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Energy Efficient Clustering Approach for Distributing Heavy Data Traffic in Wireless Sensor Networks

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Abstract

A wireless sensor network is made up of a large number of sensor nodes deployed on a wide field and it has limited battery lifetime which gets depleted at a faster rate, when heavy data traffic occurs. Most recent researches focused that, clustering the group of nodes is a better strategy for enhancing the lifetime of the sensors and also clustering organizes the network by balancing the traffic load of the sensor nodes. Inspired by the benefits of clustering approach, Event Based Routing Protocol (EBRP) was proposed. The proposed protocol involves three procedures. First procedure refers to a cluster head selection, which appoints cluster head based upon residual energy which is near to the sink node. The residual nodes in the network are to be designated as cluster head at the successive rounds. This process helps to balance the load evenly in the network. Second phase refers to an Event sensing procedure, which appoints a set of active nodes for close sensing an event and to provide coverage area near to the event. Third step refers to a node routing, to route the witnessed information based upon the shortest path. This proposed method uses residual energy for appointing a cluster head. This proposed protocol was implemented and the experimental results were shown through the network simulator. The proposed protocol outperforms the existing routing techniques in terms of alive nodes, packet delivery ratio, average remaining energy and end-to-end delay.

Key words

Clustering, Energy efficiency, Event sensing, Residual energy.

1. Introduction

The main objective of the WSN is to sense the environmental variations such as temperature, humidity, pressure and other physical quantities. Due to increased popularity in WSN application, many protocols are emerged to save energy of each sensor node. First of all, sensors are provided with limited powered battery. After deployment of sensor in the sensing field, it is impossible to recharge or replace the battery of each sensor node. Such drawback demands us to distribute the heavy data traffic evenly in the network, otherwise heavily loaded sensor nodes consumes more amount of energy which leads to node failure. Clustering is the method which appoints cluster head among all nodes within a certain region. The sensed information from all neighbor node are collected by the cluster head and it has been routed to reach the destination.

During the formation of cluster, if the cluster formed in an inappropriate manner, it will make the cluster head overloaded with more number of sensor nodes which leads to quicker death of a CHs. To overcome this issue, the unequal size clusters can be balanced. Furthermore, fault tolerance, conservation of energy, efficient data gathering, effective traffic load handling, reliable communication, end-to-end delay, prolonging network lifetime are critical issues of WSN. Many routing protocols are designed to handle these critical issues. It is expected that energy efficient routing scheme should always provide the reliable communication by considering the above challenges and enhance the life time of the sensors.

2. Related Works

In order to balance the traffic load and the energy consumption of the sensors, network lifetime becomes the critical issues in WSNs. Many researchers had proposed an energy efficient routing protocol for WSNs for extending the network lifetime. Here, some of the protocols are discussed to show the proposed one which is efficient from other protocols. To reduce high energy consumption for communication and also for large coverage with different regions, Distributed Energy-Efficient clustering algorithm [1] was proposed. The author [2] proposed an energy efficient routing protocol to route data packets towards destination or sink. It faces high data redundancy issues when it is deployed in dense networks. Next hop can be dynamically selected with probabilistic value of each node by estimating the remaining energy and the amount of energy of neighbor nodes [3].

Distributed clustering and routing algorithms (DFCR) [4] uses a runtime recovery of the sensor nodes with satisfy coverage due to the link breakage of cluster head with members. This algorithm provides better performance. But for densely deployed, it faces partial and transient failure of sensor nodes. An energy-balancing clustering approach for gradient-based routing [5] was proposed to divide an entire network into many clusters of different sizes in which each sensor node helps to find the next hop to deliver data packets towards the sink node. However in densely deployed environment, it faces collision problem in the environment. A novel differential evolution-based clustering algorithm [6] was proposed to prolong the network lifetime by extending the lifetime of highly loaded cluster heads.

The author [7] used the parameters as residual energy and the quality of the link in its neighbourhood to convey the robust information. The major issues involved are high end-to-end delay and congestion management. Low latency and energy efficient routing scheme is developed to reduce high energy consumption but memory overflow and message overheads occur. The author [9] proposed a protocol which forwards data to the sink node by considering high link quality, buffer occupancy and minimum hop counts. An efficient data-driven routing protocol was proposed in order to reduce the protocol overhead for data gathering in WSN [8-10].

With the help of one-hop distance, all cluster members can be connected with the direct communication of cluster heads. For better scalability, the link qualities between the node and the cluster head, the algorithm uses a metric called selection weight [11]. A cluster based communication protocol was specified in each round, the nodes which have at least one neighbouring node at a distance less than the threshold [12]. This algorithm has improved the updated process of the cluster centre and radius on (ECM) evolutionary clustering method and takes Davies-Bouldin Index (DBI) as classification criterion [13].

A user-oriented load balancing scheme for an energy-efficient load balancing in wireless networks is based on allocating load in wireless sensor nodes proportionally to each of the agent’s capacity and user-oriented approach. This scheme is combined with dynamic provisioning algorithm based on greedy graph and user oriented load balancing scheme for maintaining the performance and stability of distributed system in wireless sensor networks [14]. Due to bottleneck issues and the heavy data traffic load, the proposed scheme fails to achieve the lifetime using layered self-activation mechanism [15, 16]. A round refers to the successive time interval between the two cluster heads [17, 18]. MBC (Mobility Based Clustering) protocol selects the cluster heads based on residual energy and mobility of the sensor nodes for each round. It does intra cluster and inter cluster communication in each round. The major drawback in MBC protocol is link breakage and packet dropping which reduces the network utilization [19]. Message that contains location information are being shared among the nodes in the field and it does not require flooding and complicated computation for localization [20].

3. Proposed System

The proposed protocol is divided into three collaborating phases where an individual phase plays the vital role to prolong the network lifetime of the WSN.

3.1 Cluster head selection phase

The key idea of this algorithm is to distribute the heavy data traffic evenly in the network. In each individual cluster, this process plays an important role to appoint as cluster head (CH) which is almost near to the sink. During the sensing event, the rest of the cluster heads are elected as middle of each clusters. A cluster head formation algorithm takes places in two phases:

(A) Set-up phase.

(B) Steady-State phase.

(A) Set-up phase

After the deployment of sensors, BS will initiate the cluster formation process through initiation messages (init_msg) to the deployed sinks. After receiving init_msg from the sink, sensors will start to communicate with each other's by broadcasting hello_msg. The cluster selection metric is based on the residual energy, density and the distance of a node to its neighbor node in the dense deployment region and also the maximum distance from a sensor node to its neighbouring node in a cluster.

$$CSM = \frac{RE_i}{\left(\sum_{i=1}^{n} DN_i / D_{maxi}\right)^2 + \left(\rho - \left(\frac{DN_i}{100}\right)\right)^2} \quad (1)$$

where,

RE_i - Residual Energy of node i.

DN_i - Distance of a node to its neighbor node in the dense deployment region.

$D_{max\,i}$ -Maximum distance between the successive sensor node in a cluster.

ρ - Density varies from 1 to 2 for thick to thin regions.

(B) Steady state phase

Data transmission starts in steady-state phase; Sensor nodes send their data during their allocated TDMA slot to the CH and this transmission uses a minimal amount of energy. It is chosen based on the received strength of the CH advertisement. Radio of each non-CH node can be turned off until the nodes allocated TDMA slot, therefore it is minimizing the energy dissipation in these nodes.

The following assumptions are made for the network model:

- The sensor network is considered to be homogenous.
- The initial energy of the sensors is same.
- Each sensor knows its location information and velocity.
- The base station is stationary and all sensors are synchronized with time.
- Each sensor node can calculate the time for transmit a data packet.

This algorithm helps to communicate a mobile sensor node with the corresponding cluster head within an allotted TDMA schedule. The mobile nodes initiate the request message to the member nodes in order to gather the sensed information at each slots. In case, when the data is not received at the proper frame, it has to be detached from the cluster.

The detached node can be considered as a node which is not in the cluster region due to its mobility. Again the TDMA is rescheduled and transmitted to the cluster head through the cluster members. The node which went out of the cluster region, didn't receive the request message for two consecutive frames. It will able to join with the new cluster head.

Based on the received signal strength of cluster head advertisement message, the node will jo in to the new cluster. The new cluster head will review the cluster membership list and TDMA schedule and then broadcast as per the new TDMA schedule to its cluster.

In this work, the first-order radio model was used to model the energy dissipation. When the distance between the transmitter and receiver is less than a threshold value 'd_0', the free space model (d^2 power loss) is employed. Otherwise the multipath fading channel model (d^4 power loss) is used. Equation (2) shows the amount of energy consumed for transmitting 'l' bits of data to the distance'd', while (3) represents the amount of energy consumed for receiving 'l' bits of data.

$$E_{Tx}(l,d)=\begin{cases} l*E_{elec}+l*\varepsilon_{fs}*d^2 & ,d<d_0 \\ l*E_{elec}+l*\varepsilon_{mp}*d^4 & ,d \geq d_0 \end{cases} \quad (2)$$

$$E_{Rx}(l,d)=l*E_{elec} \quad (3)$$

The threshold value d_0 could be obtained via (4).

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \quad (4)$$

where,

E_{elec} - Energy consumption per bit in the transmitter and receiver circuits.

ε_{fs} - Energy consumption factor for free space.

ε_{mp} - Energy consumption factor for multipath radio models.

3.2 Event sensing phase

The main aim of the Event sensing phase is to minimize the overlapping of data and save high transmission energy consumption by minimizing the transmission distance. In this phase, it employs group of nodes in a cluster to provide coverage range nearer to the event and also cluster head for monitoring an event by placing the rest of the sensor nodes in sleeping mode. Consider the event region consists of more number of sensor nodes in a cluster. After sensing, the sensor nodes inform to their CH with the infr_msg. The infr_msg contains the energy level of sensors, distance of the node to the CH and event information. The sensor nodes in event range can send information message to the cluster head. After receiving infr_msg from all its member nodes, the cluster head can broadcast hello_msg and then the cluster head starts calculating the node sensing value by the equation (5).

$$ESP = \frac{RE_i}{\left(\Sigma_{i=1}^{n}\left(D_{CHi} + DE_i\right)/D_{maxi}\right)^2 + \left(\rho - \left(\frac{DE_i}{100}\right)\right)^2} \quad (5)$$

where,

DE_i - Distance of a node to the event

D_{CHi} - Minimum distance of a node from the cluster head.

$D_{max\,i}$ - Maximum distance from a sensor node to its neighboring sensor node in a cluster.

ρ - Density varies from 1 to 2 for thick to thin regions.

The active node sensing value depends on the residual energy, distance to the event, distance to the cluster head, density and the maximum distance. CH sends active messages to active sensor nodes and TDMA slot can be assigned for each sensors. The sensor node with higher active node values, is appointed as active node for close sensing an event and also to provide network coverage to area of the event. This algorithm makes the active node for sensing the event while the rest of the nodes are in sleeping mode. So the Event sensing phase saves energy of the sensor node by maximizing the number of sleeping nodes. The probability of active nodes rotates periodically for each round (i.e) a new active node is appointed for each round.

3.3 Node routing phase

This procedure divides entire network data traffic into two basic segments, first routing the event information from sensing region to CH and then from CH to sink or destination. In first segment, after sensing an event, each active node in a cluster forwards their sensed information directly to a CH or with the help of intermediate neighbouring nodes. Thus, entire sensing data in a cluster moves using multi-hop spanning tree towards the CH. In second segment, CH is responsible for forwarding the received information to sink and it uses the shortest path to reach destination which is mentioned in the routing table. Each sensor node in this procedure is responsible for maintaining up to two hops routing information of its neighboring nodes and storing them with priority levels The active node routing value is calculated based on the following equation (6).

$$ANRV=\frac{RE_i}{\left(\sum_{i=1}^{n}\left(DS+D_{CHi}\right)/D_{maxi}\right)^2+\left(\rho-\left(\frac{DE_i}{100}\right)\right)^2} \quad (6)$$

where,

RE_i - Residual energy.

D_{CHi} - Minimum distance of a node from the cluster head.

DS - Minimum transmission distance between two sensor nodes.

$D_{max\,i}$ - Maximum distance from a sensor node to its neighboring sensor node in a cluster.

DE_i - Distance of a node to the event.

ρ - Density varies from 1 to 2 for thick to thin regions.

The priority levels help to find the alternative sensor node to route information in case of a single route sensor nodes failure. Here, to identify the next hop sensor node failure is quite simple. Each node after receiving information, the neighbor node sends acknowledge message to its sender. If a sender does not receive this acknowledgement message in a specific time interval, then the node can be considered as a dead node. It also forwards data packets to its neighboring node having second priority in the routing table. The priority level information provides robust routing with the least amount of control message overhead and end-to-end delay which has been verified by the obtained simulations result. To reduce communication energy cost in WSNs is extremely a challenging task. The energy consumption cost during conveying information towards sink is directly linked with transmission distance and number of hop count. Thus, the transmission energy cost can be reduced when the optimum communication distance and sum of hops can be correctly estimated.

4. Simulation Results

In this section, EBRP protocol in both static and mobile scenarios can be compared with LEACH protocol. Simulation results had shown that our proposed approach outperforms with the existing algorithm. The simulation was carried out using Network Simulator. The values used in the first order radio model are described in Table I.

Table 1. Simulation parameters

PARAMETERS	VALUES
Simulation tool used	Network simulator (NS 2.33)
Number of nodes	100
Simulation area	500 m * 500 m
Energy consumed / receiving	50 nJ/ bit
Base station position	(250, 250) m
Free space energy consumption factor	10 pJ/bit/ m^2
Multipath radio model energy consumption factor	0.0013 pJ/bit/m^4

4.1 Network Animator (NAM) Window

Fig. 1 shows the network animator window for 100 nodes. In this scenario, ‘Node 0’ is the base station. ‘Node 1’ to ‘Node 99’ are neighbor nodes.

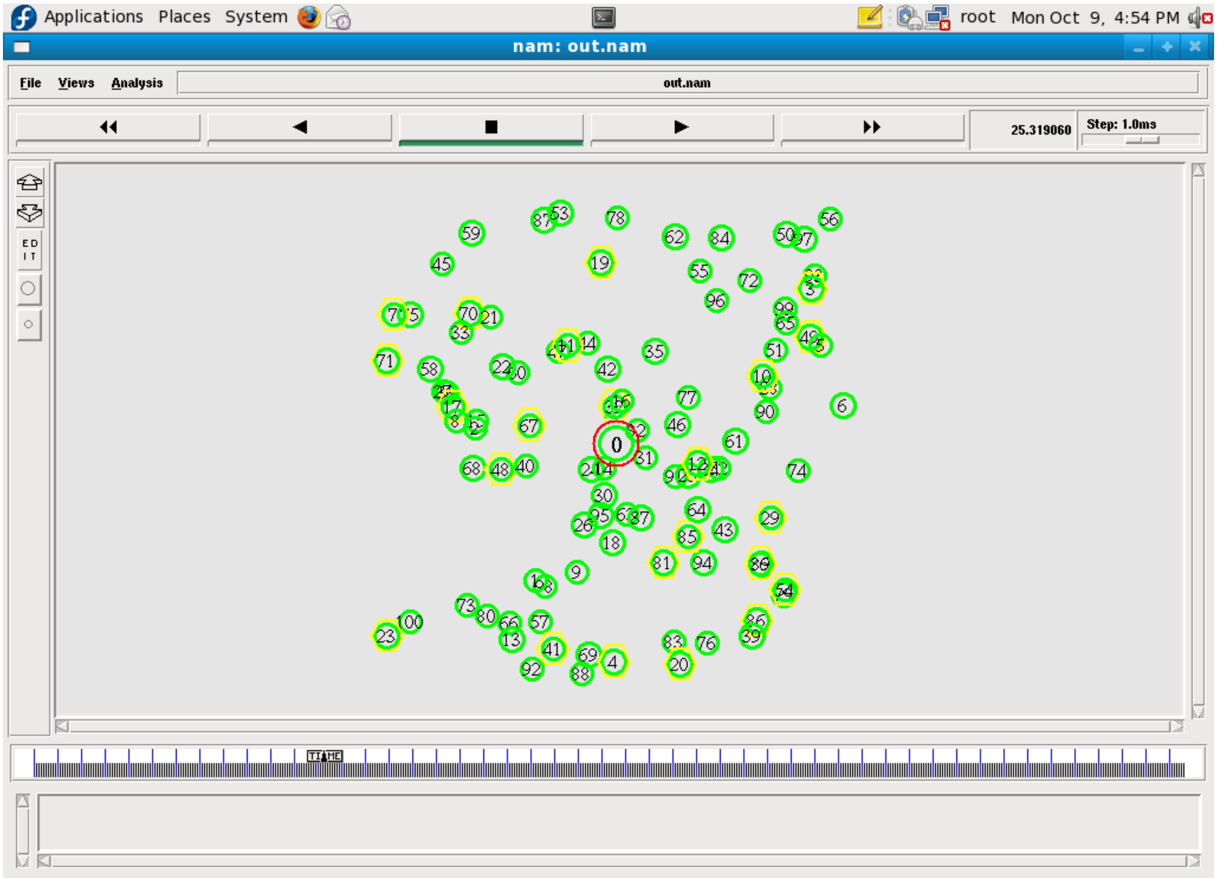

Fig.1 Network Animator window

4.2 Number of rounds Vs Number of Alive nodes

Fig.2 refers to the graph which is plotted between numbers of alive nodes with respect to the number of rounds. From the simulation, it is clearer that the EBRP protocol in mobile sensors is almost equal to the static sensors. It outperforms the existing LEACH protocol in terms of number of alive nodes. When the number of rounds increases, alive nodes get decreased.

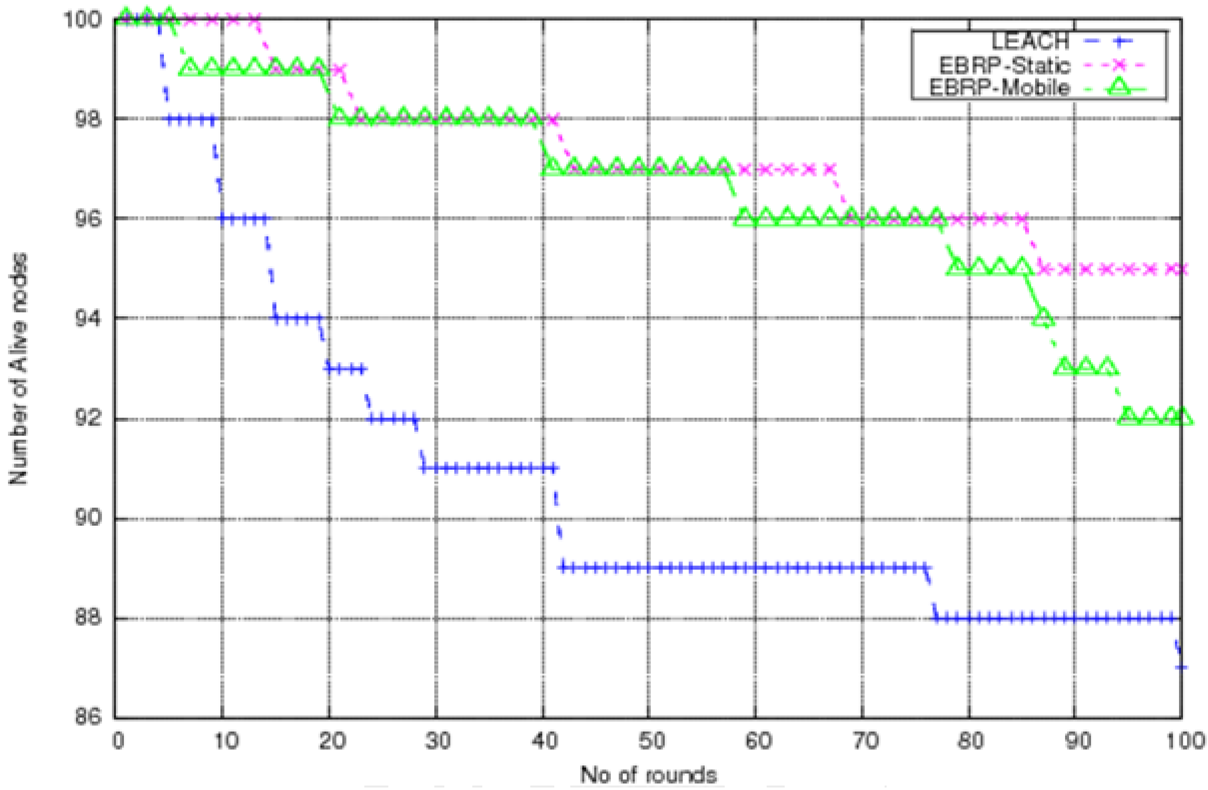

Fig.2 Number of rounds Vs. Number of Alive nodes

4.3 Number of rounds Vs End to end delay

Delay refers to the time span between the packet sent from the sensor node and packet received at the base station. It also includes the delay caused by route discovery process and the queue in data packet transmission. Only the data packets that successfully delivered to destinations that are counted. When the rounds increases, delay also increases. In this scenario, the delay can be plotted against number of rounds. Fig. 3 illustrates that the proposed EBRP-mobile and EBRP-static sensors have superior performance compared to LEACH protocol.

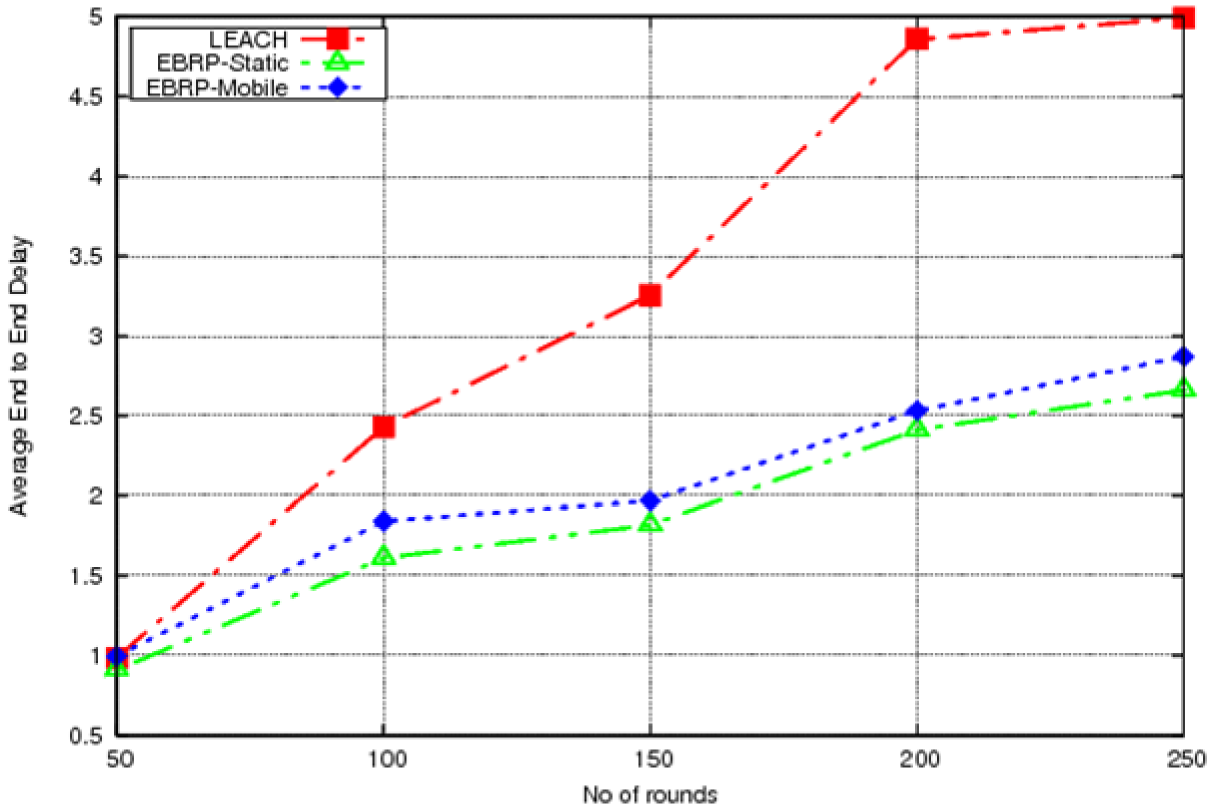

Fig.3 Number of rounds Vs. Average end to end delay

4.4 Number of rounds Vs Average Remaining Energy

Fig. 4 depicts that average remaining energy with the Number of rounds. It shows that the proposed EBRP is better when compared with the LEACH protocol.

When the round increases, the average remaining energy of the sensor nodes gets decreased. As the time increases (i.e.) the sensor nodes starts sensing from the instant of deployment, the energy of the sensors gets slowly decreasing with the increasing simulation time.

4.5 Number of rounds Vs Packet Delivery Ratio

Packet delivery ratio is defined as the ratio between the received packets by the destination to the generated packets from the source. When the packet delivery ratio is high, it refers that the protocols performance was good.

$$\text{Packet Delivery Ratio} = \frac{\sum \text{Number of packets received}}{\sum \text{Number of packets sent}}$$

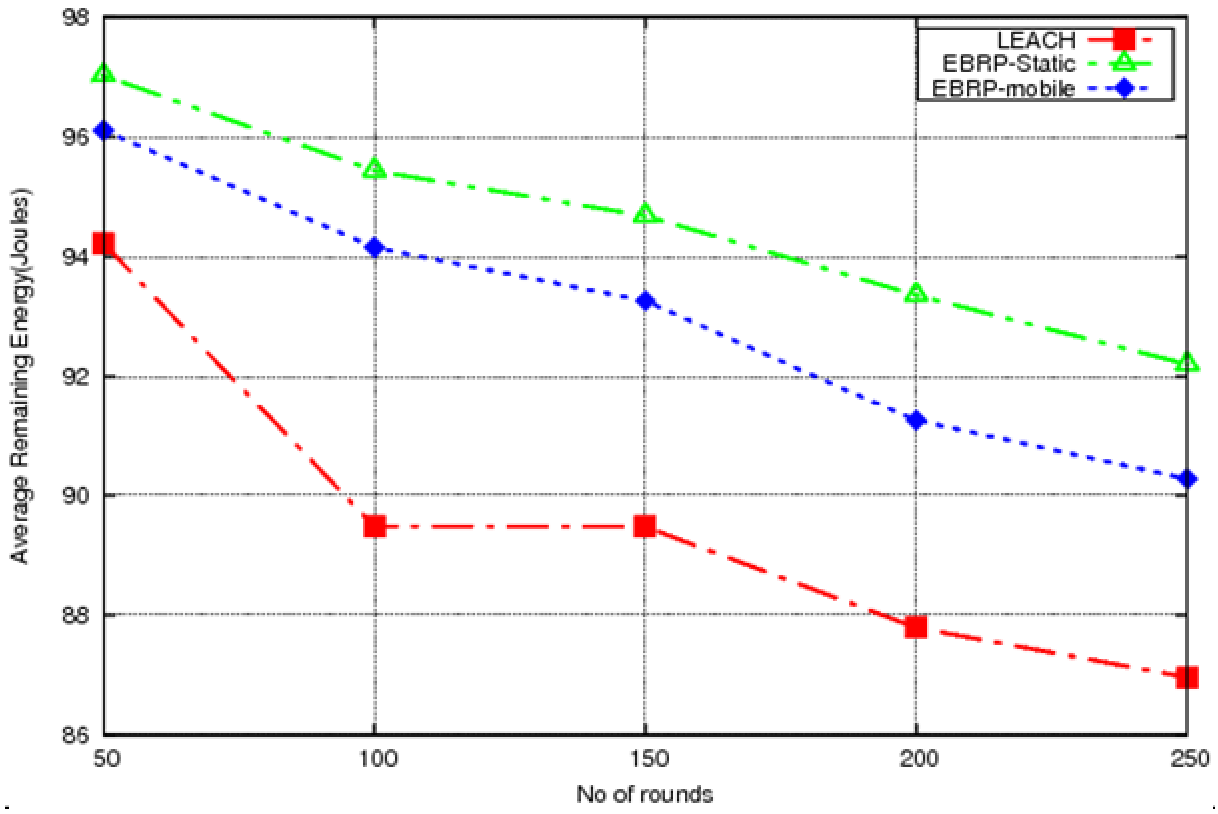

Fig.4 Number of rounds Vs. Average remaining energy

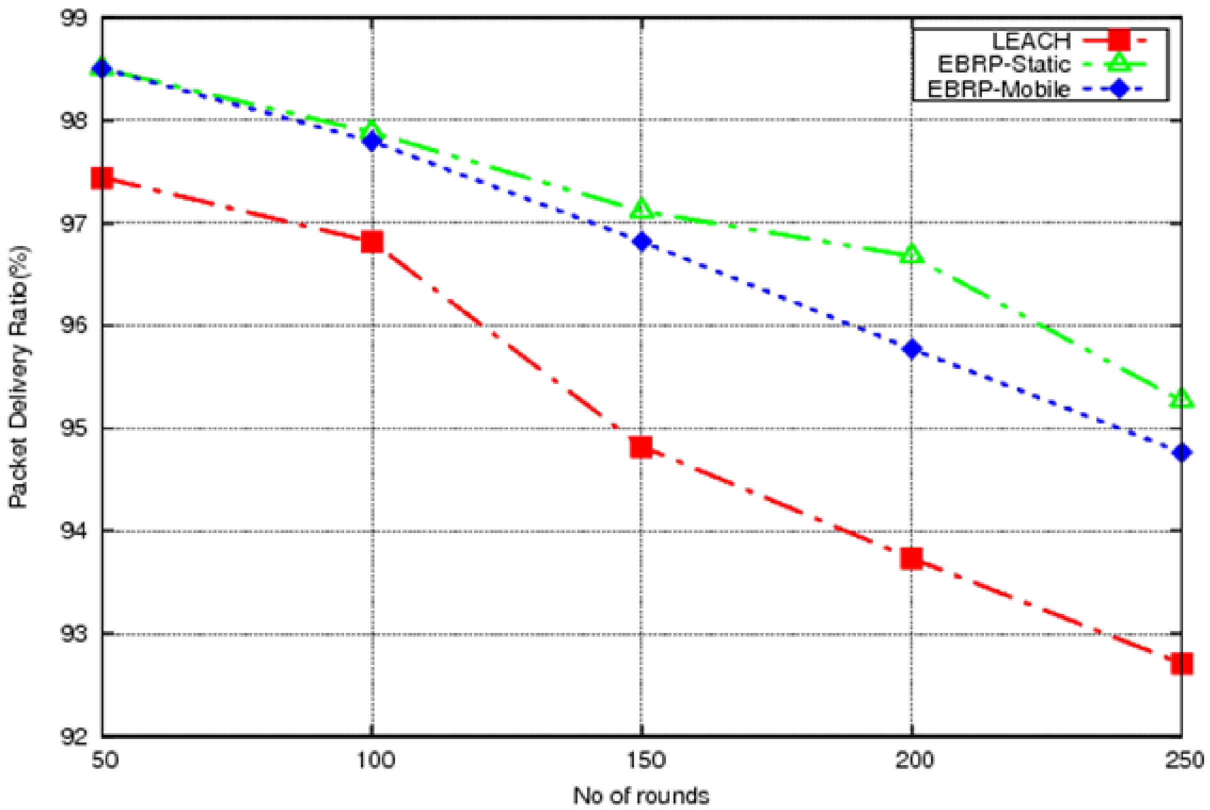

Fig.5 Number of rounds Vs Packet delivery ratio

From Fig. 5, when the number of rounds increases, packet delivery ratio gets decreased. However, the packet delivery ratio is almost maintained in the proposed EBRP protocol whereas in the case of Leach protocol it gets decreased with increase in number of rounds.

4.6 Number of rounds Vs Control Overhead

Generally routing algorithms generate small packets called as control packets. Control packets involves broadcasting messages and reply messages which helps to check that the neighbour node is active. The control packets does not carry data packets. Both, routing and data packets have to share the same network bandwidth most of the times and hence, routing packets are considered to be an overhead in the network. This overhead is called as control overhead. A good routing protocol should incur lesser control overhead.

When the number of rounds increases, control overhead also increases. The control packets used by the network increases as the rounds increases. Fig. 6 illustrates that the proposed EBRP protocol has lesser control overhead than the Leach protocol.

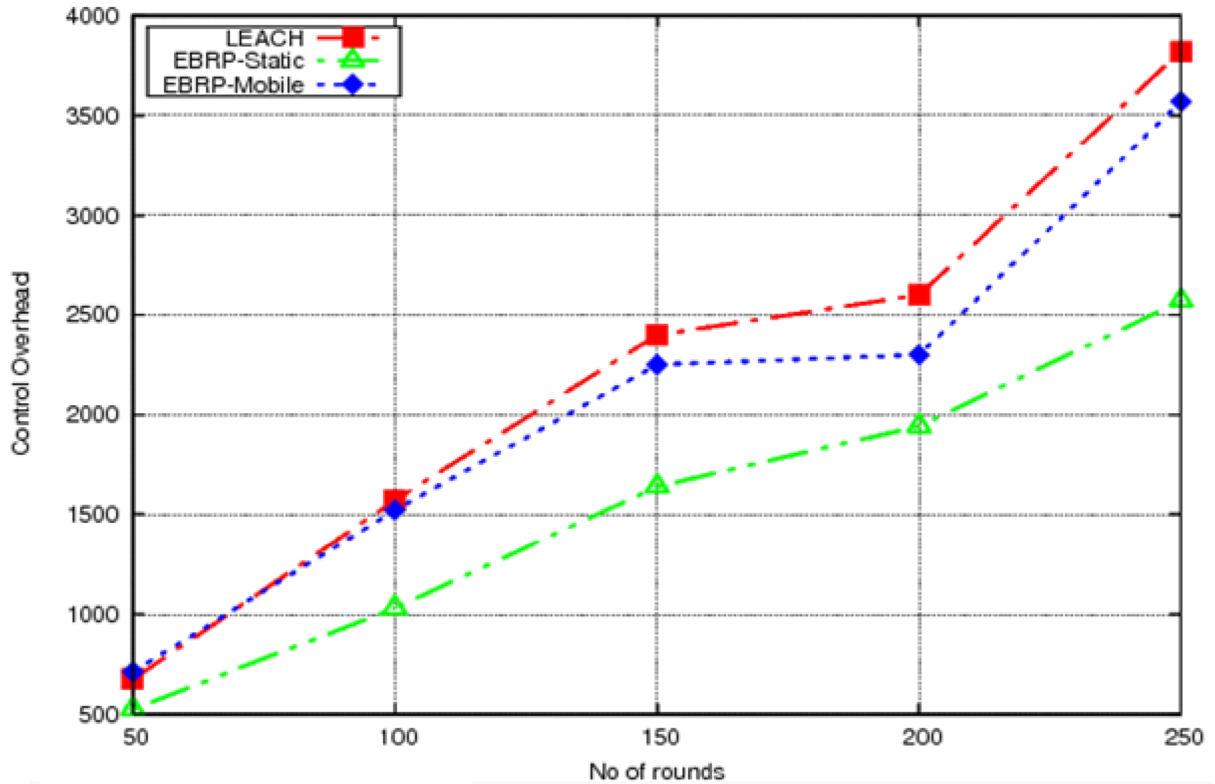

Fig.6 Number of rounds Vs Control overhead

5. Conclusion

Energy is the major factor in WSN. Though, energy saving is the difficult task in wireless sensor networks, it is very tough to achieve this target in Mobile sensors. The proposed method mainly focuses on selecting a suitable CH in a cluster for mobile nodes based on residual energy and also it appoints active node for close an event by making other nodes into sleeping mode. For forwarding witnessed information, it chooses shortest path in the routing table to reach destination. The simulation result reveals that the proposed system has better performance than other routing protocols in terms of alive nodes, end-to-end delay, energy efficiency and Packet delivery ratio.

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