own battery for power supply and have the ability to process data. The function of these sensors is to sense their assigned parameters and pass the collected data to the sink node (or base station).

Sensors are also designed with many other additional features like programmability, memories for data storage, embedded GPS, etc.

With all these advantages, still many restraints and challenges are faced by WSNs. Some of the problems may be: limited bandwidth, improper connectivity among the sensor nodes, power constraint, limited memory, data processing speed of nodes and coverage problem. Among these problems, the most common is the hindrance to use the available source of power in sensor nodes independently. Once the battery lifespan of these nodes is over, the network becomes useless and functionless. The cost of replacing these batteries is equivalent to displacing the whole network with new one which is undesirable. The most energy consuming process in sensors is the data transmission to the destination nodes as power decays more as the distance increases. The energy required by the nodes for data transmission is much more than the energy required by the electronic components of the nodes. Recently, researchers

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have developed many routing protocols for WSNs for prolonging the network lifespan and to optimise the energy usage of the whole network. Among these protocols, clustering-based protocols are the most prominent protocols.

Data channelling among the nodes in a clustered network can be of single-hop or multi-hop transmission depending on the separation between the nodes. Usually, multi-hop transmission or relay node is preferred when the direct transmission needs much power to forward the data. The sensor nodes in the clustering network can be homogeneous or heterogeneous depending on the energy level of the nodes that have been deployed. In homogeneous networks, all the nodes are of same energy level from the initial stage itself whereas in heterogeneous networks, the nodes are of different energy levels from the beginning of the network operation. Our study will be on heterogeneous network clustering based routing protocol and single-hop transmission. In static clustering network, the clustering group remains unchanged for the whole network lifetime if once formed while in dynamic clustering network it keeps on changing periodically. Both low energy adaptive clustering hierarchy (LEACH) and enhanced stable election protocol (SEP-E) are of dynamic type.

Heterogeneous network has been proposed to prolong the network operation time and to extend the first node dead (FND) period, also called the stability of the network. It consists of normal low energy nodes and some fractions of higher energy nodes. Clustering involves setting of nodes into appropriate clusters and selecting CH to transfer the collected data to the sink node or base station. The nodes with more energy are given more chances to become the CH so that the energy consumption can be balanced throughout the network. Two main factors, i.e. threshold condition and election probabilities of the CHs, decide the selection of CHs in cluster-based protocol like LEACH and SEP-E. Many research works have been done to extend network lifetime based on improved threshold condition. This study is associated with the distance- and energy-based election probabilities of CH selection to compare the network performance with that of the distance-based threshold condition in heterogeneous network.

The remaining part of the paper is categorised as follows. Section 2 contains literature review of the existing protocols. Section 3 consists of details of the proposed protocols DE-SEP and H-LEACH. Section 4 describes the radio energy model used in this paper. The MATLAB simulation results and outputs for performance comparison are included in §5. The conclusion and future outlook are mentioned in §6.

2. Literature review

Researchers have developed many routing protocols to overcome the problems of short lifespan of wireless sensor networks and to improve the overall performance of the network [4–7]. Cluster-based routing protocol is the most highlighted routing protocol to overcome the problem of short network lifespan and the most relevant protocol of this type is LEACH [8]. The whole operation of LEACH protocol is divided into many rounds where clustering process is done periodically to change the CHs among the nodes dynamically. LEACH is basically a homogeneous routing protocol but in this study, the heterogeneous condition of nodes is considered. Every round is divided into two states, namely set-up state phase and steady-state phase. The head node (HN) or CH selection is done in the set-up state and a random number is generated by the sensor nodes. The selection process is based on the condition that the random number generated by the nodes is less than or equal to the threshold condition given by (1).

$$T(n) = \begin{cases} \dfrac{p}{1 - p * (r \bmod / p)}, & n \in G, \\ 0, & \text{otherwise}, \end{cases} \tag{1}$$

where p is the probability of nodes to be HN, n denotes nodes, G is the set of nodes that has not been CH in the recent rounds and r is the current round. After election, it broadcasts as the HN for the current round. The sensor nodes will join the CH with the nearest distance to them and the HN will acknowledge their corresponding members by sending the time slots for their data transmission. The HN will accumulate the collected data from the members and transfer it to the sink node or destination.

Kumar [9] developed an energy efficient clustering protocol (EECP) for extending the network lifetime based on two types of data transmission, namely single-hop EECP and multi-hop EECP. In single-hop EECP, the CHs are elected based on the ratio of current energy of the nodes in each round to the average energy of the network in addition to the normal threshold condition. This energy-based CH selection allows higher energy nodes to become HN more often than the lower energy nodes. In this protocol, if the separation between HN and base station is very large, then multi-hop transmission is used for the routing process and is called as multi-hop EECP. The proposed protocol increases the network functioning time by 40% in single-hop EECP as against the energy efficient clustering technique (EECT) and energy efficient heterogeneous clustered (EEHC) schemes and by 12% in multi-hop EECP. It also shows improvement in packet delivery to the base station as against the EECT and EEHC.

Singh *et al* [10] proposed a heterogeneous network protocol called energy efficient heterogeneous distributed energy efficient clustering (DEEC) protocol of three energy levels to increase the lifespan of WSN. Different modified probability conditions for the CH selection were considered depending on the heterogeneity level of the nodes. The network lifetime in the proposed protocol increases considerably in comparison to the original DEEC.

Bala and Lalit [11] presented a deterministic SEP (D-SEP) protocol where CHs are elected in a distributed fashion. They have considered two-level and four-level heterogeneous conditions of nodes for the simulation purpose. The proposed protocol shows huge improvement in lifetime, data packets to base station and better stability in the network. This protocol improves the lifetime by 17.8 times the original SEP. In [12], an energy efficient heterogeneous clustered scheme for WSNs has been presented to overcome the fast death of nodes in homogeneous networks. The CH selection is based on the weighted election probabilities by taking into account the residual energy of each node. The proposed protocol shows improvement in comparison to LEACH. In [13], a stable energy efficient clustering protocol (SEECP) has been proposed to prolong the stability period of the conventional LEACH protocol. The criterion for CH selection of this energy-aware routing protocol is based on the residual energy of nodes and the data transmission takes place either directly or dual hop based on predefined distance of the CH from base station. The results of this protocol are shown to have better stability than LEACH and distance-based residual energy SEP (DRESEP).

Wang and Xang [14] proposed a heterogeneous routing protocol called distributed election clustering protocol (DECP) to extend the stability of WSNs so that the reliability of information in the whole network can be maintained for longer time. The proposed method shows good improvement compared to LEACH and SEP. In [15] a hybrid energy-efficient routing protocol for WSNs was proposed combining both the direct transmission (DT) and minimum transmission energy (MTE) methods to study the energy consumption of nodes compared to DT and MTE individually. The proposed method came out to be more energy efficient than the individual method. Youssef *et al* [16] proposed an algorithm called constrained shortest path energy-aware routing algorithm for WSN. This protocol not only reduces the energy consumption of the network but also maintains a good throughput and less delay for end-to-end transmission. This algorithm provides improvement in network lifetime and also in other network parameters. It considers distance between the nodes and number of hops between the transmitter and the receiver for routing the packet.

In [17], an energy-driven adaptive clustering hierarchy (EDACH) has been implemented for WSNs. This protocol increases the network lifespan and also provides uniform energy distribution in the whole network. The proposed work divides the network dimension into three segments so that more clusters are formed in faraway distance from the base station and nodes in these three segments have different probabilities of becoming CH. The CH will be changed by a proxy node after their selection, once their energy drops down below some calculated threshold value based on the remaining energy and location of the nodes. It shows improvement in network lifespan and uniform distribution of dead nodes compared to LEACH and proxy distribution enabled adaptive clustering hierarchy (PLEACH).

In [18], a protocol called distance-based residual energy-efficient SEP was proposed for WSNs. The authors considered three energy levels, namely normal, intermediate and advanced nodes. The condition of becoming CHs depends on the distance of nodes and residual energy of nodes in order to overcome the problem of quick death of faraway nodes from the base distance.

Chen *et al* [19] developed an unequal cluster-based routing protocol in WSNs. They used the relay nodes for data forwarding process and also took the problem of hot spot to avoid the early death of nodes lying near the base station because of excessive forwarding of data. In order to overcome this hot spot problem, they implemented unequal clustering of nodes so that the nearer CHs' energy consumption can be reduced by allowing fewer members under its headship.

Toor and Jain [20] considered mobile sensor nodes in hierarchical heterogeneous network and proposed mobile energy-aware cluster-based multi-hop (MEA-CBM) routing protocol which elects only the nodes with higher energy to be the CH. It employed nodes of three different energy levels and multi-hop transmission was used for intercluster connection. A mobile data collector sensor node was assigned in each sector after dividing the network into different sectors. The comparison was performed for different network node density and network area and the result showed that MEACBM shows better performance than energy efficient cluster based multi-hop routing (EACBM), energy efficient hybrid protocol for routing based on mobile data collectors (EEHPMDC) and node density-based clustering and mobile collection (NDCM) in terms of stability and network lifetime.

Mehra *et al* [21] proposed a zonal SEP where the whole network area was divided into different zonal regions and it was assumed that the nodes are deployed semirandomly. Advance nodes were distributed in different regions of each zone and also multi-hop communication was employed for data transmission to base station. The CH selection probability is calculated by the formula:

$$\mathrm{CH}\,(n) = \frac{E_n\,(r) * \omega_n\,(r) * \delta_n * ch}{c * \gamma_n}, \tag{2}$$

where $E_n(r)$ is the remnant energy level, ω_n is the average transmission power required to connect nodes within some predefined range, δ_n is the node density, γ_n is the distance of nodes to base station, *ch* is the number of nodes that have not been CHs and c is the number of nodes that have been CH. The simulated results showed better stability and lesser energy consumption than LEACH, SEP, distributed energy efficient clustering (DEEC) and zonal-SEP (Z-SEP). Elshrikawey *et al* [22] proposed an enhancement approach for reducing the energy consumption in WSNs by considering three additional factors for electing CHs, namely node degree, distance of the nodes from the base station and residual energy of the node. It also allowed the CH to save its energy by increasing the sleeping time period after data transmission if the cluster members are less under its leadership.

Younis and Fahmy [23] implemented a hybrid energy efficient distributed clustering (HEED) protocol by considering nodes of various power levels. This protocol took into account parameters like residual energy of nodes and node degree to enhance network lifetime and also provided uniform cluster distribution. From the earlier existing works, it can be concluded that even though many research works have been done related to the improved CH selection based on threshold condition, proper studies have not been done on election probabilities of CH selection. This comparative study is based on the improved election probabilities and improved threshold condition to analyse the network performance on these two conditions.

3. Proposed approaches

Our proposed protocol is explained in detail in this section and our implementation is based on LEACH with heterogeneous condition of nodes (in terms of energy levels) and enhanced SEP [24] for comparative analysis. Distance plays an important role for cluster selection in addition to the energy levels of nodes which can be clarified from the energy dissipation model in §4.1. This comparative analysis is based on improved election probabilities of CH selection which takes into consideration both distance and energy factors and compares with distance-based heterogeneous LEACH (H-LEACH). The main objective of this comparative analysis is to study which factors play more important roles in CH selection of heterogeneous network, election probabilities or threshold condition, for CH selection and its impact on network performance. It has been observed that many researchers have studied clustering-based protocol like LEACH and SEP-E to improve the network performance by improving the threshold condition in the CH selection process or by improving the clustering process. In this paper, we shall study the effect of distance on both election probability and threshold condition in heterogeneous network.

Some of the presumptions made in the protocols are:

- All nodes are capable of computations and are location aware nodes
- Every node has the ability to communicate with base station.
- Once deployed, every node is stationary.
- The nodes are uniformly and randomly distributed over the network irrespective of their energy levels.
- Increase in the initial energy of nodes will not affect the distribution of nodes.
- All nodes can control their power strength according to their requirement.
- Base station is independent of energy constraint and can perform all communications and computations.
- All sensor nodes will communicate with the same amount of energy depletion for transmission and reception, i.e. communication is symmetrical.
- Data aggregation is assumed to be perfect.

These two proposed approaches have the same steady-state operation but have different set-up phase perspectives. In this study, the performance comparison will be analysed in terms of stability period, packets received at the base station, system energy per round and CH selection. In the set-up phase of these protocols, two circumstances play principal roles in selecting the CH: (1) election probability of CH selection and (2) the threshold value of nodes in which a random number generated by a node will be compared with the threshold value. In this paper, heterogeneous network is analysed using different approaches for CH selection.

3.1 *DE-SEP*

In distance-based enhanced stable election protocol (DE-SEP), CH selection process (set-up phase) and data transmission process (steady-state phase) make one round operation and this round operation iterates until all nodes are dead. DE-SEP includes distance factor in the CH election probabilities of different energy levels of nodes. The distance of every node from the base station (sink) will also be given weightage for CH selection apart from considering the energy levels of nodes. In enhanced SEP (SEP-E), higher priority is given to higher energy level nodes to become CH than the lower energy level node by considering the fraction of energy difference in the election probability of CH selection. In DE-SEP, the election probability will take into account the distance factor of nodes also so that the nodes closer to base station (BS) will have higher chance of becoming CH than the far away nodes. With this additional inclusion, the energy distribution in the whole network will remain almost balanced and it will also avoid faster death of distant low-energy nodes.

For this study, nodes of three different energy level are taken, advanced nodes which have the highest energy among the nodes, intermediate nodes which have lower energy than advanced nodes but higher than the ordinary nodes and ordinary nodes which have the minimum energy among the nodes to be deployed over the observation area. Advanced nodes have a times more energy than the ordinary nodes and intermediate nodes have b times more energy than the ordinary nodes. Before the clustering process starts, base station will broadcast 'hello' message to every node in the network so that the nodes can calculate their distance from the base station with the help of the signal strength received by them. The new election probabilities of the proposed DE-SEP protocol are given as

$$p_{nn} = \left[\frac{p_1}{(1+m_a a+m_i b)}\right] * \left[1-\frac{d(i)}{d_{\max}}\right], \tag{3}$$

$$p_i = \left[\frac{p_1(1+b)}{(1+m_a a+m_i b)}\right] * \left[1-\frac{d(i)}{\mathrm{d}_{\max}}\right], \tag{4}$$

$$p_a = \left[\frac{p_1(1+a)}{(1+m_a a+m_i b)}\right] * \left[1-\frac{d(i)}{d_{\max}}\right], \tag{5}$$

where p_{nn}, p_i, p_a are CH election probabilities of normal, intermediate and advance nodes respectively; $d(i)$ is the distance of node i from the base station; p_1 is the probability of the CH selection; $d_{\min}$, $d_{\max}$ represent the minimum and maximum distance of nodes from the base station respectively; m_a and m_i represent the fraction of advanced nodes and intermediate nodes respectively of the total ordinary nodes available in the network and i is the corresponding node which may be either normal, intermediate or advance nodes.

The ratio R (assume) $= [1 - d(i)/d_{\max}]$ shows less value for the nodes lying far away from the base station. Even though the node has higher energy value, the chances of it becoming CH will decrease if it is located far from the base station. This factor will prioritise the distance over energy value of nodes as long distance data transmission is a highly energy-intensive process.

The inclusion of distance factor will control the election of CH providing more preference to nearer nodes as the probability will increase. If the distance is large, more energy is spent leading to faster death of nodes even though its energy level is high at the time of selection. The involvement of energy fractions in the election probabilities of different energy levels of nodes as given in eqs (3)–(5) also helps in selecting nodes with higher energy as CHs. This election probability gives preference to energy levels of nodes as well as distance of nodes unlike in most of the heterogeneous networks. The threshold values for different types of nodes in the proposed protocol are given by

$$T\ (nn) = \begin{cases} \frac{p_{nn}}{1-p_{nn}*(r \bmod / p_{nn})}, & n_{nn} \in Gn \\ 0, & \text{otherwise} \end{cases}, \tag{6}$$

$$T\ (i) = \begin{cases} \frac{p_i}{1-p_i*(r \bmod 1/ p_i)}, & n_i \in Gi \\ 0, & \text{otherwise} \end{cases}, \tag{7}$$

$$T\ (a) = \begin{cases} \frac{p_a}{1-p_a*(r \bmod 1/ p_a)}, & n_a \in Ga \\ 0, & \text{otherwise} \end{cases}, \tag{8}$$

where $T(nn)$, $T(i)$, $T(a)$ are the threshold values of ordinary, intermediate and advanced nodes respectively; n_{nn}, n_i, n_a are ordinary, intermediate and advanced nodes respectively; Gn, Gi, Ga are set of ordinary, intermediate and advanced nodes respectively that have not been CH in the recent rounds.

With these election probabilities of CHs selection, each node will generate a random number. Those nodes will be selected as the CH for the current round if the random number generated is less than or equal to the threshold value. After the selection, the node will announce itself as the CH for the current round so that the remaining nodes can join as cluster members to the nearest CHs based on the signal strength received by it. After acknowledging cluster members by the corresponding CHs, time slots will be allotted to them with the help of time division multiple access scheme (TDMA) by the concerned CHs for data transmission. The collected data will be transmitted by cluster members in steady-state phase which follows steps similar to that of LEACH.

The distance ratio in the election probabilities of the CH selection will lower the probability of faraway nodes to become CH even though it has higher energy from the nearby nodes. As the signal strength is inversely proportional to the second and fourth power of distance according to the radio propagation model, it is important to consider it in CH selection. Even if the node's energy is high and is at large separation from the base station, the energy will fade away very soon if it becomes CH continuously for some consecutive rounds. This proposed election probability will consider both the ratios of energy and distance for CH selection and will provide more chances to the eligible and appropriate nodes to become CHs.

3.2 *H-LEACH*

In distance- and energy-based threshold condition heterogeneous LEACH (H-LEACH) the same initial energy level of nodes is considered as in DE-SEP and also the same fraction of different nodes. In this approach, the CH election probability will be the same for all different energy level of the nodes in the network irrespective of the initial energy levels unlike DE-SEP. However, the threshold condition for selecting a node as the CH is modified with some additional distance and energy factors so that the threshold value for every round will depend on the current energy status of the nodes apart from just round value. The energy and distance ratio is included so that equal weightage can be given to both the factors while selecting the CH in every round operation. If the node is located far away from the base station, the energy in sending data is so high that death of the nodes happens very fast even though the node has high energy value.

The existing process of selecting the CH in LEACH depends only on threshold value which considers the specific rounds and the nodes which have not been CH recently in the cluster forming process. This makes the routing protocol to have short stability period which further shortens the network lifetime as the nodes are selected as CHs irrespective of their energy levels and distance from the base station which are the most important factors in deciding the network lifespan. In the heterogeneous H-LEACH, an additional factor is added in the threshold value so that the threshold value should take into account the current energy level and distance of the respective nodes while selecting the CH. This H-LEACH performance is compared with the distance-based SEP-E (DE-SEP) whose CH election probability depends on the distance in addition to energy levels to study its effect on the network performance for different network parameters. In DE-SEP, no additional factor is added to the threshold condition for different energy levels of the nodes. The new threshold condition for H-LEACH is

$$T(n) = \begin{cases} \dfrac{p_y}{1-p_y*\left(r \bmod \dfrac{1}{p_y}\right)} * \left(1-\dfrac{D_y}{D_L}\right) * S * \dfrac{E_y}{E_g}, & n \in C \\ 0, & \text{otherwise} \end{cases}, \tag{9}$$

where p_y is the probability of nodes that can become CH which is a predetermined value, r is the number of rounds, D_y is the distance of the nodes from the base station, D_L is the maximum distance of the nodes from the base station, E_y is the energy level of the node at the current round, E_g is the maximum energy level of each node, C is the group of nodes that have not been in CH role in the recent earlier rounds and S represents the successive rounds of being member nodes. The value S is added to avoid non-selection of CH due to low current energy level of the nodes. Equation (9) will generate higher value if the distance of the nodes to the base station is less and energy level is high for CH selection. The data transmission process in H-LEACH and DE-SEP follows a process similar to that in LEACH.

After the CH selection process, i.e., set-up phase, both proposed protocols follow the data transmission phase commonly known as steady-state phase. In the steady-state phase (data transmission), if the distance of the node is nearer to the base station than any of the advertised CH, then it directly transmits the data to the base station instead of joining as cluster members.

4. Radio energy model

For the purpose of implementation, a plain radio energy model is used as shown in figure 1 in which the data transmission takes place in two ways, namely Friis free space path model and multipath fading model. The radio energy model of LEACH is used for both H-LEACH and DE-SEP. If the distance of a node from the base station or distance among the nodes is more than the cross-over distance d_0 the energy dissipation will follow multipath fading propagation model whereas if the distance is below the cross-over value, then it follows the free space path model.

The propagation path loss is inversely proportional to d^2 for the free space path model and d^4 for the multipath fading model.

4.1 *System energy dissipation*

When a transmitter transmits data of length m-bit over a distance d, the energy dissipation is given by

$$E_t = m\,E_{\text{elec}} + m\epsilon_{\text{fs}}d^2,\ d < d_0, \tag{10}$$

$$E_t = m\,E_{\text{elec}} + m\epsilon_{\text{mp}}d^4,\ d \geq d_0, \tag{11}$$

where E_t is the transmitter energy required for transmission over d distance, m is the number of bits of the transmitted message, ϵ_{fs} and ϵ_{mp} are the energy required by the amplifier for amplification of a single bit for free space and multipath fading propagation model respectively, E_{elec} is the energy expenditure by the electronic components per bit, d is the distance between the transmitter and the receiver.

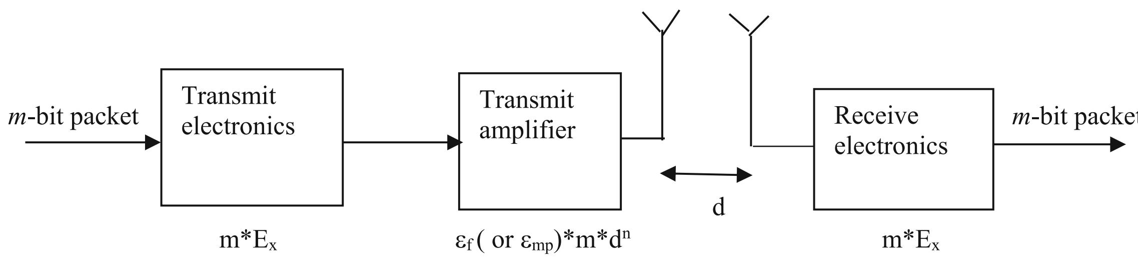

Figure 1. Radio energy dissipation model.

The cross-over distance d_0 is given by

$$d_0 = \sqrt{\frac{\epsilon}{\epsilon_{\text{mp}}}}. \tag{12}$$

The energy dissipation at the receiver to receive m-bit packet is given by

$$E_r = mE_{\text{elec}}. \tag{13}$$

Consider that in an area of $(M \times M)\text{m}^2$ the nodes are randomly and uniformly distributed and k_c is the number of CHs per round. Hence, there would be n/k_c nodes per cluster on an average, one CH and $n/k_c - 1$ cluster members (CMs) in a cluster. The energy dissipation by CH takes place when it receives m-bit data packets from the associated CMs and sending the integrated data to the destination node. Also, the CHs spend energy in aggregating the data received from the CMs which is taken to be E_{AGR} per bit (assuming a perfect aggregation process). The energy dissipation model explained in this section is followed by both heterogeneous LEACH and DE-SEP. The energy loss of the sensor nodes (SNs) is also contributed by their electronic components like transmitter, amplifier, etc. The energy consumption by the CHs in transmitting m bit message can be specified as

$$E_{\text{ch}} = mE_{\text{elec}}\left(\frac{n}{k_c} - 1\right) + mE_{\text{AGR}}\frac{n}{k_c} + mE_{\text{elec}} + m\epsilon_{\text{mp}}d_{\text{sink}}^4 \tag{14}$$

$$E_{\text{ch}} = mE_{\text{elec}}\left(\frac{n}{k_c} - 1\right) + mE_{\text{AGR}}\frac{n}{k_c} + mE_{\text{elec}} + m\epsilon_{\text{fs}}d_{\text{sink}}^2. \tag{15}$$

Equations (14) and (15) represent the energy expenditure in multipath and free space models respectively for every round based on whether the distance of the sink node (base station) from the CH is more than or less than the cross-over distance d_0. The energy consumed by the non-CH per round can be given as

$$E_{\text{non-ch}} = mE_{\text{elec}} + m\epsilon_{\text{fs}}d_{\text{ch}}^2, \tag{16}$$

where d_{ch} represents the distance to the CH from a node and d_{sink} represents the distance of the CH from the base station (or sink node).

The energy dissipated in a cluster per round can be calculated as

$$E_{\text{cluster}} = E_{\text{ch}} + \left(\frac{n}{k_c} - 1\right)E_{\text{non-ch}} \tag{17}$$

The network energy depleted per round can be estimated as

$$E_{\text{tot}} = k_c E_{\text{cluster}}. \tag{18}$$

5. Simulation results

For simulation purpose, the network dimension is taken to be 100×100, 200×200, 300×300 and $400\times400\ \text{m}^2$. The base station distance from the centre of the network is taken at different locations for the comparative study namely (50, 50), (50, 150), (50, 250) and (50, 350). The initial energy of the ordinary node is assigned to be 0.25, 0.5, 0.75 and 1 J. The energy consumption by the electronic components for both the transmitter and the receiver per bit is taken as 50 nJ/bit, ϵ_{fs}, the amplifier energy per bit for free space propagation is taken as $100\ \text{pJ/bit/m}^2$, ϵ_{mp}, the amplifier energy for multipath fading propagation is taken as $0.0013\ \text{pJ/bit/m}^4$. Total number of nodes deployed in the network is taken as 50, 100, 200 and 300, p_1 and p_y (probability of CH selection among nodes in the network) is taken to be 0.1 for both the protocols in heterogeneous network. The values of m_a, m_i, a and b are taken to be 10%, 20%, 3 and 2 respectively. In this simulation, H-LEACH represents the proposed protocol distance and energy-based threshold condition heterogeneous LEACH and DE-SEP represents the distance-based enhanced stable election protocol.

From figures 2 and 3 it can be observed that the stability period of DE-SEP is longer than the extended heterogeneous LEACH (H-LEACH). This longer stability is accomplished because of the selection of

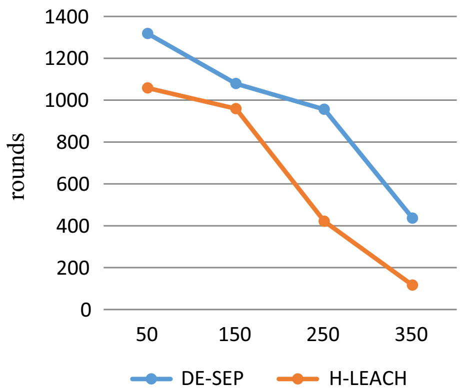

Figure 2. Stability period vs. rounds for increase in the base station distance from the centre of the network (50, 50), (50, 150), (50, 250) and (50, 350).

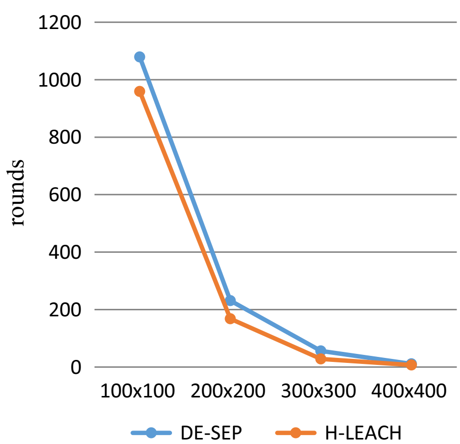

Figure 3. Stability period vs. rounds with increase in network dimension.

appropriate nodes as the CHs for every round operation. DE-SEP is able to achieve better stability period even when the base station distance increases from the centre of the network and the same result can be seen when the network dimension is increased. This shows that election probability of CH plays a more important role than the threshold condition in cluster-based protocol in selecting appropriate nodes as CHs. The stability period becomes very short for both H-LEACH and DE-SEP as shown in figure 3 when the network dimension is increased. It is because the distance between the CHs and cluster members is also increased apart from the increased separation range between the base station and the nodes which further leads to more energy consumption by the cluster members in intracluster data transmission.

In WSN, longer stability is desirable for those applications where reliability is required to be maintained for a longer time. Stability period can be defined as the duration between the first node death and the initial

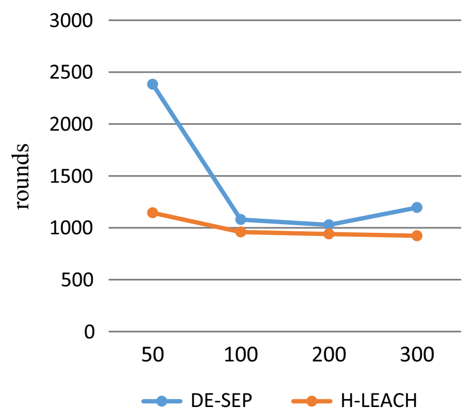

Figure 4. Stability vs. rounds for different number of nodes.

operation of the network. Figure 4 shows the stability period for different number of nodes. It can be observed that DE-SEP has better stability performance than H-LEACH when the density of the network increases for the same network dimension and the same base station position. This shows that the proposed protocols can tolerate change in the number of network nodes. It can also be concluded from figure 4 that the energy exhausted in aggregating data due to the increased number of nodes has less affect in the network energy in H-LEACH.

From figure 5 it is seen that when the network initial enery level is high, i.e. 1 and 0.75 J, the first node dead (FND) of H-LEACH occurs some rounds later to DE-SEP because the energy level of ordinary nodes also becomes higher in addition to the energy levels of intermediate and advance nodes. But the stability period of H-LEACH drops down when the initial network energy level is reduced (0.5 J and 0.25 J) as there is a selection of appropriate nodes as CHs in DE-SEP which takes distance and energy priorities in the election probabilities. The election probability of CH is the same for all the nodes in H-LEACH where the distance and energy weightages are given in the threshold condition. This shows that distance and energy-based thresholds have less effect in the CH selection process than distance and energy-based election probabilities in the heterogeneous network. The early death of the first node in H-LEACH is due to the energy-intensive process (CHs) performed by ordinary nodes rather than the higher energy level nodes (intermediate and advance nodes). Also, the initial energy level of the nodes has great impact in the network performance.

Figures 6 and 7 show the variation of CHs with random rounds for increased base station distance for H-LEACH and D-SEP respectively. In H-LEACH, when the distance of the base station is increased, the election of CH remains almost unchanged, i.e., the variation

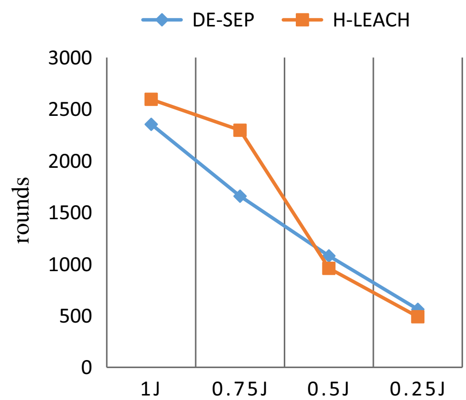

Figure 5. FND vs. rounds for different initial energy levels of the network.

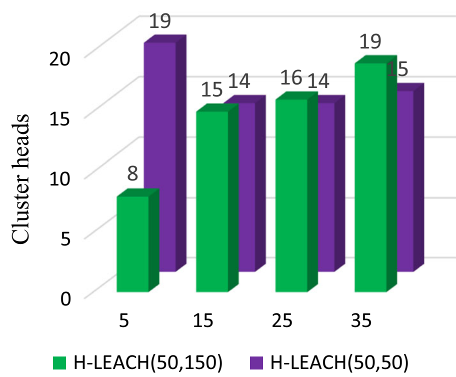

Figure 6. Cluster heads vs. random rounds for H-LEACH.

is very less with random rounds. But in DE-SEP the variation in CH selection is more when the base station distance is increased. As the separation range between the nodes and the base station is increased, the CH election probabiitity decreases signifying the role of distance in CH election of DE-SEP. The CH selection decreases as the distance increases. This result indicates that DE-SEP shows better CH selection than H-LEACH. Hence, it can be observed that even though both the proposed protocols have considered these additional factors (distance and energy), H-LEACH has considered it in threshold value in which the CH selection is also dependent on the random number generated by the nodes. Hence, the selection of CH nodes turns out to be more appropriate when these parameters are considered in the election probability rather than considering in the threshold vaue.

Figures 8 and 9 show the CH selection in DE-SEP and H-LEACH at random rounds respectively where * represents the CHs of the heterogeneous network. From figure 8 we can notice that the role of the CH is distributed properly among different energy levels of the nodes in the network according to their election probabilities in DE-SEP. In figure 9, the role of the CH which

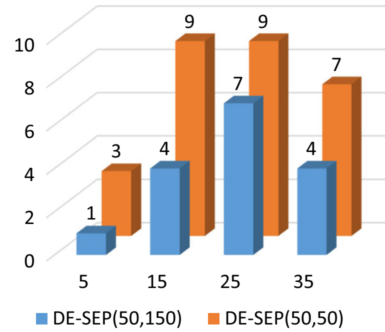

Figure 7. Cluster heads vs. random rounds for DE-SEP.

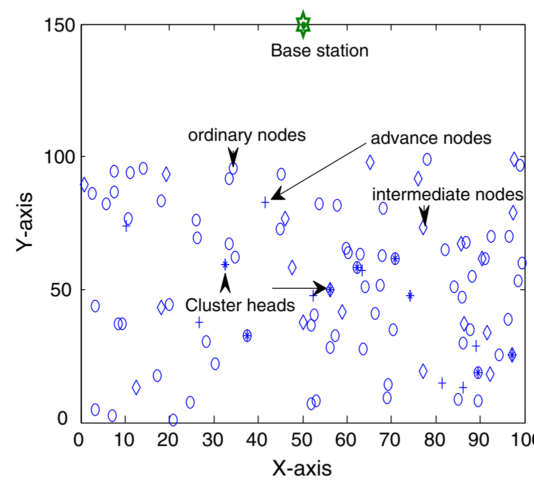

Figure 8. Cluster head selection in DE-SEP at random round.

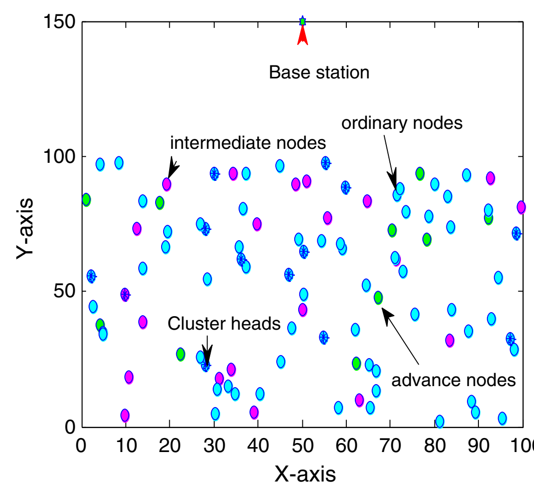

Figure 9. Cluster head selection in H-LEACH at random round.

is a highly energy-consuming process, is taken mostly by ordinary nodes in H-LEACH having the same election probability with priorities given in the threshold condition. This further leads to the early death of the

Table 1. Summary of active nodes, system energy, packets at base station, rounds for DE-SEP and H-LEACH.

Protocols	Active nodes	System energy (J)	Packets received at base station (bits)	Rounds
DE-SEP	80%	22.87	11, 222	1482
	60%	20.66	11, 636	1547
	40%	18.75	12, 115	1636
	20%	3.128	17, 411	2910
H-LEACH	80%	34.98	12, 016	1367
	60%	33.99	12, 163	1406
	40%	32.88	12, 355	1460
	20%	3.86	19, 804	4189

first nodes and hence, short stability period as we have noticed in figures 2 and 3.

Table 1 shows the summary of active nodes, system energy, packets to base station, rounds for DE-SEP and H-LEACH. From the table it can be observed that even though the first node dead in H-LEACH happens much earlier than in DE-SEP for base station location (50,150), the overall system energy is much more in H-LEACH than in DE-SEP for the same percentage of active nodes. This is because in H-LEACH there is no proper selection of CHs. Therefore, the ordinary nodes die much early compared to DE-SEP. Majority of the remaining nodes in H-LEACH is of intermediate nodes and advance nodes and so there is more system energy even though the stability period is short compared to DE-SEP. We can also see from the table that the packets received by the base station gradually increases with rounds in DE-SEP but the received packets' increment is less in H-LEACH with rounds. In H-LEACH from rounds 1460 to 4189 (2729 rounds) the increment is approximately 7,449 packets but in DE-SEP the increment in received packets is around 5,296 from rounds 1636 to 2910 (1274 rounds), i.e., there is less packet delivery as the round proceeds in H-LEACH although it shows proper reception of packets by the base station at the earlier rounds. This difference in received packets is due to the reason that the packets are not being transmitted to the base station in some rounds due to improper selection of CHs in H-LEACH.

From figure 10 we can observe that the active nodes of H-LEACH and DE-SEP reduce rapidly upto 1500 rounds (approx.) and the steepness of the graph decreases as the round increases showing less number of dead nodes. In DE-SEP, the reduction in active nodes follow gradual slope after 1500 rounds indicating that there is proper CH selection with increase in round numbers. The CH selection of H-LEACH shows different performance to that of DE-SEP even though both consider distance and energy factors in CH selection process. The graph of H-LEACH shows almost a flattened slope after 1500 rounds as the participation of

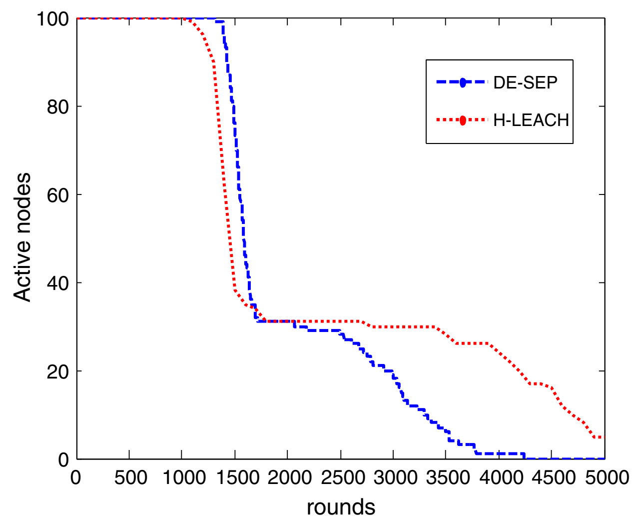

Figure 10. Active nodes vs. rounds.

nodes in CH role reduces as the round proceeds because the current status of energy level of nodes becomes less with rounds. The threshold value becomes lesser than the random number generated and hence no proper CH selection takes place in H-LEACH. Even if there are some alive nodes, they are not selected as CH because their energy levels are not sufficient enough for transmitting data to the base station irrespective of their distance from the sink node (or base station). In terms of network lifetime we can say that H-LEACH shows better lifetime than DE-SEP for a heterogeneous network. The lifetime of a network is basically defined as the duration of period from the initiation of functioning of network till the death of the last node or till the network is able to deliver reliable data to the base station or as per the requirement.

6. Conclusion and future work

Even though there are many challenges faced by WSNs in the current scenario, some of the important challenges are: network lifetime, unbalanced energy consumption and stability of the network. Many protocols have been proposed by researchers to face these challenges and to improve the overall network performance. This paper mainly focusses on the comparative analysis of heterogeneous network based on LEACH and enhanced SEP. This study is brought up to analyse the effect of CH election probability on the network performance and threshold value of CH selection for different network sizes and base station (BS) locations.

The studies show different results for various WSN parameters like packets delivered to BS, network lifetime variation of CHs with random rounds, system energy and stability period. It is found that DE-SEP performs better than H-LEACH in the majority of the network parameters even though H-LEACH shows better extension in terms of network lifetime. It is also observed that for WSN whose network dimension is larger, DE-SEP and H-LEACH show early FND since the energy consumption in intracluster data transmission is more, resulting from the increased intracluster distance in the network. Overall network energy depletion also becomes prominent as the network dimension increases with the same node density.

This paper focusses on the study of the effect of CH selection on network performance. In future, the network performance analysis can be done using additional techniques like adding mobility condition to nodes, incorporating cryptography techniques to these protocols and also other network parameters like latency, etc. can be analysed.

References

[1] M Akkaya and Md Younis, *Ad Hoc Netw.* **3**(**3**), 325 (2005)
[2] S Tyagi and N Kumar, *J. Netw. Comput. Appl.* **36**(**2**), 623 (2013)
[3] V K Arora, V Sharma and M Sachdeva, *Optik* **127**(**16**), 6590 (2016)
[4] M J Handy, M Haase and D Timmermann, *4th International Workshop on Mobile and Wireless Communications Network, IEEE Xplore*, https://doi.org/10.1109/MWCN.2002.1045790 (2002)
[5] S Tyagi*et al, Telecommun. Syst.* **59**(**1**), 43 (2015)
[6] E A Khalil and B A Attea, *Wirel. Pers. Commun.* **69**(**4**), 1799 (2013)
[7] G Smaradagkis *et al*, *SEP: A stable election protocol for clustered heterogeneous wireless sensor networks* (Boston University (Computer Science), 2004)
[8] W B Heinzelman, A P Chandrakasan and H Balakrishnan, *IEEE Trans. Wirel. Commun.* **1**(**4**), 660 (2002)
[9] D Kumar, *IET Wirel. Sens. Syst.* **4**(**1**), 9 (2013)
[10] S Singh, A Malik and R Kumar, *Eng. Sci. Technol. Int. J.* **20**(**1**), 345 (2017)
[11] M Bala and A Lalit, *Int. J. Intell. Syst.* **7**, 1 (2012)
[12] D Kumar, T C Asari and R B Patel, *Comput. Commun.* **32**(**4**), 662 (2009)
[13] N Mittal, U Singh and B S Sohi, *Wirel. Netw.* **23**(**6**), 1809 (2017)
[14] X Wang and G Xang,*Computational Science - ICCS 200, part III, LNCS* (2007) Vol. 4489, pp. 105–108
[15] F Farazandeh *et al*, *11th IEEE International Conference on Industrial Informatics (INDIN 2013)* (2013) pp. 18–23
[16] M A Youssef, M F Younis and K A Arisha, *IEEE Wireless Communications and Networking Conference Record, WCNC 2002*, USA (2002) pp. 794–799
[17] K T Kim and H Y Youn, *Embedded and Ubiquitous Computing workshops 2005, LNCS* (2005) Vol. 3823, pp. 1098–1107
[18] N Mittal and U Singh, *Arab. J. Sci. Eng.* **40**(**6**), 1637 (2015)
[19] G Chen, C Li, M Ye and J Wu, *Wirel. Netw.* **15**, 193 (2009)
[20] A S Toor and A K Jain, *AEU - Int. J. Electron. Commun.* **102**, 41 (2019)
[21] P S Mehra, M N Doja and B Alam, *Int. J. Inf. Technol.* **11**(**3**), 507 (2017)
[22] M Elshrkawey, S M Elsherif and M E Wahid, *J. King Saud Univ. - Comput. Inf. Sci.* **30**(**2**), 259 (2018)
[23] O Younis and S Fahmy, *IEEE Trans. Mob. Comput.* **3**(**4**), 366 (2004)
[24] F A Aderohunmu and J D Deng, *An enhanced stable election protocol for clustered heterogeneous networks* (Department of Information Science, University of Otago, New Zealand, 2009)