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Analytical Study of an Improved Cluster based Routing Protocol in Wireless Sensor Network

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Abstract

Objectives: To analyze the homogeneous protocols like Low Energy Adaptive Clustering Hierarchy (LEACH), Improved Energy Balanced Routing Protocol (IEBRP) and some of the heterogeneous protocols like Distributed Energy Efficient Clustering (DEEC) and Modified Stable Election Protocol (M-SEP). **Methods/Statistical Analysis:** We focus on the different levels of energy such as single energy level (LEACH, IEBRP), Distributed Energy Level (DEEC) and multi energy level (M-SEP). Later we compare the algorithms of design of LEACH, IEBRP, DEEC and M-SEP protocol too. Finally we simulate all the four protocols using C platform and calculated the lifetime of sensor networks with the help of four new matrices: First Node Died (FND), Some Node Died (SND), Half Node Died (HND) and Last Node Died (LND). **Findings:** Finding out the best suited path from sensor node to sink and calculating the efficiency with respect to different routing protocols determines that M-SEP is more efficient than other three routing protocols. M-SEP has more alive nodes with respect to number of rounds. **Application/Improvements:** Simulating all the matrices with respect to different parameters result reveals that M-SEP performs 22%, 40% and 55% respectively longer than LEACH, IEBRP and DEEC. It also increases the lifetime, no of data packet send to the BS and data transmission rate, other than three routing protocols.

Keywords: Clustering, Homogeneous, Heterogeneous, Network Life Time, Wireless Sensor Network

1. Introduction

A sensor network consists of a set of nodes used for sensing, computing and communicating to different components, in a specific environment. The features of a sensor network are: Combinations of localized or distributed sensors, an interconnection network, the Central Point (CP) of a cluster and a group of computing resources at that central point. The sensor nodes are randomly deployed and in case of occurrence of an event, the sensor node sends the signal to the Base Station (BS) through sink. To communicate with other network, BS serves as a gateway. As supply energy is limited to a particular node, the total amount of energy available at a node needs to be an important aspect in order to transmit the data to other nodes in the network.

In a network, performance, scalability, routing overhead, end-to-end delay, throughput, network life time, packet delivery ratio, alive nodes per round, packets send to BS and the total energy are the major issues. So the idea behind them is protocol design in efficient way. Generally routing protocols are cluster based, choosing a Cluster Head (CH) among the nodes in a cluster i.e., LEACH, PEGASIS. Cluster Head sends the message to the sink and then to Base Station (BS). Clustering is the first approach to extend the life time and reduce the energy consumption[1]. LEACH and PEGASIS are more balanced routing cluster based protocol proposed by[2,3] proposed a Multi-Hop cluster based Routing Protocol (SEP)[4] for longer life time and larger transmission range in WSN. That protocol consists of two parts, cluster management and data transmission (between BS and sensor area). It performs better than single-hop clustering routing protocol (LEACH, IEBRP) in terms of N/w life time and energy consumption. In the protocol Energy Balanced Clustering routing protocol (EBC)[5] discuss about the CH in heterogeneous distributed environment. Highest signal intensity controls the

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distance between nodes and the highest remaining energy with the node select as CH among the cluster nodes.

We follow the homogeneous networks i.e., LEACH[6], PEGASIS[7] where all nodes have the same initial energy level[8] and Hybrid Energy Efficient Distributed clustering (HEED)[9]. In later part we also follow some of the heterogeneous distributed clustering protocol i.e., Stable Election Protocol (SEP)[10], Energy Efficient Clustering Protocol (EECP)[11].

Routing protocol describes about the stability of a sensor node, location of the sink and the BS. Some protocols are highly stable depending upon the base station and the sensor field. The next part describes about the clustering process and selected routing protocols that are not necessarily cluster based.

2. Formation of Clusters

Creating a group in a specified area is called a cluster which has two different phases namely, setup phase and the steady state phases which are depicted Figure 3. Here a detailed elaboration is presented relating to the process of formation of clusters, process of selection of cluster heads and subsequently the design of algorithms for different cluster based as well as non cluster based routing protocols.

2.1 Cluster Formation and Cluster Head Selection

Formation of clusters is of different types i.e. 1. Hierarchical clustering (based upon connectivity)[12], 2. Centroid based clustering. 3. Distribution based clustering and 4. Density based clustering.

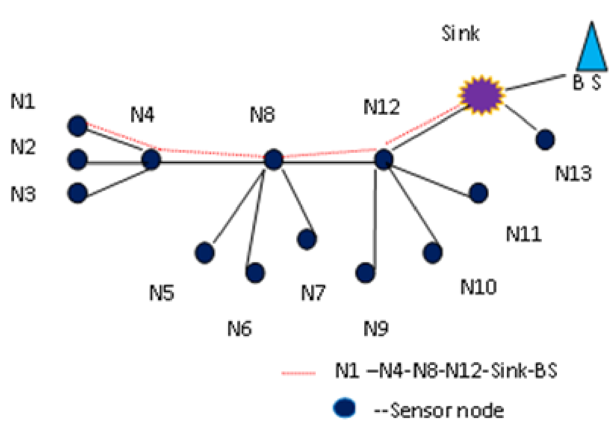

Figure 1. Cluster head selection in a hierarchical network.

In Hierarchical Clustering, general nodes select the hierarchical Cluster Heads (CHs) depending upon the data received and transmitted such that maximum amount of energy is harvested and preserved. In Figure 1, it shown that groups of nodes (N1,N2,N3); (N5,N6,N7); (N9,N10,N11); (N13) make four separate clusters. If the node N1 wants to send a message to the sink node, then it must cover the path F1, F2, F3 and F, then to the BS. Nodes N4, N8 and N12 act as cluster heads in the network. Design of algorithms (given below) for different protocols depends upon the luster head in the network (homogeneous or heterogeneous).

2.2 Design of Algorithm flow of LEACH, IEBRP, DEEC and M-SEP

LEACH

1. Initial
2. Assume All alive nodes
3. Select a node (n) from set G
4. Calculate T(n) (Threshold Value) for a node (n)
5. If generated random number < T(n)
   Then
   Selected node (n) as Cluster Head(CH)
6. End

IBERP

1. Initial
2. Broadcasting energy value
3. Receive broadcasting message from other nodes
   Whose signal intensity > G
4. If my energy is largest
   i. broadcast the election message
   ii. wait for another message joining into that cluster
   iii. make them TDMA schedule & sending them to cluster members
5. Else i. Wait for the election result from CH
   ii. Receiving the result, find out the nearest CH
   iii. Sending the message to CH and join with that cluster
   iv. Wait for TDMA time slot come
6. End if
7. Communication occurs within the clusters
8. End

DEEC

1. Initial
2. Assume All alive nodes & maximum energy levels
3. Select a node (n) from set G
4. Generate a Random number from selected node

5. Calculate T(n) (Threshold Value) for a node (n)
6. If generated random number < T(n)
   Then
    Selected node (n) as Cluster Head (CH)
7. Repeat it from 1 to 6 for intermediate energy level
8. Find all the CH for multi energy level
9. End

M-SEP

1. Initial
2. Assume all alive nodes
3. Chose node type i) Advance ii) Intermediate iii) Normal
4. Select a node (n) from set G
5. Generate a Random number from selected node
6. Calculate T(n) (Threshold Value) for a node (n)
7. If generated random number < T(n)
   Then
    Selected node (n) as Cluster Head (CH)
8. Repeat for all Node Types chose CH
9. End

2.3 WSN Routing Protocol LEACH

LEACH belongs to the category of hierarchical routing protocols implemented in WSN. In this protocol, nodes are randomly deployed creating n number of groups named as clusters. First of all, it is needed to choose a cluster head for each cluster. From the sender node, the data are transmitted to the cluster head of different regions (clusters) i.e., C1, C2 and C3 as shown in the Figure 2. In each round, the cluster head may change. Then the data need to be sent to the sink node. In order for a node n to be elected as the cluster head, it needs to generate a random number v in the interval 0 and 1 that is compared with a predefined threshold value of T(n) and if T(n) appears to be larger than v, then node n is elected as the Cluster Head (CH). Selection of the CH from the cluster is very difficult because all the nodes possess same energy value and energy dissipation is also the same. The threshold value of nodes those served as CH in the last 1/p rounds is not taken into consideration in the current round where p is the probability of selection of a node as the CH. The threshold value T(n) of a node n that participates in the CH selection process can be represented as

$$T(n) = \begin{cases} \dfrac{1}{1 - p\left(r \bmod \dfrac{1}{p}\right)}, & if\ n \in G \\ 0, & Otherwise \end{cases} \qquad (1)$$

Here G represents the collection of nodes those were not selected as CH in the last 1/p rounds of CH selection process and *r* refers to the current round of selection. Once a node becomes the cluster head, the chances of it being again a CH in the next 1/p rounds is negligibly less. When the CH selection process is complete, the newly selected CH continues transmitting data to the members in the cluster and advertising to them regarding their responsibilities in the cluster. On receiving the information about CH, the members of the cluster need to select the nearest CH in order to form the cluster. Randomly choosing the position of the CH in LEACH protocol prevents the sensor node's battery from being drained out and also schedules a technique to prevent the intra cluster collisions which are depicted in Figure 2.

2.4 IEBRP

Improved Energy Balanced Routing Protocol (IEBRP) is the advanced version of LEACH protocol[13]. In the model of IEBRP protocol[14], the following assumptions are made:

- The sensor nodes in the WSN are randomly placed in the sensing area which can be regulated by base station. A sink node is present in the network that is placed near the base station.
- The entire sensor node has some and equal initial energy, each can transmit and receive data. Each node has storage capacity but although we can harvest energy at the sensor node through ambient sources we ignore that part. In addition, the battery power at each node in the network can be regulated depending on its distance from the base station.

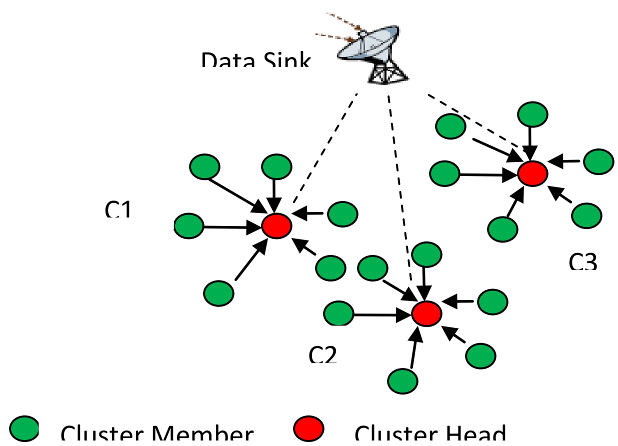

Figure 2. Network model of LEACH.

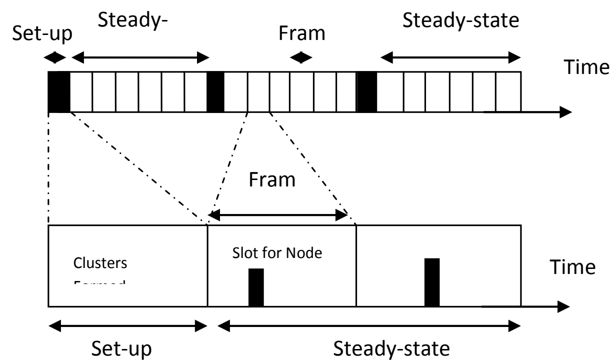

Figure 3. Different phases of LEACH.

- The sensor network is also called as a data collection network. The sensor nodes continue monitoring the network environment on a regular basis by virtue of the activities like sending and receiving the data from the nearer nodes and send data to the BS at a constant rate. The cluster head verify that data and send the acknowledgment to the sender, and transmits to the Sink.
- GPS controls all the sensor nodes.
- Each node has a unique identity in the WSN.

The improvement of the EBRP[15] protocol shows following advantages:

- The protocol generates frequent consumption of energy, and thus, our first improvement is to reduce the number of clusters.
- By adding power factor and optimizing the cluster head selection algorithm, the distance between cluster head and the sensor node is decreased.
- Sending the request to forward region, finding the members of the cluster, cluster division, the CH is chosen basing upon the highest remaining energy.
- In LEACH protocol, cluster head may not remain fixed throughout the whole network, rather dynamically changes the position which may lead to failure of the network connectivity. Changing the CH frequently in the cluster and collecting the data from different nodes may increase the redundancy and wastage of energy. IEBRP protocol reduces the number of clusters, combining the cluster heads attempts to reduce the network size. The threshold (T (n)) presented below can be applied to select the cluster head.

$$T(n)=\frac{p}{1-p(r\bmod\frac{1}{p})}\left[\frac{E_{n_{current}}}{E_{n_{initial}}}+(r_s\frac{1}{p})(1-\frac{E_{n_{current}}}{E_{n_{initial}}})\right] \quad (2)$$

Where, P is the total number of nodes in a cluster, r is the current number of round, r_s is the number of rounds, $En_{current:}$ is the current energy and $En_{initial:}$ is the initial energy.

2.5 DEEC

Distributed Energy Efficient Cluster Protocol (DEEC)[16] adopts clustering techniques and distributed Energy-Efficient Clustering algorithm which are also used in heterogeneous wireless sensor networks. The procedure of election of a CH is carried out on the basis of a probability that is taken with respect to the ratio of residual energy available at a node to the average energy maintained in the network. Nodes in the network with a higher initial battery power and higher residual energy at the point of the election of CH possess a higher priority to be elected as the CH as compared to the nodes with relatively lower energy level. It basically focuses at the state of the network when it is stable for a significant period of time by using heterogeneous aware clustering algorithm. We mainly focused at the advanced nodes (better chances of being elected as CH) for the reason that when their residual energy decreases, it still remains in a normal range. In this case the advanced node dies quickly than the normal nodes in the network.

Our fundamental assumptions are:

- There are as many as n sensor nodes that are uniformly deployed in the network in a 100mx100m square region.
- Two levels of heterogeneity are defined for the deployed sensor nodes, i.e., normal nodes and advanced nodes, distinguished according to their performance levels.
- The base station in the network exists at the center of the above mentioned region.
- The CH collects the data from general nodes, aggregates those data and transmits directly to the BS through sink node.
- The nodes have capability to transmit the data to the sink and a base station, which may be in between the sensing area.

Nodes those have a higher residual energy have the higher priority to get elected as the CH. Thus the residual energy plays the key role in the process of election of the CH. Thus DEEC is capable of providing an optimal number of CHs in each round that can be calculated on the basis of the formulas given below.

$$P_i = \begin{cases} \frac{P_{opt} * E_i(r)}{(1-\alpha m) * E'(r)}, & Si - Normal\ node \\ \frac{P_{opt} * (1+\alpha) E_i(r)}{(1+\alpha m) * E'(r)}, & Si - Advance\ node \end{cases} \quad (3)$$

Here E' (r) represents the average energy of the network as a whole in round r and is determined from the expression given below.

$$E'(r) = \frac{1}{N} \sum_{i=1}^{N} E_i(r) \quad (4)$$

Here, E_i (r) refers to the residual energy of i-th node in round r. As per the value of P(i), DEEC estimates the threshold as:

$$p(s_i) = \frac{p_{opt} * N(1 + a_i)}{N + \sum_{i=1}^{N} a_i} \quad (5)$$

DEEC assumes that if the residual energy at a node appears to be higher than the average energy of the network as a whole, then the node acquires a higher probability to be elected as the CH. Hence, it can be inferred that the distribution of energy in the network is fairly even.

2.6 M-SEP

Modified stable election protocol (M-SEP)[17], as the name suggests it is a modification of existing protocol SEP. In this approach, nodes in the network are classified into two categories like advanced nodes (with higher energy level) and normal nodes (with lower energy level) with reference to the initial battery power available at nodes. But in other protocols, nodes are assumed to have the same amount of energy. This is the first improvement incorporated into SEP protocol that assumes the WSN to be a heterogeneous network in which the nodes are partitioned into two types on the basis of energy levels. The average network energy of the whole network is 32.206 kj and the total energy consumption is 11.1953 kj after 950 rounds. The alive node at that time is 1. In that round, anyone of both normal as well as advanced nodes can be selected as the CH. So the modified equations for the threshold value and selecting the cluster heads from normal and advanced nodes are as follows.

$$T(S_{nrm}) = \begin{cases} \frac{3 * P_{nrm}}{1 - P_{nrm}(r \bmod \frac{1}{3 * P_{nrm}})} * \frac{E_{avg}(r)}{E_{current}(n)} & \text{f } S_{nrm} \in M \\ 0 & \text{Otherwise} \end{cases} \quad (6)$$

Where, M is the group of normal nodes anyone of which may become a CH, $E_{avg}(r)$-Average energy of the N/W and $E_{current}(n)$ - is the current energy of the node.

$$P_{nrm} = \frac{P_{opt}}{1 + \alpha m * E_{current(n)}} \quad (7)$$

$$T(S_{adv}) = \begin{cases} \frac{3 * P_{adv}}{1 - P_{adv}(r \bmod \frac{1}{3 * P_{adv}})} * \frac{E_{avg}(r)}{E_{current}(n)} & \text{f } S_{nrm} \in M' \\ 0 & \text{Otherwise} \end{cases} \quad (8)$$

Where, M' is set of advance nodes, which can become CH and

$$P_{adv} = \frac{P_{opt}}{1 + \alpha m * E_{current}(n)}(1 + a) \quad (9)$$

3. Energy Consumption Model

As each node performs transmission and reception of data with its neighbors, the amount of energy consumed in this process varies for every node in the network[18]. As per our model, the amount of energy consumed depends upon l, the amount of data sent or received and d, the distance between the sending and the receiving nodes. Thus for l bit of data to be received by a CH node and a non CH node from a distance of d meters can be given respectively as:

$E_{CH} = lE_{elec} + l\epsilon_{amp} d_{toBS}^4$ and $E_{Non_{CH}} = lE_{elec} + l\epsilon_{amp} d_{toBS}^2$ (10)

3.1 Network Setup

In our simulation environment, 100 sensor nodes are deployed in an area of 100x100 square meters. The base station is located in the network at a position with coordinates (50,175). For each node the amount of energy is 0.1 J. The message size (Data packet length)[19] is 2000 bits per round and Broad-cast packet length is 200 bits. All other parameters are given in Table 1. The probability P of selection of a cluster head is set to 0.05. It refers to a fact that in each round, 10 nodes are elected as CHs. The experiments are carried out considering three aspects 1. Varying the number of nodes, 2. Varying the speed of mobile nodes, and 3. Varying number of connection between source nodes and destination nodes. Table 1 shows the common simulation parameters which have been used for all four experiments.

4. Results Analysis

The life time of WSN depend upon the alive nodes with respect to round. The number of nodes those are alive in

Table 1. Simulation parameters

Parameters	Values	Parameters	Values
Network size	100× 100 meters	ε_{amp}	$0.0013*10^{-12} j/bit/m^4$
Broad-cast packet length	200bit	E_{da}	$5*10^{-9} j/bit/signal$
Data packet length	2000bit	ε_{fs}	$10*10^{-12} j/bit/m^2$
E0(Advance node)	E0*(1+a)J	d0	70m
E_{elec}	$50*10^{-9} j/bit$	A	1
E_0(Normal node)	0.1J	M	0.1

Table 2. Network life time

Protocols	FND	SND	HND	LND
LEACH	124	140	175	240
IEBRP	138	169	422	580
DEEC	159	247	420	1000
M-SEP	186	265	470	1200

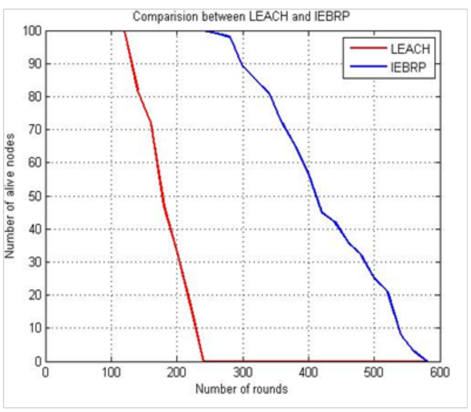

Figure 4. Number of alive node vs round between LEACH and IEBRP.

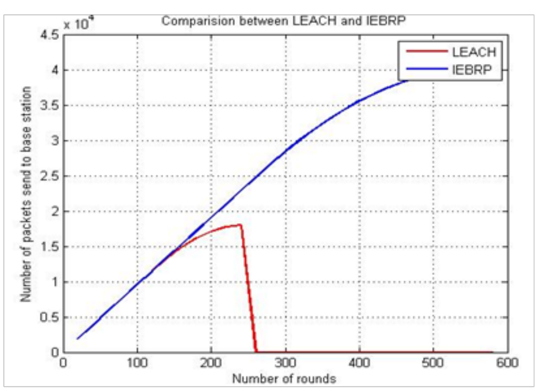

Figure 5. No of rounds vs no of packets send to base station in LEACH and IEBRP.

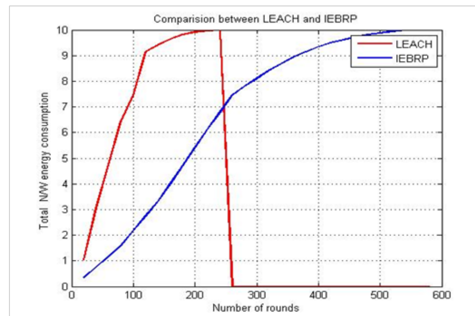

Figure 6. Total energy consumption vs no of round between LEACH and IEBRP.

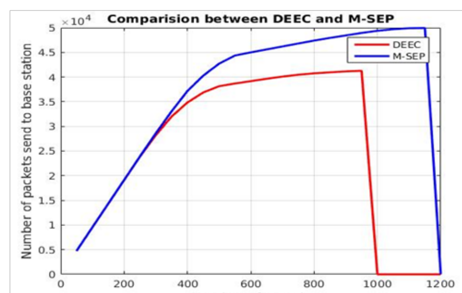

Figure 7. No of rounds vs no of packets send to base station in DEEC and M-SEP.

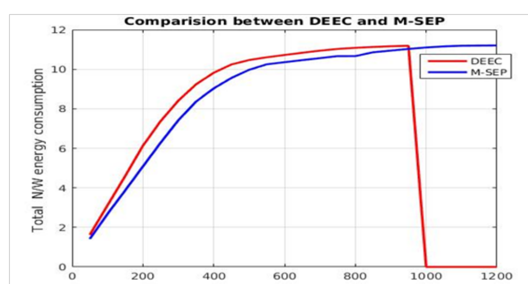

Figure 8. Total energy conservation vs no of round between DEEC and M-SEP.

each round during the simulation[20] of each of the above mentioned protocols is depicted in Figure 4 and Figure 9. The obtained the results after setting the network as mentioned above. It can be observed that M-SEP protocol outperforms[21] thereby increasing the stability period of the typical network approximately by 22%, 55%, 40% respectively, longer than LEACH, IEBRP, DEEC shown in Figure 10. A comparison of number of packets sent to the BS in different rounds using different protocols are shown in Figure 5 and Figure.7. Comparisons of total energy consumed in different rounds using different protocols are depicted in Figure. 6 and Figure 8. The observation states that in LEACH, the average total network energy is 9.2009j/s, in IBERP the average total network energy is 11.034j/s and in DEEC the average total network energy is 13.5641j/s where as in M-SEP the average total network energy is 32.206j/s. So SEP represents the most suitable protocol in all respect with all the nodes having initial energy. So we can say that the stability period[22] of the network using M-SEP is more than that LEACH, DEEC and IEBRP which are given on Table 2. With the help of four new matrics First Node Died (FND), Some Node Died (SND), Half Node Died (HND) and Last Node Died (LND) we also determined the network life time.

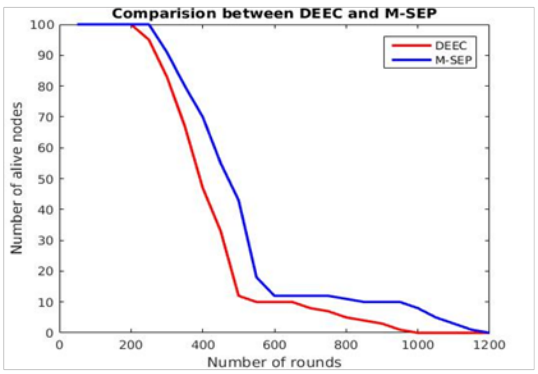

Figure 9. Number of alive node vs round between DEEC and M-SEP.

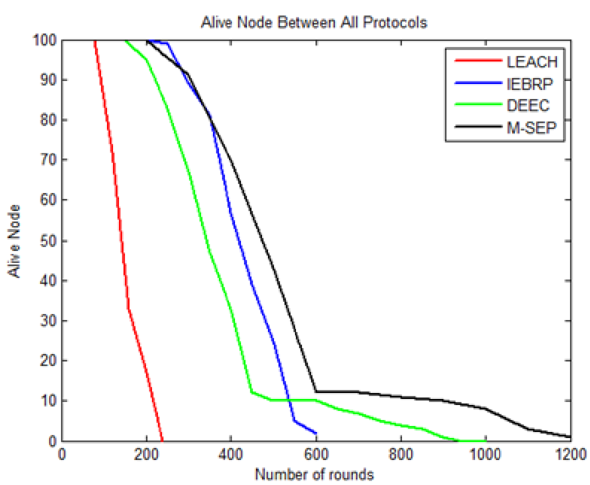

Figure 10. Network life time comparison with respect to alive nodes.

4.1 Analysis of the Packets Sent to the BS

The efficiency of a routing protocol depends upon the received data packets at the base station, packet drop and alive nodes with respect to round. Figure 12 represents the comparison of all different protocols in form of graph, which shows the number of packets sent to the BS with respect to no. of rounds. Evaluation results depict that more number of packets (50017) are sent to the base station when M-SEP is used as compared to the other protocols (17988 for LEACH, 40606 for IBERP, 41389 for HEED) due to highest remaining energy at that CH.

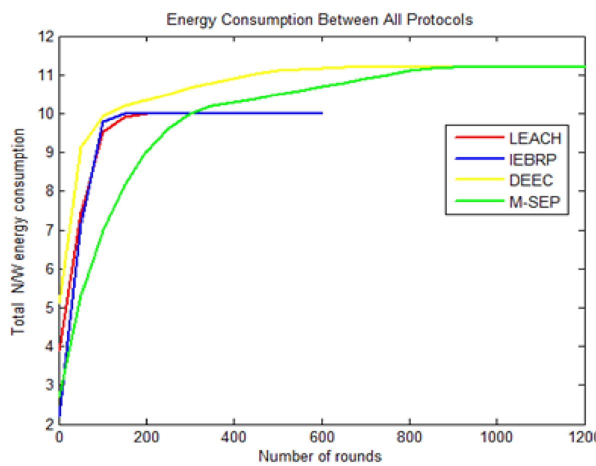

Figure 11. Total energy consumption vs round.

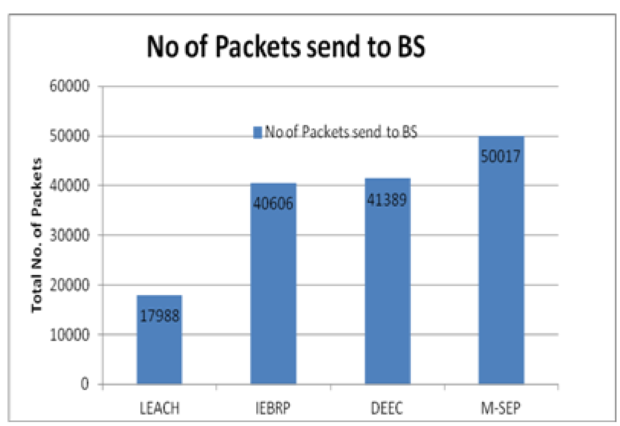

Figure 12. Total number of data packets sent to BS.

5. Conclusion

From the above analytical study, we highlighted about the homogeneous protocols like LEACH, IEBRP and some of the heterogeneous protocols like DEEC and M-SEP. We can conclude that M-SEP protocol performs better than protocols LEACH, IEBRP, DEEC in terms total energy consumed versus number of rounds in the context of network lifetime and number of data packets sent to the BS. In this protocol, the total network energy also decreases with respect to round and sensor nodes deplete their energy slowly. So from the evaluation results, we arrive at a conclusion that using M-SEP provides a longer stability period (on an average three times more than LEACH), appears to be more energy efficient, and overall lifetime is more than other three routing protocols.

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