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D-LEACH: Dynamic Cluster Head Selection Algorithm for LEACH Protocol in Wireless Sensor Networks

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ABSTRACT

In this paper, a modified cluster head selection algorithm (D-LEACH) is proposed on LEACH which considers the residual energy of the cluster head nodes before initiating the cluster head selection process at the end of each round, with the objective of reducing the number of cluster head selection and thereby prolonged network lifetime. Simulation using NS2 shows that the proposed D-LEACH algorithm has reduced number of cluster head selection count by manifold when compared to Static LEACH and LEACH protocol, resulting in reduced overhead in cluster head selection process and substantial increase in lifetime of the network.

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INTRODUCTION

Wireless Sensor Networks (WSN) is a network of hundreds or thousands of cheap sensor nodes that allow the user to accurately monitor a remote environment by intelligently combining the data from the individual nodes. The routing is complex and challenging process in these networks due to the adhoc and dynamic nature of the network, limited battery life of the nodes, computational overhead in cluster head selection, cluster formation and routing, lack of conventional addressing scheme, and limited transmission range of sensor nodes. As the sensors have limited power, the residual energy of the nodes becomes a vital factor and hence these networks need energy efficient communication protocols that provide prolonged network lifetime. A number of routing protocols have been proposed for WSN (Al-Karakil and Kamal, 2004) and among the numerous hierarchy based routing protocols developed (Abbasi and Younis, 2007), (Martirosyan *et al.*, 2007), Low-Energy Adaptive Clustering Hierarchy (LEACH) proposed by (Heinzelman *et al.*, 2000) is one of the hierarchical routing protocols with first major improvements on conventional clustering approaches in WSN. LEACH protocol selects a cluster head (CH) based on a probability model and rotates the cluster heads periodically to preserve maximum network coverage and lifetime. Many clustering algorithms were developed based on the LEACH's ideology and architecture (Aslam *et al.*, 2010). However, the LEACH clustering strategy is mainly depends on the randomly selected cluster-heads (CHs), resulting the fluctuation of the number of cluster heads and the ignorance of the node's residual energy. In order to prolong the life span of the entire network, this paper presents a modified cluster head selection algorithm for LEACH protocol with criteria for cluster head selection from the second round based on the residual energy in each cluster head. As a result, the number of cluster heads selected is reduced and total energy dissipation of the sensor nodes is minimized.

LEACH Algorithm:

LEACH proposed by Heinzelman *et al.* (2000) uses a concept of round and cluster formation during each round. LEACH runs with many rounds and each round contains two states: cluster setup state and steady state. In the set-up phase, each node decides whether or not become a cluster-head for current round. This decision is

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made by the node n choosing a random number between 0 and 1. If the number is less than a threshold $T(n)$, the node becomes a cluster-head for the current round. The threshold is set as:

$$T(n) = \begin{cases} \frac{p}{1 - p \times (r \times \text{mod} \frac{1}{p})} & n \in G \\ 0 & n \notin G \end{cases} \quad (1)$$

Where p is the desired percentage of cluster heads, r is the current round, and G is the set of nodes that have not been cluster-heads in the last $1/p$ rounds. Then, operation moves to the steady phase and the steady phase is divided into frame, where nodes send their data to the cluster head at most once per frame during their allocated transmission slot. After a period, the entire networks are renewed, preparing for the new round.

First Order Radio Model:

There are different assumptions about the radio characteristics, including energy dissipation in transmit and receive modes of the low-energy radios. In LEACH, a simple model is assumed where the radio dissipates with $E_{elec} = 50\text{ nJ/bit}$ to run the transmitter or receiver circuitry and $\epsilon_{amp} = 100\text{ pJ/bit/m}^2$ for the amplifier circuit in transmitter to achieve an acceptable E_b/N_0 . An energy loss of r^2 is assumed due to transmission channel (Al-Karakil and Kamal, 2004).

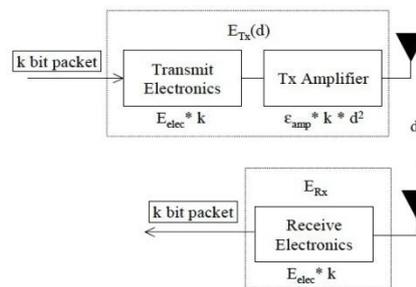


Fig. 1: First order radio model.

Thus, to transmit a k -bit message to a distance d , the transmitter of the radio model expends,

$$E_{Tx}(k, d) = E_{Tx-elec}(k) + E_{Tx-amp}(k, d) \\ E_{Tx}(k, d) = E_{elec} * k + \epsilon_{amp} * k * d^2 \quad (2)$$

and to receive this message, the receiver radio expends:

$$E_{Rx}(k) = E_{Rx-elec}(k) \\ E_{Rx}(k) = E_{elec} * k \quad (3)$$

Where $E_{Tx}(k, d)$ and $E_{Rx}(k, d)$ is the energy consumed by the transmitter and receiver for k bits and for a distance of d between transmitter and receiver.

Thus, the energy dissipation in LEACH protocol is reduced by the following features.

1. Reduce the number of transmission to sink using cluster-head
2. Reduce the data to be transmitted through aggregation technique
3. Increase the life time of all nodes through randomized rotation of being cluster-heads
4. Allow the non-cluster-head nodes to be in sleep mode except for a specific time duration.

This routing protocol make nodes die randomly and dynamic clustering enhances the network lifetime

Limitations of LEACH Protocol:

The algorithm for cluster head selection in LEACH protocol avoids quick drain of energy of nodes acting as cluster heads by probabilistically selecting the cluster head from the set of available nodes. Therefore, LEACH protocol prolongs the network life time in contrast to plane multi-hop routing and static routing. However, there are still more scope for improvements to be done in the LEACH protocol.

First, the probability based selection of cluster heads ignores the residual energy of nodes. Therefore, those nodes with less residual energy may be chosen as the cluster head which will lead to fast energy loss of these nodes, hence making them invalid.

Second, the apart from the residual energy of the nodes, the average distance between the member nodes of a cluster can be considered for cluster head selection to reduce the transmission range of the member nodes with the cluster head.

Third, the stochastic cluster-head selection of LEACH is prone to result in the unbalanced clusters partition in the network and thus increase the total energy dissipated in network. The traditional LEACH Protocol divides clusters randomly which leads to uneven distribution of clusters. Eventually the portioned clusters may not be the best. For instance, some clusters may have more nodes than others and some clusters may have fewer nodes.

Some cluster heads may be placed relatively in the centre of clusters, some clusters heads may be in the edge of clusters, far away from its members. These phenomena can cause increase in energy consumption and impact on the overall performance of the network.

Fourth, in steady state, cluster heads send data to sink directly. But, this does not take the non-uniform distribution of the cluster heads into consideration. A cluster head farther from the sink must spend more energy to communicate with the sink directly. It will crash soon because it runs out of energy. Especially accompanied by the expansion of the scale of the network, these effects are more noticeable and affect the network life seriously (Shan et. al., 2010).

Literature Survey:

Numerous modifications have been proposed to enhance the performance of LEACH and in specific the improvement of energy consumption and network life time (Bhuvaneshwari and Vaidehi, 2009), (Gnanambigai et. al., 2012) and for balancing of the energy in nodes (Liao and Zhu, 2013), (Madheswaran and Shanmugasundaram, 2013),(Wang and Peng, 2013). Finding the right node to act as cluster head during the cluster formation is one of the critical tasks in hierarchy based clustering. The following researches are carried out to select the best node for cluster head and optimal cluster partitioning to minimize the energy consumption.

A. LEACH-B (LEACH-Balanced):

LE-ACH-B is an enhanced LEACH protocol proposed by Tong and Tang (2010) which adds a second selection of cluster heads to modify the number cluster-head in the set-up phase considering the node's residual energy per round. In order to save the energy consumption and to prolong the life span of the network, the protocol needs to ensure that the partition of cluster is balance and uniform. This protocol with balancing of node energy achieves the improvement of energy consumption by 25% when compared to LEACH.

B. LEACH-C (LEACH-Centralized):

Despite the advantages in LEACHs distributed cluster formation algorithm, it offers no guarantee about the placement and/or number of cluster head nodes. Since the clusters are adaptive, obtaining a poor clustering set-up during a given round, will greatly affect overall performance. However, using a central control algorithm monitored by base station to form the clusters produce better clusters by dispersing the cluster head nodes throughout the network. This is the basis for LEACH-centralized (LEACH-C) protocol which uses a centralized clustering algorithm and the same steady-state protocol as LEACH (Heinzelman et. al., 2002), (Muruganathan et. al., 2005).These algorithms provide minimized energy consumption when compared to LEACH by around 35%.

C. Improved LEACH Protocol:

The classical hierarchical protocols such as LEACH and LEACH-C have better performance in saving the energy consumption. However, the formula chosen neglecting the change of nodes' energy will make the nodes acting as cluster heads too many times die early owing to the consumption of too much energy. Also, the high frequency of re-clustering wastes certain amount of energy in overhead. In order to make the energy distribute more evenly among different nodes, the tradition equation used for selecting cluster heads is improved with considering the dynamic change of nodes' energy in an Improved LEACH protocol proposed by Zhao et. al., (2012). To establish a vice cluster head for each cluster during the communication process, to diminish the energy consumption spent on the re-clustering and prolong the time of being in a steady-state phase, threshold $T(n)$ is modified in improved LEACH protocol to the following equation:

$$T(n) = \begin{cases} \frac{p}{1-p \lceil r \bmod \frac{1}{p} \rceil} \times \left[\frac{E_{n,current}}{E_{n,init}} + \left(1 - \frac{E_{n,current}}{E_{n,init}} \right) \times \frac{P}{CH_{times} + VCH_{times} + 1} \right] & n \in G \\ 0, & n \notin G \end{cases} \quad (4)$$

D. Improved LEACH Protocol based on Energy and Distance factor:

The improved protocol developed by Shan et. al., (2010) adds energy factor and distance factor to the threshold $T(n)$. The multi-hop routing algorithm of cluster head is introduced based on the hop count and the remaining energy. The simulation data suggests that the death rate of nodes of the improved protocol was lower than the traditional one. The improved LEACH protocol can balance network load and extend the life-cycle of network.

The simulation result shows that, when the active nodes of the LEACH protocol retain 40%, the active nodes of the improved LEACH protocol just start to decrease. The improved LEACH protocol formula for threshold is as follows:

$$T(n) = \begin{cases} \frac{p}{1-p \times n \lceil r \times \bmod \frac{1}{p} \rceil} * \left(1 - \frac{d_n}{E_n} * \frac{E_{ce}}{R_c} \right) & , if n \in G \\ 0 & , else \end{cases} \quad (5)$$

E. Energy Balancing and Hierarchical Clustering Based Routing algorithm (EBHCR):

As the energy constraint is one of the most important restrictions in WSN, the energy balancing is essential for prolonging the network lifetime. Hamed *et. al.*, (2011) proposed a new clustering protocol namely EBHCR which uses hierarchical dynamic routing algorithm. This algorithm selects a best sensor node as a cluster head in terms of energy, number of neighbours and distance. Simulation results show that the EBHCR prolongs the network lifetime about 45% compared to the LEACH.

F. Soft Threshold based Cluster Head Selection:

In LEACH, within each $1/p$ rounds, once a node has been selected as a cluster-head (CH), its threshold will be set to 0, and thus it will lose the chance to participate in cluster-head selection, even if it still has enough energy. A novel cluster-head selection algorithm is proposed by Rong Ding *et. al.* (2009). In this algorithm, instead of changing the threshold to 0 directly, the threshold of each node is adjusted gradually according to the roles they have played in the last round, so that more nodes could have the opportunity to be CHs. Simulation results show that the proposed algorithm outperforms LEACH in network lifetime by an average of 30% approximately.

G. Improving on LEACH Protocol using Fuzzy Logic:

The energy is the most important factor in designing the protocol for WSN. LEACH is one of the most famous clustering mechanisms that select cluster heads based on probability model. However in LEACH, some cluster heads may be very close to each other or it can be located at the edge of the network. These in-efficient cluster heads might not maximize the energy efficiency. A method proposed by Ge Ran *et. al.* (2010) provides an improvement of LEACH by using fuzzy logic and choosing battery level, distance and node density as the attributes for the efficient cluster head selection. Compare to LEACH, this method provides an enhancement of 3.8 times of network life time.

In addition to the above, numerous research have been conducted to extend the life time of the network by considering the residual energy of the nodes, distance between the nodes, using spare nodes / cluster heads and by varying the time duration of each round (Xiaoyan Cui 2007), (Yun Li *et. al.*, 2011), (Kumar and Sharma 2012), (Yassein *et. al.*, 2009).

Method: Dynamic Cluster Head Selection Algorithm:

The Dynamic cluster head selection algorithm (D-LEACH) is a modified version of the LEACH protocol and it considers the residual energy available in the nodes before cluster head selection process is initiated in LEACH. The cluster heads are selected from the set of given nodes N based on probability in the first round and at the end of first round, the residual energy available in the cluster heads are compared with a threshold value. If cluster heads are found to have energy above the threshold, the cluster head selection process is ignored and the existing cluster heads are allowed to continue as cluster head with the same member nodes in the next round. The whole process is repeated until the end of all rounds.

This D-LEACH algorithm reduces the number of cluster heads selected and thereby reduced overhead in selection process and minimized energy dissipation in all nodes. The flow chart of Dynamic cluster head selection algorithm is shown in figure 2.

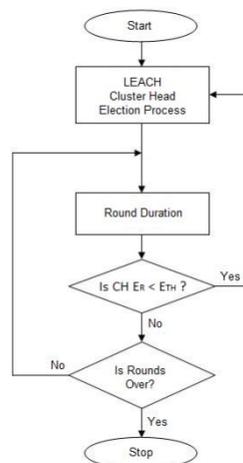


Fig. 2: Dynamic Cluster Head Election Algorithm.

Assuming the total number of sensor nodes in the network as N and the probability of cluster heads elected from the set of N nodes as P_{CH} , the expected number of Cluster head selected per round (CH_{Static}) in Static LEACH is given by

$$CH_{Static} = P_{CH} \times N \quad (6)$$

If the total number of rounds is R ; then the total number of cluster heads elected (CH_{LEACH}) in LEACH is given by

$$CH_{LEACH} = P_{CH} \times N \times R \quad (7)$$

Assuming the threshold for residual energy as E_{Th} , residual energy in nodes as E_R , and the probability of nodes having energy greater than threshold as $P(E_R > E_{Th})$, then the new number of cluster heads selected ($CH_{D-LEACH}$) in D-LEACH satisfying the condition $E_R > E_{Th}$ is given by

$$CH_{D-LEACH} = P(E_R > E_{Th}) \times P_{CH} \times N \times R \quad (8)$$

In the set-up phase of D-LEACH protocol, each node decides whether or not become a cluster-head in the first round based on probability, and from second round based on the residual energy of a node. This decision is made by the node n choosing a random number between 0 and 1. If the number is less than a threshold $T(n)$ and residual energy greater than pre-set value, the node becomes a cluster-head for the current round. The threshold for the D-LEACH is set as:

$$T(n) = \begin{cases} \frac{p}{1 - p \times (r \times \text{mod} \frac{1}{p})} & \text{if } n \in G \text{ and } E_R(n) > E_{Th} \\ 0 & \text{else} \end{cases} \quad (9)$$

Where $E_R(n)$ is residual energy of node n and E_{Th} is threshold for residual energy.

If E_O is the energy consumed in a single cluster head selection process, then the total energy consumption in D-LEACH is given by:

$$E_{D-LEACH} = \sum_{R=1}^R P(E_R > E_{Th}) \times N \times P_{CH} \times E_O + E_{Data} \quad (10)$$

In the above equation, the term $P(E_R > E_{Th})$ decides the number of cluster heads elected in each round. It is apparent that if the total number of cluster heads elected is reduced by setting the threshold for residual energy in D-LEACH, energy consumption can be considerably reduced by minimizing the number of cluster heads elected, when compared to Static LEACH and LEACH protocols.

Results:

Simulation was carried out in network simulator NS2 and the performance of D-LEACH protocol is analyzed by comparing it with static cluster LEACH and LEACH protocols.

The network model considered for simulation of D-LEACH is as similar in LEACH (Heinzelman et. al., 2000) with the following assumptions:

1. The base station is constant and localized far from the sensors
2. All nodes in the sensor network are homogeneous.
3. The sensor nodes are energy constrained with a uniform initial energy allocation.
4. All sensor nodes are immobile.
5. A fixed base station is located far away from the sensor nodes.
6. Each node senses the environment at a fixed rate and always has data to send to the base station.
7. All nodes can transmit with enough power to reach the base station if needed and the nodes can use power control to vary the amount of transmit power.

The two key elements considered in the design of D-LEACH are the sensor nodes and base station. The sensor nodes are geographically grouped into clusters and capable of operating in two basic modes, cluster head mode and sensing mode.

- In the sensing mode, the nodes perform sensing tasks and transmit the sensed data to the cluster head.
- In cluster head mode, a node gathers data from the other nodes within its cluster, performs data fusion, and routes the data to the base station through other cluster head nodes. The base station in turn performs the key tasks of cluster formation, randomized cluster head selection, and CH-to-CH routing path construction.

The simulation is done on Network Simulator NS2 with a network of 100 homogeneous sensor nodes randomly deployed and the following parameters were set for simulation in NS2:

Table 1: Parameters considered for Simulation.

Simulation Parameters	Value
Network Area	500x500 m ²
Total Simulation time	1000 Sec
Round Duration	10 Sec
Initial Energy in each node	0.1 J
Total Number of nodes	100
Probability of CH Selection	0.4
Threshold for E_R Comparison	0.4
Data Rate	1 Kbps

Even though the optimal number of cluster heads was chosen as 5% in LEACH (Al-Karakil and Kamal, 2004), the optimal number of cluster heads is re-estimated again for the present scenario by making experimentation on the modified LEACH protocol with probability of cluster head selection ranging from 0.1 to 0.5. When the probability was chosen low (for eg. 0.1), the number of cluster heads are less and the nodes have to transmit to the CH at farther distance. Hence, the first node die time was at an early stage. When the probability was chosen high (for eg. 0.5), too many selection of CHs resulted in very large number of CHs selection, thus resulting in additional overhead in CHs selection than the existing optimal value.

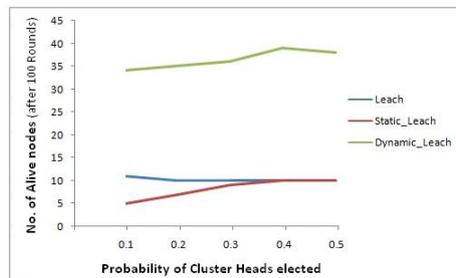


Fig. 3: Comparison of Alive nodes in three protocols for various probabilities.

It is found from fig.3 that the number of nodes alive at the end of 100 rounds is more only at probability of 0.4. Similarly, when the time at which the first node died is compared for the three protocols (fig. 4), it is found that only at probability of 0.4, the FND (first node die) time is better.

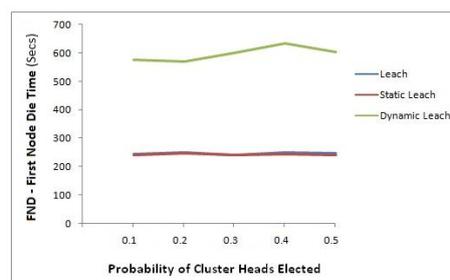


Fig. 4: Comparison of First Node Die (FND) Time in three protocols for various probabilities.

Thus, the probability is chosen as 0.4 for cluster head selection and further experiment is conducted to find the optimal threshold value for comparing the residual energy in the cluster heads.

In the experiment conducted for estimation of threshold for residual energy in Cluster Head (E_R), it is found that when threshold for residual energy in CH is chosen at high value (for eg. 70% of initial energy), the number of cluster head selection process rapidly increased, resulting in more overhead during the CHs selection process. Similarly, when threshold was chosen at low value (for eg. 20% of initial energy), the number of cluster head selection process was very less, but the energy of the node acting as CH was rapidly depleted due to intra and inter cluster communication. Hence, experiment is carried out to find the optimal threshold value for comparing the residual energy of the sensor nodes with values of threshold at 0.2 and 0.4. The fig. 5 and 6 shows the comparison of number of a live nodes and residual energy in D-LEACH protocol for threshold value of 0.2 and 0.4.

From the results obtained in experiment for estimating the optimal threshold value, it is found that residual energy and number of a live nodes is high only at the threshold value of 0.4 of initial energy of nodes in D-LEACH protocol.

An experiment is carried out on three protocols, D-LEACH, Static LEACH and LEACH with threshold of 0.4 of initial energy for comparison of residual energy in nodes acting as CHs, and the probability of 0.4 for cluster head selection, keeping the other parameters the same. The number of CHs elected, residual energy and number of a live nodes are estimated for the total simulation duration to compare the performance for all above three protocols.

Fig. 7 shows the comparison of number of cluster heads selected in Leach and D-LEACH and Fig. 8 shows the comparison of number of cluster heads selected in Static Leach and D-LEACH during the total simulation duration.

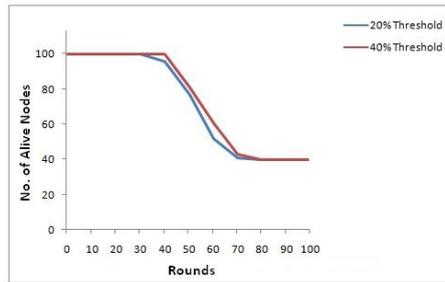


Fig. 5: Comparison of Alive nodes in D-LEACH for various energy thresholds.

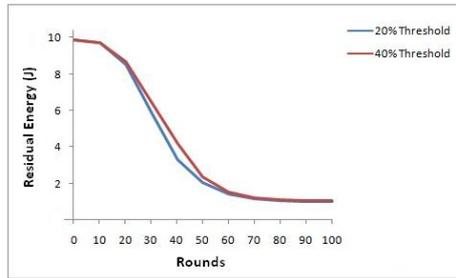


Fig. 6: Comparison of First Node Die (FND) Time in D-LEACH for various Energy thresholds.

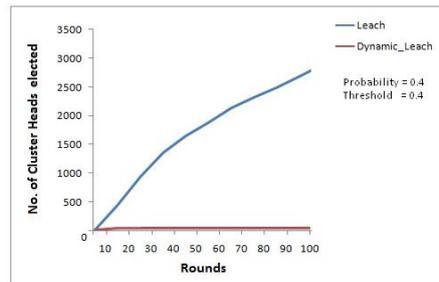


Fig. 7: Comparison of the No. of cluster head elected in Leach and D-LEACH.

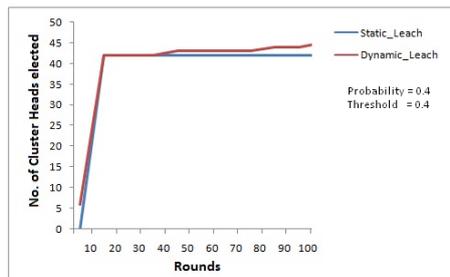


Fig. 8: Comparison of the No. of cluster head elected in Static Leach and D-LEACH

From the figure 7 and 8, it is apparent that D-LEACH algorithm has substantially less number of CHs selected when compared to LEACH and just above when compared to the Static LEACH.

The table given below shows the total number of cluster heads selected at the end of each round in all the three protocols during the simulation.

In LEACH, the CHs selection carried out at the end of each round is predetermined using probabilistic model and hence, the number of CH selection process increases as the round increases. In Static LEACH, the CHs selection is carried only once in the first round and it is fixed till the end of simulation. In D-LEACH, the CHs are selected at the end of each round only when its residual energy is less than the threshold value. On comparison of the three protocols, it is observed that the total number of cluster heads selected in D-LEACH is very less compared to LEACH protocol and the count is almost close to the static LEACH. In specific, three additional CHs are selected during 40th round and one additional CH is selected during 80th and 100th round in

D-LEACH. This clearly indicates that overhead involved in cluster head selection in modified D-LEACH algorithm is very less and hence minimum energy dissipation in nodes acting as cluster heads using the dynamic Cluster Head selection algorithm.

Table 2: Comparison of number of CHs selected in all three protocols.

Protocols \ Rounds	LEACH	Static LEACH	D-LEACH
1	40	40	40
20	937	40	40
40	1639	40	43
60	2129	40	43
80	2493	40	44
100	2885	40	45

The experiment is carried out with identical parameters of previous experiment for estimating the residual energy of the nodes in three protocols. All nodes are assumed to possess equal energy of 0.1J at the beginning of simulation. At the end of simulation of 100 rounds, the residual energy of nodes in all three protocols is compared. Fig.9 shows the comparison of total residual energy available at the end of simulation in all nodes of the network for the three protocols.

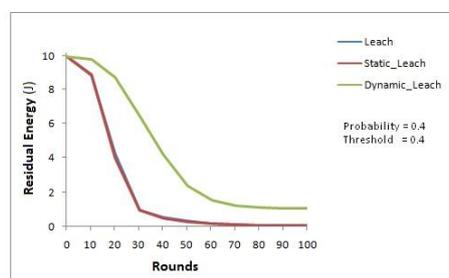


Fig. 9: Comparison of Residual energy in three protocols at the end of total simulation duration.

The number of CHs in static LEACH is fixed and hence the energy of nodes acting as CHs alone is quickly depleted. As the number of cluster heads elected was very high in LEACH, enormous amount of energy is wasted in overhead of CH election process in LEACH. From the results obtained, it is observed that due to less number of cluster head selection in D-LEACH, the residual energy is high when compared to LEACH and static LEACH. Thus, residual energy of nodes in D-LEACH is higher by tenfold when compared to other two protocols.

The number of alive nodes at the end of total simulation and the time at which the first node died in the network was analyzed for all three protocols and the fig.10 shows the comparison of number of alive nodes in all three protocols. Table 3 shows the exact time (round) at which the first node died because of energy depletion and the total number of alive nodes at the end of total simulation.

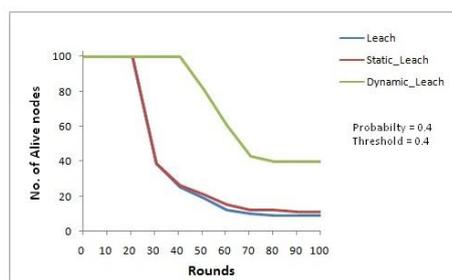


Fig. 10: Comparison of No. of Alive nodes in three protocols

Table 3: Comparison of No. of Alive nodes and First Node Die time in three protocols.

Protocols	First Node die time (at round)	No. of Alive nodes (after 100 rounds)
LEACH	21	9
Static LEACH	21	10
D-LEACH (proposed)	44	40

On comparing the number of alive nodes at the end of 100 rounds in three protocols, it is observed that the total energy of the first node depleted at round 21 for static LEACH and LEACH. But in the D-LEACH, the total energy of the first node depleted only at round 44. At the end of 100 rounds, the total number of alive nodes is 40 in D-LEACH and 9 and 10 for static LEACH and LEACH. Thus, the number of alive nodes is higher in D-LEACH by four times compared to static LEACH and LEACH.

Conclusion:

In this paper, a modified LEACH algorithm called D-LEACH was developed to overcome the limitation of the original LEACH protocol by considering the residual energy of nodes acting as cluster heads during the cluster head selection process at the end of each round. The simulation result shows that D-LEACH provides better energy efficiency and prolonged network lifetime in terms of reduced cluster head selection with the CH count reduced to 1.56% of LEACH, improvement in the residual energy of nodes in the network by 10 times and increase in number of alive nodes by 4 times when compared to static LEACH and LEACH.

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