Energy and Memory Efficient Routing Protocol (E&MERP) for Wireless Sensor Networks

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ENERGY AND MEMORY EFFICIENT ROUTING PROTOCOL (E&MERP) FOR WIRELESS SENSOR NETWORKS

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Abstract

Wireless Sensor Networks (WSNs) consist of sensor nodes with capabilities of sensing, computing, and communicating. But sensors have limited energy and memory capacity to perform the above operations. Therefore, using the available energy and memory efficiently is a challenging issue in WSNs. Clusters-based routing protocols are used to maximize network lifetime. In this paper, we propose a new combination of clustering and replacement algorithm to reduce energy consumption, extend network lifetime and improve throughput during frequent transmission. The proposed protocol, reduce energy consumption by finding the cluster head (CH) node with maximum residual energy, thereby preventing energy hole thus improving network lifetime, and manage memory by using replacement algorithm in case of buffer overflow. The simulation show the proposed protocol has longer network lifetime, increased data delivery than protocols like LEACH, LEACH-C, SEP and EEEHR protocols.

Keywords: Memory management, sensor networks, network lifetime

1. Introduction

Micro wireless sensors are used for sensing, wireless communication and information processing. These inexpensive and power-efficient sensor nodes works together to form a network for monitoring the target region. Sensor nodes collect and send various kinds of message about the monitored environment (e.g. temperature, humidity, etc.) to the sink node, which processes the information and reports it to the user. Wireless sensor networks have a wide-range of applications, including military surveillance, disaster prediction, and environment monitoring, and thus have attracted a lot of attention from researchers in the military, industry and academic fields. In wireless sensor networks, the sensor node resources are limited in terms of processing capability, bandwidth, battery power and storage space, which distinguishes wireless sensor networks from traditional ad hoc networks.

In most applications, each sensor node is usually powered by a battery and expected to work long without recharging. Hence the limited resource such as energy and memory are to be used efficiently, especially when sensors are densely deployed or frequent transmission occurs. Due to the high density, multiple nodes may transmit or receive data leading to high energy consumption and high memory storage which may result in reduction in network lifetime and throughput. For a sensor node, energy consumption includes three parts: data sensing, data processing, and data transmission/reception, amongst which, the energy consumed for communication is the most critical. Communication to the right next node is taken care by the CH and hence the choice of CH based on residual energy is very important. Hierarchical mechanisms using clustering are helpful to reduce data latency and increase network scalability, and they have been extensively exploited in previous works.

2. Related Works

Low-cost WSNs are made with large number of sensor nodes with limited energy, storage, transmission and processing facility [1]. All the physical and environmental characteristics like moisture, pressure, temperature, combustion, movement were monitored by these sensor nodes of WSNs which is used for different real-time applications like surveillance devices, monitoring weather, tracking of objects, healthcare management, disaster assistance, mapping of biodiversity, building rational behaviour, precautionary management, etc.

In unmanned, unattended and aggressive environment [2] like Warfield, nuclear plant, chemical industries, refineries, jungle field were monitored with the deployment of sensor nodes. In such scenarios, replacing the battery becomes a tough job. Base Station (sink) has affluent resources [3] with infinite storage, power and transmission capability which receives data from the sensor nodes of hard line environment.

Many of the routing protocols in WSN concentrate on increasing the lifetime and throughput of the network [4, 5 & 6]. The algorithm increases the lifetime by scheduling the communication module and limiting the number of bits sent through the communication module. The energy hole in WSN prevents communicating to the sink though the nearby nodes are capable of transmission. Increasing number of sinks and mobility of sink provides solution to the energy-hole problem [7].

The first hierarchical based routing protocol Low Energy Adaptive Clustering Hierarchy (LEACH) [4] was developed for WSNs. It has two phases; setup and steady-state phases. The LEACH routing protocol provides better lifetime and throughput when compared with layered architecture. [4] proposes an energy-efficient routing protocol with centralized clustering control called Low Energy Adaptive Clustering Hierarchy (LEACH-C) and it is a modification of LEACH protocol for WSNs. Based on the collected information and residual energy about each node in the network, the CH was centrally placed and the cluster was configured with other nodes in the setup phase of LEACH-C protocol. [8] proposed an algorithm related to LEACH, called Power Efficient Gathering in Sensor Information Systems (PEGASIS). These authors noticed that for a node, within a range of some distance, the energy consumed for receiving or sending circuits is higher than that consumed for amplifying circuits. In order to reduce the energy consumption of sensor nodes, PEGASIS uses the GREED [ ] algorithm to form all the sensor nodes in the system into a chain. According to its simulation results, the performance of PEGASIS is better than LEACH, especially when the distance between sensor network and sink node is far large.

A new clustering algorithm Cluster-based self-Organizing Data Aggregation (CODA) [9] proposed in order to relieve the imbalance of energy depletion caused by different distances from the sink. CODA divides the whole network into a few groups based on node's distance to the base station and the routing strategy.

Stable Election Protocol (SEP) [10] was designed to prolong the time interval before the death of the first node in heterogeneous network that is essential for many applications where the feedback from the sensor network must be reliable.

The authors proposed a Hybrid Energy-Efficient Distributed (HEED) clustering algorithm [11] which periodically selects cluster head according to a hybrid of the node residual energy and a secondary parameter such as node proximity to its neighbours or node degree. HEED terminates in O(1) iterations and incurs low message overhead. It achieves fairly uniform cluster head distribution across the network.

An unequal clustering size model [12] for network organization, can lead to more uniform energy dissipation among cluster head nodes, thus increasing network lifetime. Energy Efficient Clustering Scheme (EECS) [13] for Wireless Sensor Network with Mobile Sink which achieves good cluster head distribution with no iteration and introduces a weighted function for the plain node to make a decision, that which proper cluster should be joined.

Energy hole and hotspot problem are solved by modelling the recovery effect of the battery as proposed by Battery recovery based lifetime enhancement algorithm [7]. The CH is selected based on the battery voltage level as addressed in Fail Safe Fault Tolerant algorithm [14 & 15]. The battery voltage level is the vital parameter to calculate the node's residual energy. The energy consumed by the node depends on distance and number of bits transmitted to the receiver [6, 16 & 17].

The CH selection influences the network lifetime and throughput in WSN. Energy Efficient Energy Hole Repelling (EEEHR) [18] algorithm developed for Delay Tolerant

Wireless Sensor Network with static nodes, take care of energy hole and hotspot in the network which creates additional load to the nodes making the hole larger. The problem is solved by increasing clusters and reducing the CMs in the clusters near the sink. Forming clusters, reducing CMs and optimal election of CH are done with respect to the position of the sink and energy level of the node in the cluster. EEEHR is efficient in providing better network lifetime and delivery of packets to the sink.

In this paper, we propose Energy and Memory Efficient Routing Protocol (E&MERP) for WSNs. Here, a node with higher residual energy will have a large probability to become the cluster head. This can better handle heterogeneous energy circumstances than existing clustering algorithms which elect the cluster head only based on a node's own residual energy. When the CH is continuously used and the energy becomes equal to that of Cluster Members (CMs), node with higher residual energy and memory capacity will be chosen as CH. When there is a memory overflow, replacement algorithm is used and the new incoming packets are accommodated in the memory. With the increase in node density, this approach can guarantee that the network lifetime will be linear with the number of deployed nodes, which significantly outperforms the previous works designed for these applications.

The remainder of this paper is organized as follows: Section 2 describes the proposed protocol and section 3 presents the system model. Section 4 reports the result of E&MERP effectiveness and performance via simulations and a comparison made with LEACH, LEACH C and SEP. Section 5 outlines the conclusion and future work.

3. Proposed Model

E&MERP algorithm is proposed to increase the network life time by reducing the energy hole created because of repeatedly using the same node. More numbers of clusters are created near the sink compared to the numbers of clusters created far from the sink. The nodes nearer to the sink get easily overloaded because these are the major access to sink. The routing of data from the same cluster and from far away cluster makes the CH nearer to the sink to get drained of its major energy. The proposed approach in clustering takes distance to sink as a factor for forming clusters. The nodes nearer to the sink are loaded with its own cluster load and routing load, hence the clusters nearer to the sink are provided with less number of CMs and clusters away from the sink are having more CMs. The proposed algorithm increases the number of clusters near the sink, thereby equal sharing of load is done by all CHs and network lifetime is extended.

Initially the CH is selected based on the residual energy of the sensor node until the residual energy of CH node equals the energy of remaining nodes, and further selection of

CH depends on the number of times the node was a cluster head in earlier rounds of clustering process and memory availability of the sensor node.

Input: Initial Energy of advanced node & Normal node(E_1 & E_2), Residual Energy (RE),Distance with sink, Memory available
Output: Optimal Cluster Head (CH)

Begin process:
While( )
Initial_CH Selection
CH Selection_Memory

function Initial_CH Selection

if_1 ***cluster head one hop to the sink***
compute expected energy expenditure with intra cluster distance
elect node with low energy expenditure as Cluster Head
be a CH till node reaches level E_2
else

*if_2***($d>d_0$)**
compute the expected energy expenditure with distance to sink
elect node with low energy expenditure as Cluster Head
end if2

end if_1
end function

function CH Selection_Memory

if_3 **$RE_1 = E_2$ && memory_availability>>threshold**
compute energy expenditure based on distance to sink
elect node with low energy expenditure as Cluster Head

end if_3
end function

Fig.1 Pseudo Code for proposed routing algorithm

3.1 Node Deployment

In a heterogeneous network, all sensor nodes are static in nature and randomly deployed. All nodes have different battery capacity and the sink is powered with permanent source. The base station is deployed at a fixed place inside the region of interest. The distance between the nodes can be calculated by

$$d_{xy}= \sqrt{(x_x - x_y)^2 + (y_x - y_y)^2} \quad (1)$$

In this protocol, energy consumption model is considered to be free space model to transmit in omni-direction and it focuses on the energy consumed by the nodes for communication in the network. As described in Radio energy model, the equation (2) gives the energy consumed by node to transmit the data and equation (4) gives the energy consumed by the node to receive the data.

$$E_{tx}(k,d) = E_{elec}k + E_{fs}kd^2; \quad d<d_0 \tag{2}$$

$$= E_{elec}k + E_{mp}kd^4; \quad d>d_0 \tag{3}$$

$$E_{rx}(k) = E_{elec}k \tag{4}$$

where k is the number of bits, d is distance, E_{elec} is energy dissipated per bit to run the transmitter or the receiver circuit, E_{fs}, E_{mp} are energy dissipated per bit to run the transmit amplifier based on the distance between the transmitter and receiver and d_0 threshold range calculated by transceiver parameters.

3.2 Cluster Head Election

The energy remaining in each node is used to determine if the nodes can be used as a Cluster Member or Cluster Head. Node with higher residual energy can be used as Cluster Head and nodes below the range can be used as Cluster Members. This mitigates the issue of losing a node because of energy drain and thus improves the network life time. CHs consume energy while transmitting, receiving and data aggregation.

Assigning the weight to the optimal probability p_{opt} of the normal nodes and the advanced nodes as p_{adv}, as follows:

Weighted probability for normal nodes,

$$p_{nrm} = \frac{p_{opt}}{1+\alpha.m} \tag{5}$$

Weighted probability for advanced nodes,

$$p_{adv} = \frac{p_{opt}}{1+\alpha.m} * (1+\alpha) \tag{6}$$

During CH election, a node already existing as CH will not become CH for one epoch, i.e. 1/p round if the percentage of CH equals the nodes in the cluster. The threshold for normal nodes $g(t_{nrm})$ and the threshold for advanced nodes $g(t_{adv})$ to elect the CH in each round is given in equations 7 & 8

$$g(t_{nrm}) = \begin{cases} \frac{p_{nrm}}{1-\left(p_{nrm}*mod\left(r, round\left(\frac{1}{p_{nrm}}\right)\right)\right)}, & t_{nrm} \epsilon G' \\ 0, & otherwise \end{cases} \tag{7}$$

$$g(t_{adv}) = \begin{cases} \frac{p_{adv}}{1-\left(p_{adv}*mod\left(r, round\left(\frac{1}{p_{adv}}\right)\right)\right)}, & t_{adv} \epsilon G" \\ 0, & otherwise \end{cases} \tag{8}$$

where, G’ and G” is the set of nodes that has not acted as CH for normal nodes and advanced nodes.

The election probability of nodes ∈ G to become CHs increases in each round in the same epoch and becomes equal to 1 in the last round of the epoch. The decision is made at the beginning of each round by each node ∈ G’ and G” independently choosing a random number in [0,1]. If the random number is less than a threshold $g(t_{nrm})$ and $g(t_{adv})$ then the node becomes a CH in the current round.

Traffic Load is defined as the total number of packets handled by the particular node in a particular unit time period. Number of packets generated by the node and number of packets relayed by the node is the total number of packets handled. The load distribution for the above considered network scenario is given in [19] and the expected traffic load is expressed as

$$Traffic(r) = \frac{R^2-r^2}{2rh}\,\bar{O} \qquad (9)$$

where, R is the network area, r is all node deployed within the network area and having distance r ∈ (0,R), h is the mean hop length and $\bar{O}$ is traffic rate.

Now approximated traffic load function is given equation (10),

$$Traffic\ (r) = \begin{cases} \frac{R^2-r^2}{2rh}\,\bar{O}, & if\ \mathrm{r} \in (0, \mathrm{R}-\mathrm{h}), \\ \bar{O}, & if\ \mathrm{r} \in (\mathrm{R}-\mathrm{h}, \mathrm{R}) \end{cases} \qquad (10)$$

The energy consumption of the network is totally depended on the total traffic load of the deployed nodes. The node density ρ in the deployed area is given as:

$$\rho = \frac{n}{\pi R^2} \qquad (11)$$

The expected traffic load over the entire network nodes are estimated by substituting equation (10) & (11) is given below:

$$Traffic_{total} = \iint Traffic\ (r)\ \rho\ d\sigma \qquad (12)$$

$$= \int_0^{2\pi} d\theta \int_0^{R-h} \frac{R^2-r^2}{2rh}\ \bar{O}\ \frac{n}{\pi R^2} r\ dr + \int_0^{2\pi} d\theta \int_{R-h}^{R} \bar{O}\ \frac{n}{\pi R^2} r\ dr$$

$$= \frac{n\bar{O}}{hR^2} \int_0^{R-h} (R^2 - r^2)\ dr + \frac{2n\bar{O}}{R^2} \int_{R-h}^{R} r\ dr$$

$$= n\bar{O}\ [\frac{2R}{3h} + \frac{h}{R}\left(1 - \frac{2h}{3R}\right)]$$

$$Traffic_{total} \approx \frac{2R}{3h} n\bar{O} \qquad (13)$$

The energy consumption of each node mainly depends on the traffic load as derived in equation (13). Once the node with highest residual energy is chosen, memory is considered.

The replacement algorithm used in memory is First in First out (FIFO). To accommodate the packet that arrives at a router, the first packet is to be replaced. Given that the amount of buffer space at each router is finite, if a packet arrives and the queue (buffer space) is full, then the router discards that packet and throughput is decreased. In order to avoid this, the packets which came first are discarded and replaced with new incoming packets. This is done without regard to which flow the packet belongs to or how important the packet is.

3.3 Markovian model

Markovian model uses variables that are independent in nature. They are designed to represent systems which remember the past states of the system, dependence of some model of interest. Let X = {Xn} represents the past values that are non-Markovian but rely only on a finite "memory" the systems are considered as the Markov models

The role of the sensor node is modelled as FSM with SLEEP, CM & CH states. Figure 2 illustrates the FSM model of the E&MERP algorithm. The node which has a minimum energy cost among the participants is chosen as CH. The CH works for a period up to the waiting time of the sink. Once the CH transmits the data, then it claims the re-election and new CH will be selected. When the CM loses energy below the minimum value, then it goes into the sleep mode without disturbing the network operation. When the number of participants is less, the node which is in SLEEP condition participates as CM. The entire node in the cluster gets equal opportunity and equal load condition based on this modelling. The CH rotation reduces the loading effect, HOT SPOT issue and energy hole problem in the network. The FSM is realized using the Markov model. The node operation status is purely based on the current input energy level and cost. Hence the FSM is realized as Markov model. The probability of choosing x state to y state for n steps is given in Equations (14), (15), (16), (17) and (18).

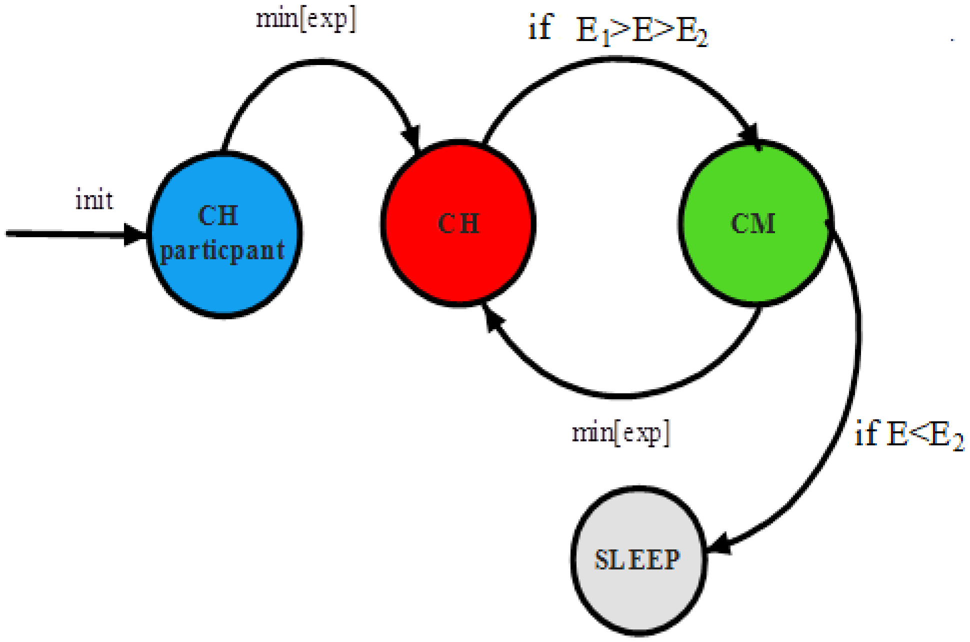

Fig. 2 Finite State Machine representation of E &MERP

The state transition of the FSM is purely based on present state and not on the historic past inputs. Hence Markov model is used to evaluate the state transition of the FSM. Probability of opting ***a*** state to ***b*** state for ***m*** steps is given in equation:

$$P_{ab} = P_r\left(P_m = b / P_0 = a\right) \quad (14)$$

The probability of single transition from ***x*** to ***k*** is given in :

$$P_{xk} = P_r\left(P_1 = k / P_0 = x\right) \quad (15)$$

The time-homogeneous Markov chain is illustrated in equation:

$$P_r\left(P_n = y\right) = \sum_{r \in s} P_{ry} P_r\left(P_{n-1} = r\right) \quad (16)$$

Generalized probability of choosing r steps is given in equation:

$$P_r\left(P_n = y\right) = \sum_{r \in s} P_{ry} P_r\left(P_0 = r\right) \quad (17)$$

The above equations represent the probability of choosing the next state by the node in the system model. The equation (18) represents the state transition matrix with state transition probabilities.

$$P = \begin{matrix} & S_1 & S_2 & S_3 \\ S_1 & P_{r11} & P_{r12} & P_{r13} \\ S_2 & P_{r21} & P_{r22} & P_{r23} \\ S_3 & P_{r31} & P_{r32} & P_{r33} \end{matrix} \quad (18)$$

The nodes in the network fall into anyone of the states S1, S2 and S3 representing CH, CM and SLEEP modes respectively. Pry represents the probability the nodes moves from one state to the next.

4. SIMULATION RESULTS

The proposed E&MERP compared with EEEHR, SEP, LEACH and LEACH-C algorithms. The proposed algorithm is implemented with 200 nodes and simulation parameters are as given in Table 1.

Table 1 Simulation Parameters

Parameters	Value
Network Size	200 x 200 m^2
Nodes Count	200
location of base station	(100,100)
E_e	50nJ/bit
E_f	10pJ /bit-m^2
Initial Energy	1 Joule
Probability of becoming as cluster head	0.1
Size of Data message	4000 bytes
Header Size	270 bytes
Memory	2 Mb
Data Rate	250 kbps

The distribution of theoretical traffic load is calculated for small network size and low density of the nodes. The experimental traffic load for the same is even and coincides with the theoretical experiments is shown in Fig.3.

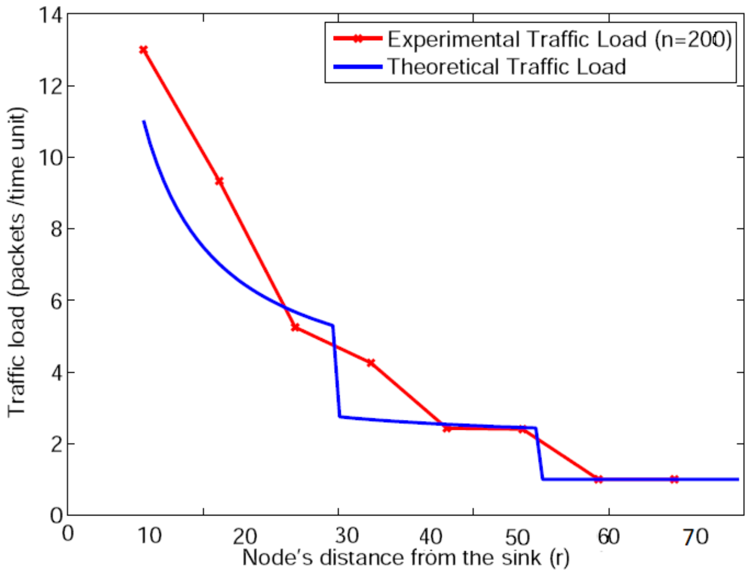

Fig.3 Distribution of Traffic Load in a network where n=200, with disk area radius R=100 with one hop distance to the sink.

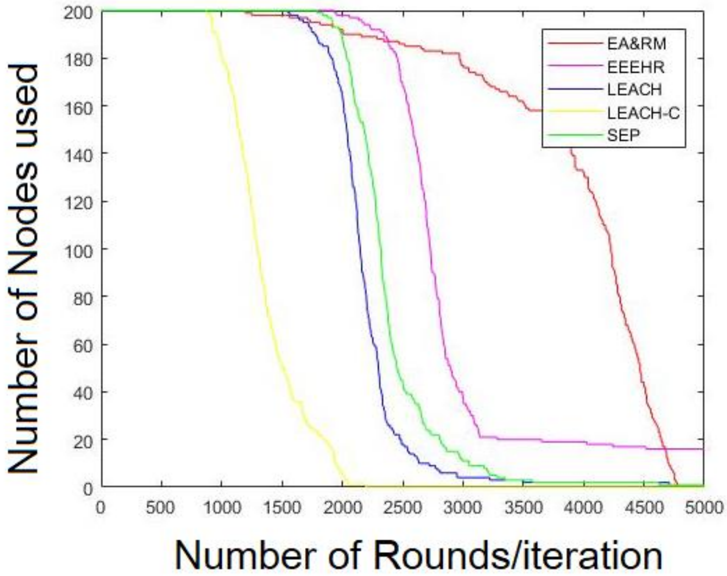

Fig. 4 Network Life time

From Fig.4, it is shown that the proposed algorithm performs better than the existing EEEHR, SEP, LEACH, LEACH-C algorithms by surviving more number of rounds.

The Fig.5 shows the network lifetime of E&MERP for different values of m and alpha, where m represents the percentage of advanced nodes in the network and alpha represents the number of times the energy of advanced nodes is higher than normal nodes. The plot indicates that, as the percentage of advanced nodes and energy level of advanced node is increased the network lifetime of E&MERP is also increased.

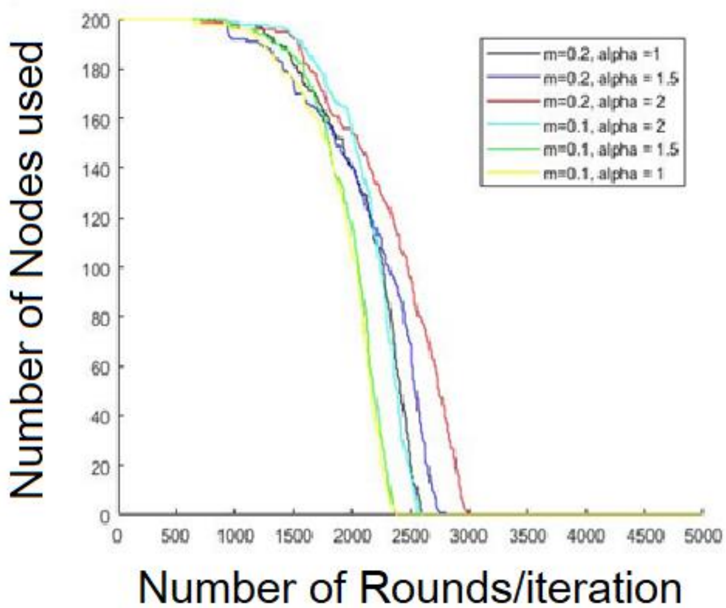

Fig.5 E&MERP lifetime metrics for various m and alpha

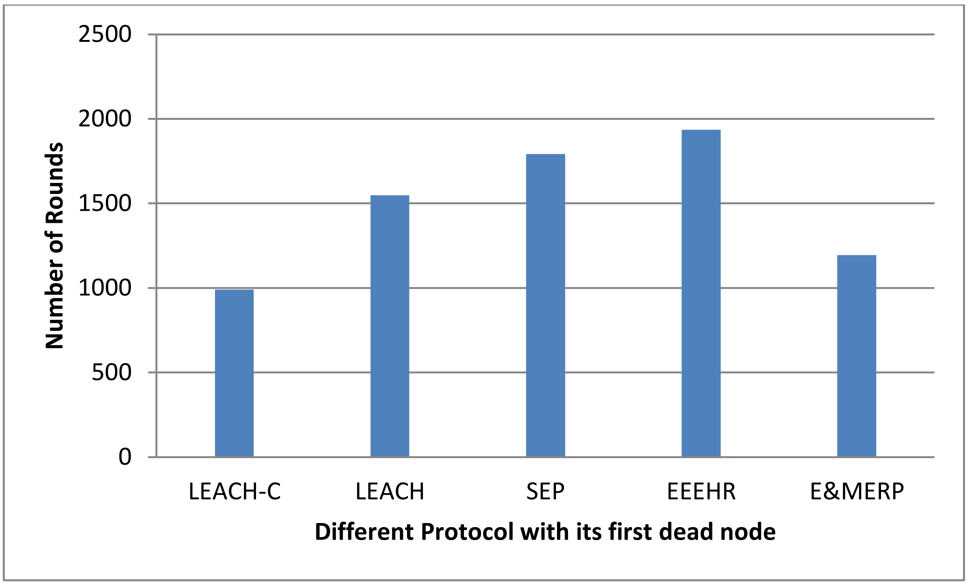

Fig.6 First Dead Node

Fig. 6 illustrates the First Dead Node (FDN) and Fig. 7 illustrates the Half Node Alive (HNA) of the proposed, EEEHR, LEACH, LEACH-C and SEP algorithms. The proposed E&MERP algorithm outperforms the compared algorithms providing good survivability.

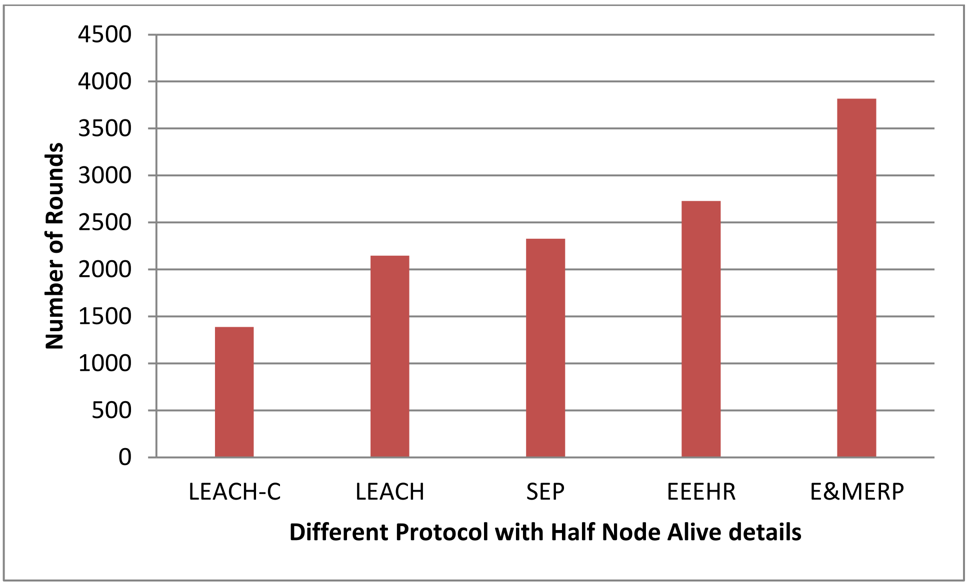

Fig. 7 Half Node Alive

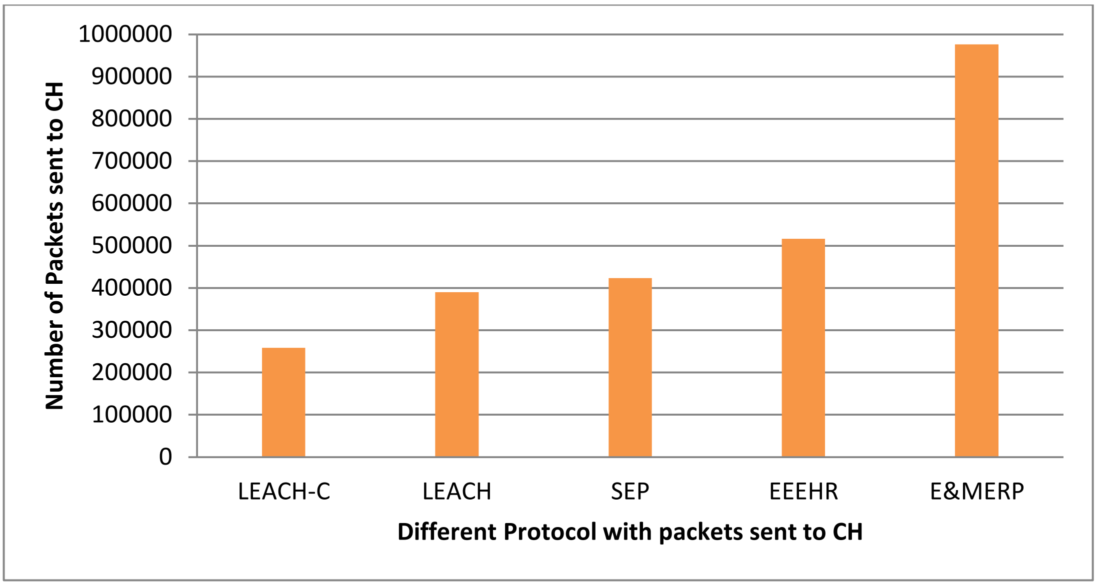

Fig.8 Packets Sent to CH

Fig.8 illustrates the number of packets sent to CH and Fig. 9 shows the packets sent to BS of the proposed, EEEHR, LEACH, LEACH-C and SEP algorithms. The proposed E&MERP algorithm outperforms the compared algorithms.

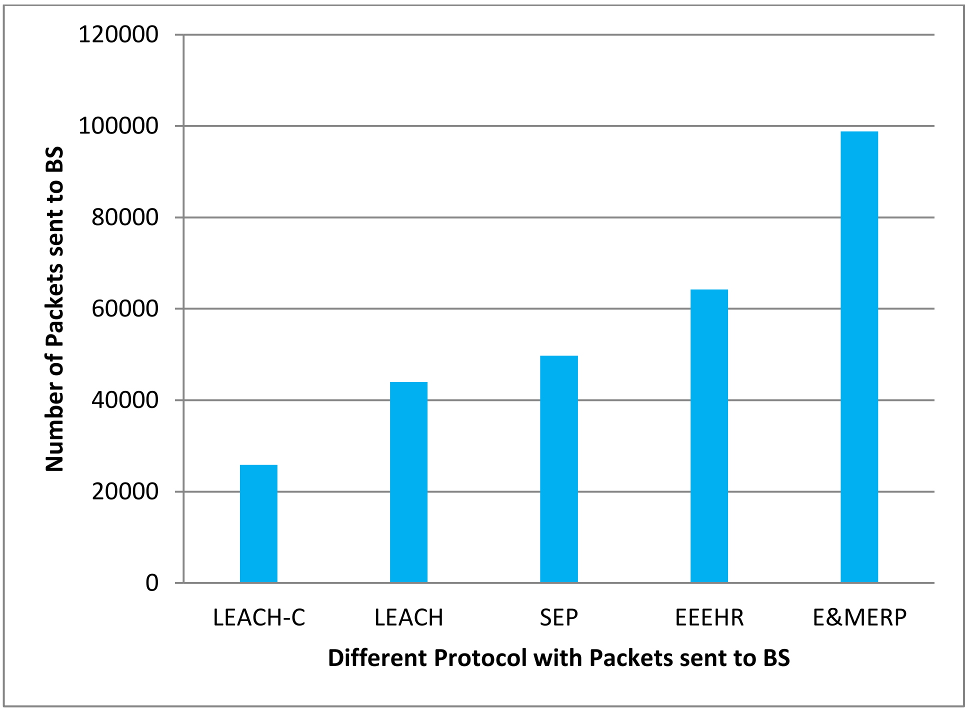

Fig. 9 Packets to BS

5. Conclusion

In this paper, E&MERP for WSN was proposed and evaluated using MATLAB. Simulation results show that E&MERP provides improved network life time and increased data delivery. Energy hole and hotspot inside the network creates additional load to the nodes making the hole larger. The problem is solved by keeping smaller clusters near the sink and larger clusters far from the sink in the network. The proposed algorithm provides better clustering and reduces the energy hole when compared to other LEACH, LEACH –C, SEP and EEEHR algorithm. The proposed algorithm provides better lifetime and throughput to the network. E&MERP serves to be a novel solution for the energy problem and buffer overflow currently faced by the network. Performance analysis of network for various mobility models could be done as future work.

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