Performance Analysis of Variable Energy Levels of Clustering Protocols for Wireless Sensor Network

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Abstract

Wireless sensor networks (WSNs) are emerging in various fields like wildlife monitoring, mining industries and security surveillance. The efficiency of sensor networks strongly depends on the routing protocol used. Routing protocols providing an optimal data transmission route from sensor nodes to sink to save energy of nodes in the network. Different routing mechanisms have been proposed to address energy optimization problem in sensor nodes. Clustering mechanism is one of the popular WSNs routing mechanisms. To check the efficiency of different clustering scheme against different-level of energy for sensor nodes, this paper select four cluster based routing protocols; Low Energy Adaptive Clustering Hierarchy (LEACH)-single energy level nodes, Stable Election Protocol (SEP)- two energy level nodes, An Enhanced Stable Election Protocol(SEP-E)-three energy level nodes and Distributed Energy Efficient Clustering (DEEC)- multi energy level nodes. Here, perform analytical simulations in MATLAB by choosing number of alive nodes, number of dead nodes, overall life time of the network, number of packets and energy consumption , as performance metrics. Simulation results reveal that DEEC protocol outperforms by increasing the stability period of the typical network approximately by 48.91% ,34.86% , 22.8% respectively longer than LEACH,SEP and SEP-E, and shows that in DEEC number of packets transmission increases as compare with other protocols. Also DEEC is more energy efficient since nodes in this protocol deplete their energy in very slow rate.

Also, this paper presents the comparison of the performance of different cluster-based routing protocols with the various locations of Base Station(BS) from the sensing fields. The stability period of those protocols via computer simulation are analyzed by varying the position of the BS.

The simulation results show the high performance for DEEC when the BS is located at the center to the network dimension but SEP-E show higher performance than DEEC when placing the BS far from the center of the network dimension.

Keywords: *Wireless Sensor Network, Energy Efficient, Clustering, Network Life Time.*

1. Introduction

Wireless Sensor network (WSN) is a large network which is consist of huge number of sensor nodes and these nodes are directly interacting with their environment by sensing the physical parameters such as temperature, humidity, etc[1]. All the sensor nodes send or receive data to/from a fixed wired station called base station (BS). The base station usually serves as a gateway to some other network. WSNs have a comprehensive range of applications in this field including environmental applications, military applications, home security, etc.

A Sensor Node (SN) is composed of processor, sensor, transceiver, and power units as showing in Fig.1. The main challenge is related to the limited energy supply of the sensor nodes. Hence, the available energy at the nodes should consider as a major constraint while designing the routing protocols. Different routing techniques have been proposed to address these issues. Hierarchical-based routing protocols also known as cluster based routing protocols enforces a structure on the network to use the energy efficiency, extend the lifetime and scalability. In cluster routing, sensors are divided into groups called clusters, with each cluster electing one node as the head of the cluster, so that sensors communicate information only to cluster heads and then the cluster heads communicate the aggregated information to the Base Station.

Clustering is an efficient way to reduce energy consumption and extend the life time of the network, doing data aggregation and fusion in order to reduce the number of transmitted messages to the BS [2].

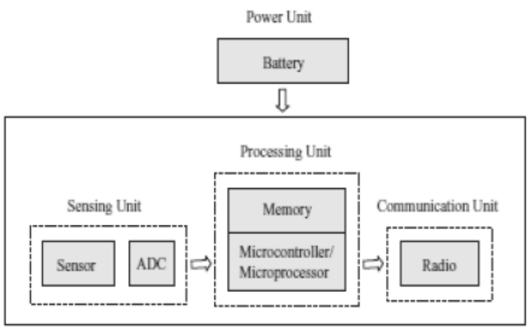

Fig. 1 The components of sensor node.

In literature there are two types of clustering schemes have been proposed. Firstly, the clustering algorithms applied in homogeneous networks, those are known as homogeneous schemes, where all nodes have the same initial energy like the Low-Energy Adaptive Clustering Hierarchy (LEACH) [3], Power-Efficient Gathering in Sensor Information Systems (PEGASIS) [4], and Hybrid Energy Efficient Distributed clustering (HEED) [5].
Heinzelman et al. proposed LEACH [3] protocol based on network clustering. Basically any clustering algorithm is concerned with the management of clusters, which includes: forming a appropriate number of clusters, selecting a cluster head for each cluster, controlling the data transmission within clusters and transmitting the data from cluster heads to the base station (BS). LEACH chooses cluster heads periodically and distributes energy consumed uniformly by rotation. But under the conditions of network heterogeneity this protocol will not be efficient and gives poor performance. Further the LEACH-C was proposed in [6] is a centralized LEACH, where the BS initially receives all the information about each node regarding their energy level and location. After acquiring the requisite information, the formation of cluster heads and clusters is done by using LEACH-C algorithm at BS. Here the number of cluster heads is restricted and the choice of the cluster heads is also haphazard but the BS makes certain that a node with less energy does not become a cluster head. However, LEACH-C is not viable for larger networks because nodes are far away from the BS and will have difficulty in sending their status to the BS and as the assignment of cluster heads rotates, so every time the far nodes will not able to send the information to BS, which thereby increasing the latency and delay.
Secondly, the clustering algorithms applied in heterogeneous networks, those are called heterogeneous schemes, where a few nodes have the different initial energy. There are plenty of heterogeneous clustering algorithms, such as Stable Election Protocol (SEP) [7], Energy Efficient Clustering Scheme (EECS) [8], DEEC [9].
SEP [7] is a proposed scheme for heterogeneous wireless sensor networks. Here two types of nodes (Advanced and normal nodes) are considered with different initial energy. The advanced nodes are equipped with more energy than the normal nodes at the beginning. Further, in literature it has been observed that the SEP yields longer stability region for higher values of extra energy brought by more powerful nodes, but it cannot be applied to multi-level heterogeneous WSNs. An extension of SEP protocol is Enhanced-SEP[10], by considering three types of nodes which it refer to as three tiers in-clustering, in two level of hierarchy network.
Li Qing et al propose and validate the DEEC protocol[9] , which uses a new conception based on the ratio between residual energy of each node and the average energy of the network. The epochs of being cluster-heads for nodes are different according to their initial and residual energy. The nodes with high initial and residual energy will have more chances to become the cluster-heads than the nodes with low energy.
Almost all of the clustering techniques consist of two phases, i.e., setup phase and steady state phase. In setup phase, election of CH and formation of cluster is performed, while in steady state phase data is transmitted from node to CH, CH then aggregates this data and transmit it to BS.
In this paper different clustering mechanisms with different levels of sensor nodes energy, i.e., Low Energy Adaptive Clustering Hierarchy (LEACH), Stable Election Protocol(SEP) , Enhanced-SEP (SEP-E) and Distributed Energy Efficient Clustering (DEEC) is select, the analytical simulations for these schemes/protocols performs in MATLAB. Different performance parameters; number of alive nodes, number of dead nodes, overall lifetime of the network, number of packets and energy consumption are selected to evaluating the performance of these routing protocols.
Also in this paper ,the performance of these protocols by varying the position of the BS was shows. It will shows that in general, the choice of positions has a marked influence on the life time, stability period of the WSNs. Some routing protocols provide high stability period than other routing protocol when BS is located at the center of the sensor field coordination while some routing protocols provide comparatively higher stability period when BS is located far from the sensor fields.
The rest of the paper is organized as follows. In the next section, the selected cluster-based routing protocols will briefly summarize. Simulations and results of experiments are discussed in the section 3. In section 4, concludes the work presented in this paper .

2. Clustering Process in Chosen Protocols

Almost all of the clustering techniques consist of two phases, i.e., setup phase and steady state phase. Next, cluster head selection criterion and cluster formation process in the hierarchical clustering protocols, in other words, setup phase will describe. After it, in the next subsection, the steady state phase in LEACH, SEP, Enhanced-SEP and DEEC protocols will describe.

2.1 Cluster Head Selection and Cluster Formation Process in Hierarchical Clustering Protocols (Setup Phase)

In wireless sensor networks, cluster heads chooses for data aggregation and transmission in such a way that more energy is conserved, with the help of CH selection criterion in different protocols (homogenous or heterogenous) may enhance the stability region and life time of the whole network. Next, different CH selection criterion and cluster formation process for selected protocols will describe.

1) LEACH Protocol: LEACH follows self organizing and adaptive CH selection criteria. here, all nodes have the same initial energy, single-level of sensor nodes energy In setup phase, CH is elected on the bases of following threshold Eq.(1) .

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

where, *P* is the desired number of CHs, r is the current round and G is the set of nodes that have not been CH in the current epoch. Epoch is the number of rounds for a CH, after which again it become eligible to become a CH. Each node generates a random number between 0 and 1, if the number is less than the node's threshold, then this sensor node becomes a CH. Fig.2 shows CH selection mechanism in LEACH protocol.

2) SEP Protocol: SEP is a protocol for two-level heterogeneous network; heterogeneity in terms of initial energy deployment in Sensor Nodes. SEP assumes that in real environment nodes have different energy, therefore in SEP there is two types of nodes (two tier in-clustering), i.e., advance nodes and normal nodes. Advance nodes have an amount of more energy than normal nodes. SEP assign a weighted probability to each node based on its initial energy. Moreover, it improves the cluster formation of LEACH by decreasing the CH epoch interval of advance nodes, i.e., advance nodes get more chances to become a CH. A weight is assigned for individual probabilities for election of CHs for advance and normal nodes. Therefore SEP gives two different threshold formulae given in Eq.(2) and Eq.(4).

$$T(Snrm)=\begin{cases}\dfrac{Pnrm}{1-Pnrm*(r \bmod (1/Pnrm))} & \text{if Snrm} \in G' \\ 0 & \text{otherwise}\end{cases} \qquad (2)$$

where, G' is the set of normal nodes which can become CH and

$$Pnrm=\frac{Popt}{1+\alpha.m} \qquad (3)$$

$$T(Sadv)=\begin{cases}\dfrac{Padv}{1-Padv*(r \bmod (1/Padv))} & \text{if Sadv} \in G'' \\ 0 & \text{otherwise}\end{cases} \qquad (4)$$

where, G'' is set of advance nodes, which can become CH and

$$Padv=\frac{Popt}{1+\alpha.m}(1+\alpha) \qquad (5)$$

CH selection process of SEP is depicted in Fig. 3.

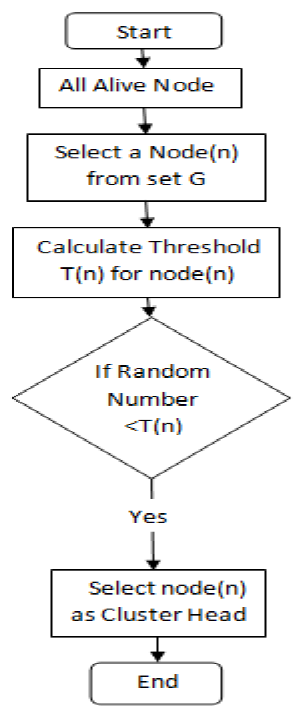

Fig. 2 Flow chart of CH selection in LEACH protocol.

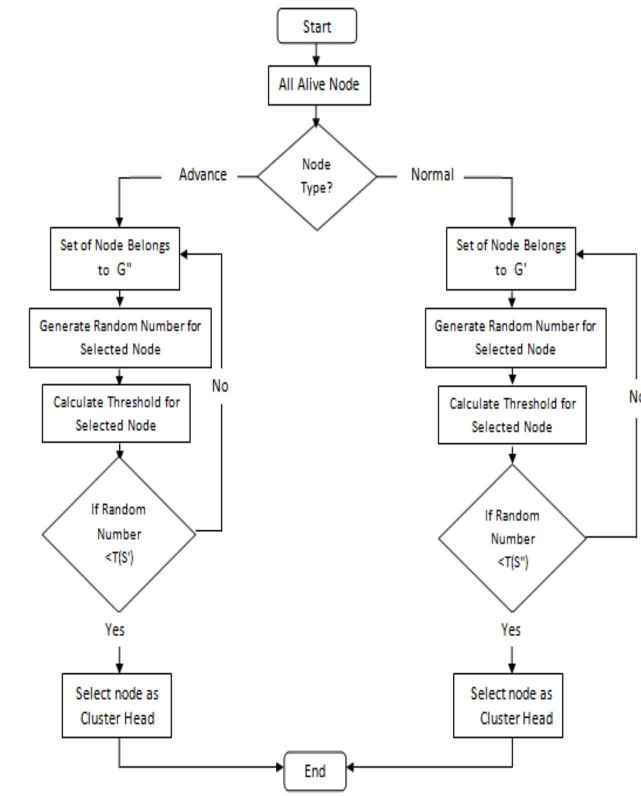

Fig. 3 Flow chart of CH selection in SEP protocol.

3)Enhanced-SEP : is an extension of the SEP protocol , by considering three types of nodes which it refer to as three tiers in-clustering. The new node type for the purpose of this enhanced protocol is referred to as "intermediate nodes", which goal is to achieve a robust self configured WSN that maximizes lifetime.

Here, $Pnrm$, $Pint$ and $Padv$ is the probabilities of becoming normal, intermediate and advanced nodes respectively as showing in Eq.(6), Eq.(7), and Eq.(8).

$$Pnrm = Popt/(1 + m.\alpha + b.\mu) \qquad (6)$$

$$P\text{int} = (Popt) \times (1 + \mu)/(1 + m.\alpha + b.\mu) \qquad (7)$$

$$Padv = (Popt) \times (1 + \alpha)/(1 + m.\alpha + b.\mu) \qquad (8)$$

To guarantee that the sensor nodes must become cluster heads as it have assumed above, it must define a new threshold for the election processes. The threshold $T(n_{nrm})$,$T(n_{int})$ and $T(n_{adv})$ for normal, intermediate and advanced respectively becomes:

$$T(n_{nrm}) = \begin{cases} \dfrac{Pnrm}{1 - Pnrm * (r \bmod (1/Pnrm))} & \text{if } n_{nrm} \in G' \\ 0 & \text{otherwise} \end{cases} \qquad (9)$$

From above it have $n \times 1-m-b$ normal node, and G' is the set of normal nodes that has not become cluster head in the past $(1/Pnrm)$ round r. The same analogy follows for the intermediate and advanced nodes.

$$T(n_{\text{int}}) = \begin{cases} \dfrac{P\text{int}}{1 - P\text{int} * (r \bmod (1/P\text{int}))} & \text{if } n_{\text{int}} \in G'' \\ 0 & \text{otherwise} \end{cases} \qquad (10)$$

having $n \times b$ intermediate nodes; with G'' as the set of intermediate nodes that has not become cluster head in the past $(1/Pint)$ round r.

$$T(n_{adv}) = \begin{cases} \dfrac{Padv}{1 - Padv * (r \bmod (1/Padv))} & \text{if } n_{adv} \in G''' \\ 0 & \text{otherwise} \end{cases} \qquad (11)$$

CH selection process of DEEC is depicted in Fig. 4.

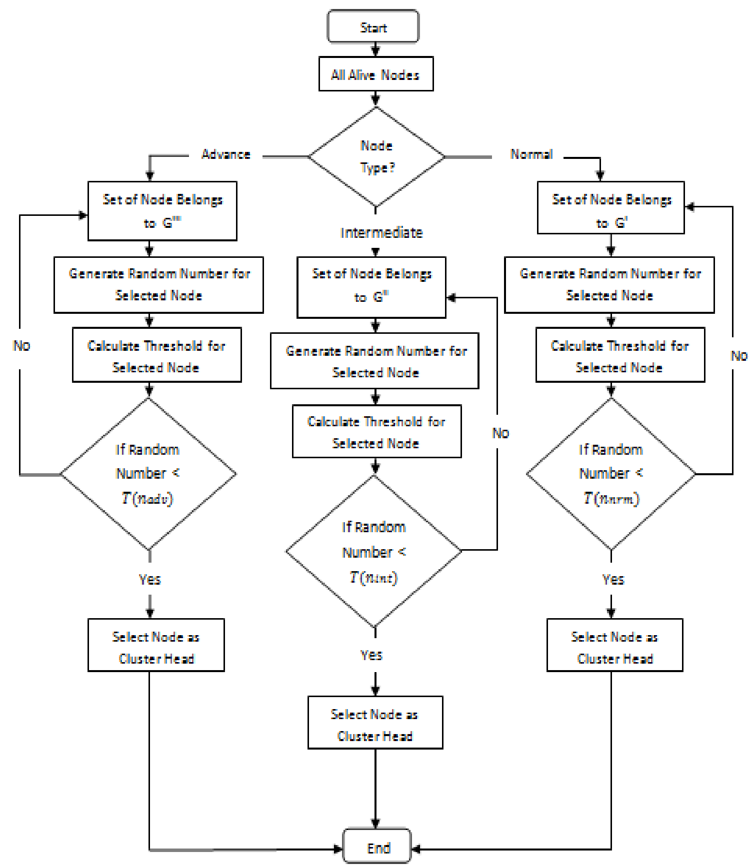

Fig. 4 Flow chart of CH selection in Enhanced- SEP protocol.

4) DEEC Protocol: DEEC is another enhancement of LEACH for multi-level heterogeneous environment with respect to level of energies in WSNs. In SEP, energy distribution for two levels, i.e., advance nodes and normal nodes, whereas DEEC introduces multi-level heterogeneity for maximizing network life time.

The nodes having greater residual energy have more right to become a CH. Therefore, CH formation in DEEC is based on residual energy of entire network and residual energy of the node that wants to become a CH. In DEEC, for multilevel heterogeneous node energy environment, nodes with higher residual energy attains more chances to become a CH. Therefore, DEEC calculate optimum number of CHs for each round from the following two equations .

$$P(i) = \begin{cases} \dfrac{Popt * E_i(r)}{(1+\alpha m)E'(r)} & \text{if } S_i \text{ is normal node} \\ \dfrac{Popt * (1+\alpha)E_i(r)}{(1+\alpha m)E'(r)} & \text{if } S_i \text{ is advance node} \end{cases} \quad (12)$$

where, E'(r) is the average energy of the network at round r and is given by:

$$E'(r) = \frac{1}{N}\sum_{i=1}^{N} E_i(r) \quad (13)$$

Ei (r) is the residual energy of the node at round r. Based on Pi, DEEC calculates threshold as:

$$p(s_i) = \frac{Popt * N(1+a_i)}{(N + \sum_{i=1}^{N} a_i)} \quad (14)$$

DEEC evaluates that if the residual energy of the node is greater than the average energy of the network, then it has more chances to become a CH. Thus, energy is well distributed in the network as it evolves. CH selection process of DEEC is depicted in Fig. 5.
After the election of CHs in each of the above protocols, each CH advertises its status using CSMA MAC protocol. Node selects its CH, on the bases of RSSI and link quality of all CHs, existing in range of that node. All nodes send their membership willingness message to the suitable CH, using CSMA MAC. Then CHs schedule all nodes using TDMA for data transmission. In steady-state phase, each node transmits its data to their respective CH in specific allocated time slots. CH then aggregates data and send the compressed data to BS.

2.2 Steady-State Phase

In LEACH, SEP, Enhanced -SEP and DEEC protocols, the cluster members nodes sense the required information from the environment in which they are deployed and then transfer their sensed information to the CH in the allocated time slots. The CH accumulates the cluster members sensed information and after evaluating compression on the sensed data, CH further transmits aggregated data to the BS. In the same manner, other clusters in these protocols, transmits their information to the BS, and thus, they make mono-level hierarchy in WSNs.

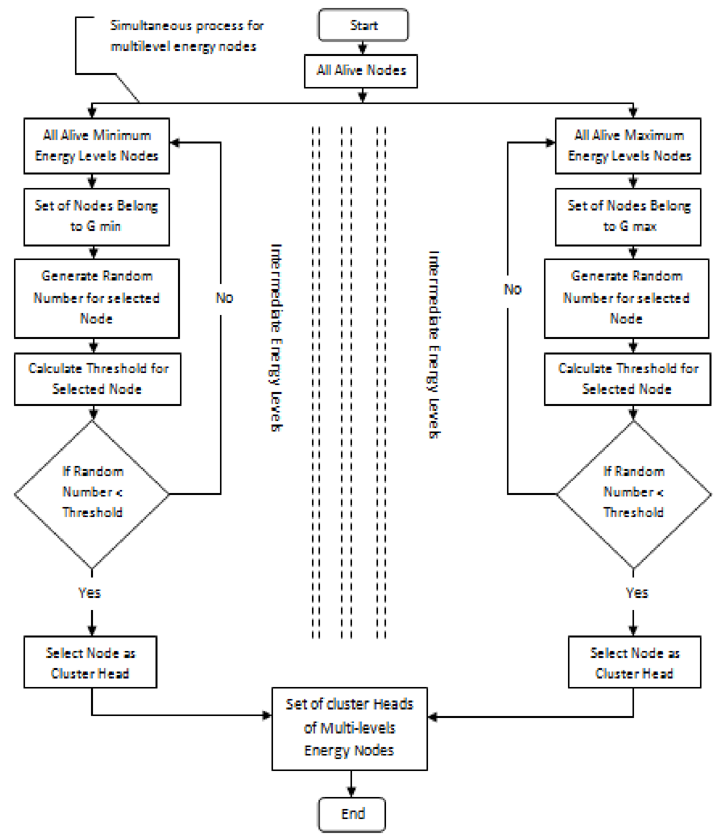

Fig. 5 Flow chart of CH selection in DEEC protocol.

3. Performance Evaluation

3.1 Simulation Environment

In order to evaluate the performance of the selected protocols ,analytical simulations will perform in MATLAB. Simulation parameters are given in table 1. The reference network used in our simulation has 100 nodes which are randomly distributed over 100m×100m square region. BS is placed at the center of the network field. Adjust the heterogeneity level for different routing protocols according to their proposed model ,in order to obtain more realistic results. Assume that in this paper (m=0.1 and α=1 for SEP) ,(m=0.2,α=3,μ=1.5 and b=0.3 for SEP-E) and (a=3 for DEEC). The energy dissipation model used in this paper is shown in Fig. 6, where the transmitter dissipates energy to run the radio electronics and the power amplifier, and the receiver dissipates energy to run the radio electronics is shown.

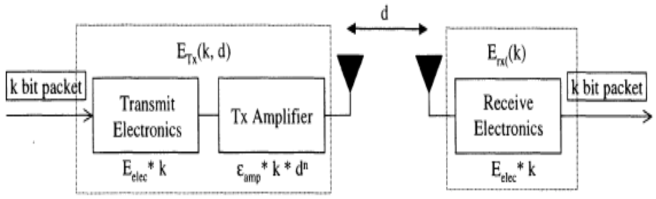

Fig. 6 Radio energy dissipation model.

Depending on the distance between the transmitter and receiver, both the free space (d^2 power loss) and the multi path fading (d^4 power loss) channel models are used. If the distance is less than a threshold, the free space model is used; otherwise, the multi path model is used. Thus, to transmit a k-bit message a distance *d*, the radio expends:

$$E_{Tx}(k,d) = E_{Tx\_elec}(k) + E_{Tx\_amp}(k,d)$$

$$E_{Tx}(k,d) = \begin{cases} kE_{elec} + k\varepsilon_{friss\_amp} d^2 & : d < d_o \\ kE_{elec} + k\varepsilon_{two\_ray\_amp} d^4 & : d \geq d_o \end{cases} \quad (15)$$

Where

$$d_o = \sqrt{\frac{\varepsilon_{friss\_amp}}{\varepsilon_{two\_ray\_amp}}} \quad (16)$$

And to receive this k-bit message, the radio expends:

$$E_{Rx}(k) = E_{Rx\_elec}(k)$$

$$E_{Rx}(k) = kE_{elec} \quad (17)$$

Table 1: Simulation parameters

Parameter	Value
Network size	100 x 100 meters
Minimum initial energy	E=0.5 Joule
P_{opt}	0.1
Packet size	4000 bits
Transmit/Receive Electronics	E_{elc} = 50 nJ/bit
Data Accumulation	E_{DA} = 5 nJ/bit/report
Transmitter Amplification (d<=do)	E_{fs} = 10 pJ/bit/m2
Transmitter Amplification (d>do)	E_{mp} = 0.0013 pJ/bit/m4

3.2 Performance Matrices Used in Simulation

Stability Period: Time duration between the starting of network process and expiry of very first node in the network.
Instability Period: Time duration between the expiry of very first sensor node and very last sensor node of the network.
Network lifetime: Time duration between the network process initialization and the expiry of the very last alive sensor node in network.
Alive nodes per round: These are total number of nodes that have not till yet expended all of their energy.
The total Remaining Energy in each Round: Represents the total remaining energy of all nodes in the network for each round.
Packets to BS: These are total data packets that are successfully sent from the CHs to the BS.

3.3 Simulation Results

3.3.1 Life time of the network

Stability period and network life time of the network for all routing protocols with respect to alive nodes in number of rounds is shown in Fig.7. It can observe that stable period of LEACH is very short. Stability period of LEACH is almost 10.42%, 21.25%, 48.91% less than SEP, SEP-E and DEEC, respectively. Because LEACH treats all nodes without energy discrimination therefore it looses full advantage of nodes that have more energy.
While SEP treats all the nodes with initial energy discrimination, therefore, the stability period of SEP is more than LEACH. Enhanced-SEP(SEP-E) has longer stability period than LEACH and SEP by 21.25% and 9.81% due to the presence of three-level of nodes(normal, intermediate and advance), while DEEC has almost 48.91%, 34.86%, 22.8% longer stable period than LEACH,SEP and SEP-E, as depicted in Fig.7. This is because of heterogeneity-awareness of DEEC, which provides feasible solution.
Fig. 8 shows number of dead nodes as network operation proceeds. Results shows the instability and life time of the network. It can see that network lifetime results are identical, as shown in previous Fig.7. An important information that it can derive from this figure is instability faced by routing protocols that LEACH has minimum and DEEC has maximum unstable region.

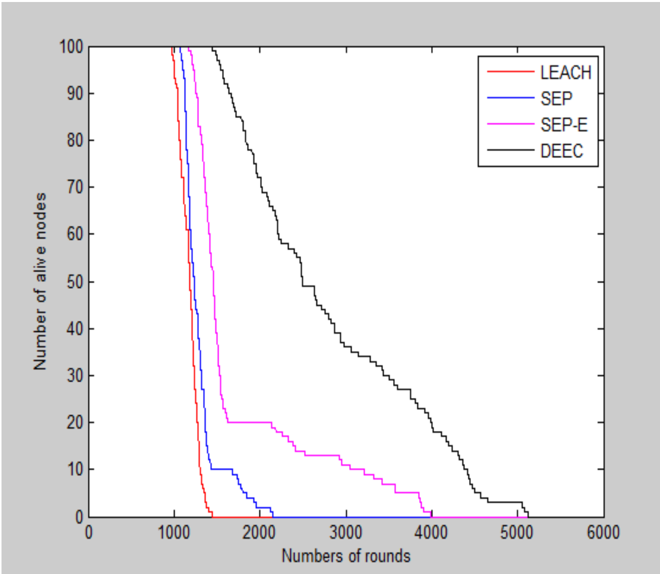

Fig.7 Network life time of four protocols.

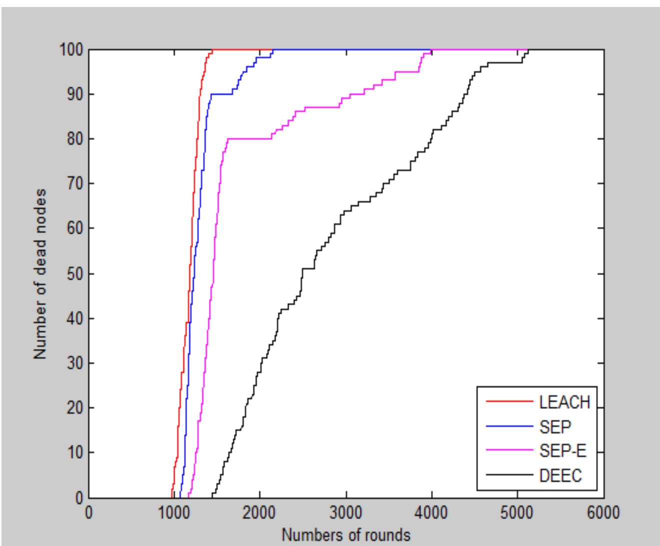

Fig. 8 Dead nodes versus number of rounds.

The overall life time of the network for the selected protocols shown in table 2.This table will gives the number of rounds when 1%,20%,50% and 100% of the nodes dead.

Table 2: Number of rounds when 1%, 20%, 50%, and 100% nodes die

Protocol	1%	20%	50%	100%
LEACH	969	1041	1162	1445
SEP	1070	1122	1192	2144
SEP-E	1175	1264	1412	3982
DEEC	1443	1669	2218	5124

As it is observes from the table that DEEC protocol have the best overall life time by having the longer time until 1%,20%,50% or 100% of the nodes dead.

3.3.2 The Total Remaining Energy

Fig. 9 represents the total remaining energy of the network in each round. It can be observes that in both LEACH and SEP, the energy depletes very fast at constant rate. While both SEP-E ,DEEC are more energy efficient. Energy in DEEC is deplete in very slow rate.

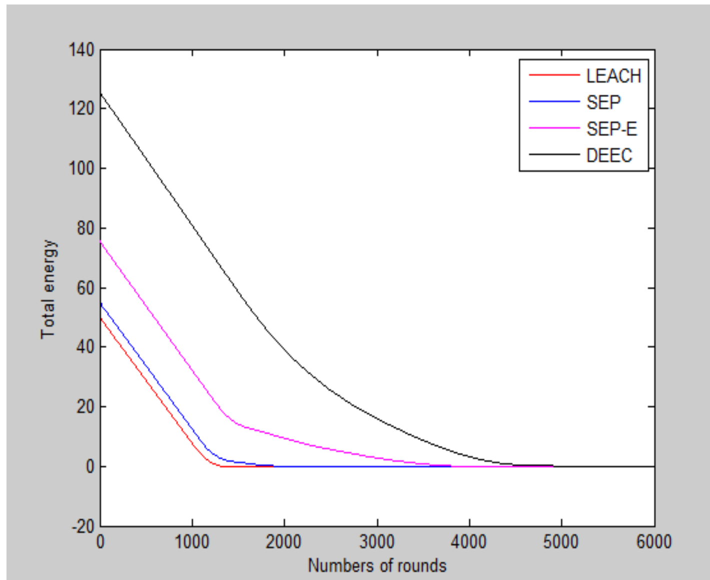

Fig. 9 The total remaining energy(in joules) in each round.

3.3.3 Packets Sent to Base Station.

Successful data delivery at BS is an important factor to analyze quality of routing protocol. Fig.10 shows the comparison of every protocol for number of packets that are sent to BS. Result shows that more number of packets is sent in the case of DEEC in comparison with the other protocols, as heterogeneity-awareness will be having more probability of becoming the cluster heads, due to more residual energy so more number of packets will be sent to the base station. Thus, the DEEC sends more effective data packets to the base station.

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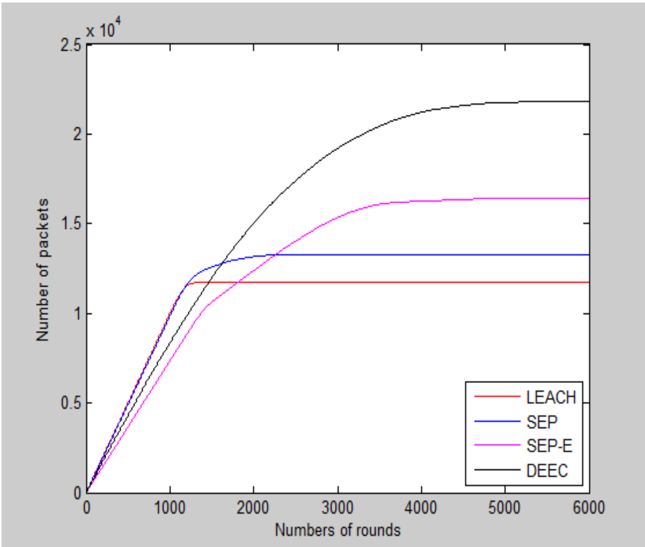

Fig. 10 Packets sent to the BS versus rounds.

3.3.4 The performance of different routing protocols in terms of stability period vary with the varying position of the BS.

Some routing protocols provide greater stability period when BS is located at center of the network dimension. But as the location of BS of the networks placed far away from the center of the network dimension then other protocols performs better than those which performs better when BS was located at center of the network dimension.
For instance, when BS is located at the coordination (50,50) i.e. at the center of the network dimension, DEEC protocol outperforms by increasing the stability period of the typical network approximately by 48.91% (LEACH), 34.86% (SEP),22.8% (SEP-E). But this scenario change when place the BS far from the network area like at the coordination of the BS at (50,150). In that case, SEP-E significantly outperforms than all other routing protocols to provide longer stability period by 37.46%, 38.03% and 9.24% longer than LEACH,SEP and DEEC respectively. Table 2 shows the stability period of the routing protocols with the varying position of the BS. It is seen from table2 that when place the BS gradually far away from the center of the network dimension then comparative stability period of that network is significantly decreases and the longer stability period gives by the selected protocols will also different.

Table 2: Length of stability period of different routing protocol with varying position of BS

Protocol	(50,50)	(50,100)	(50,150)	(50,200)	(50,25)
LEACH	969	959	774	408	208
SEP	1070	985	831	443	223
SEP-E	1175	1185	1064	652	389
DEEC	1443	1315	974	610	431

4. Conclusions

Energy optimization and efficient route discovery are challenging issues in WSNs. Different techniques have been proposed up till now to address these issues. Clustering technique is one of them, and this paper is devoted to evaluate the efficiency of different clustering schemes with different energy levels of sensor nodes. The cluster-based routing protocols that chooses in this paper are LEACH, SEP,SEP-E and DEEC. It is concluded from the analytical simulation results that DEEC is the most energy efficient protocol by having the longer stability period and the best overall life time than other protocols. Also DEEC is more energy efficient since nodes in this protocol deplete their energy in very slow rate and DEEC is efficient in sending maximum information to BS, thus overall DEEC outperforms among selected protocols by providing feasible optimum solutions against constraints of modeled frame work.
Also in this paper ,the performances of different hierarchical routing protocols for wireless sensor networks in terms of stability period by varying in the positioning of the base station present. From the simulation results, it have shown that the performance of any considered routing protocols can either improve or degrade as compared with another in terms of stability period depending on the location of the base station which would be either inside or outside of the sensor field.

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