Energy Optimized Cluster Based Heterogeneous Routing Protocol for Wireless Sensor Network

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***Abstract*—The technological advancements in sensing technology has made it possible to produce small sized sensors, which can monitor the surroundings and report at the base station through data transmission. The wireless nature of sensor network has proliferated the requirement for effective utilization of the battery of sensor node. It is due to the fact that once the battery of sensor node is exhausted, a node is said to be dead. Considering the prospect of energy conservation, an energy-optimized cluster based on heterogeneous routing (EOCHR) protocol is proposed. The selection of Cluster heads (CHs) in the clustering process adopted for routing among the sensor nodes is improved by introducing the node density along with energy and distance. The circular radius as defined in DRESEP and SEECP protocol is defined on the basis of the average distance of nodes from the sink. It reduces the energy consumption incurred by the far placed CHs. Simulation results show that the proposed EOCHR outperforms the DRESEP and SEECP protocol by enhancing the stability period by 31% and 166% respectively and the network lifetime by 440% and 158% respectively. It is highly suitable for large area networks due to dual hop communication in the network.**

***Index Terms*— Cluster Head selection; DRESEP; Dual Hop Communication; EOCHR; Heterogeneous WSN; SEECP.**

I. INTRODUCTION

Wireless Sensor Networks (WSNs) have been significantly developed for large area network, such as various environmental operations, smart battlefield, traffic monitoring, agricultural operations, etc [1]. The spatial distribution of sensor nodes helps covering the monitoring area for data collection. These sensor nodes have some particular sensors embedded onto their platform. These sensors are attributed to the applications, for which the sensor node is used. The applications of sensor network are limited by imagination, in which some of them include industry, agriculture, military operations, environmental monitoring, etc. [2]. However, the major hindrance in exploring the applications of WSNs is caused by the limited battery power of a sensor node.

Basically, sensor nodes have four components, namely the processing unit, power unit, transceiver unit and sensing unit, as shown in Figure 1. The energy of a sensor node is mostly consumed while its communication with the other sensor nodes or with the base station. The communication is made efficient by defining the energy efficient routing strategies. The cluster-based routing has its significance as it provides the scalability facility to the WSN i.e. the number of nodes can be added without disturbing the whole topology of the network. It is to be observed that WSNs are not centralized as they are involved in peer-to-peer communication between the nodes. The architecture of WSN is shown in Figure 2.

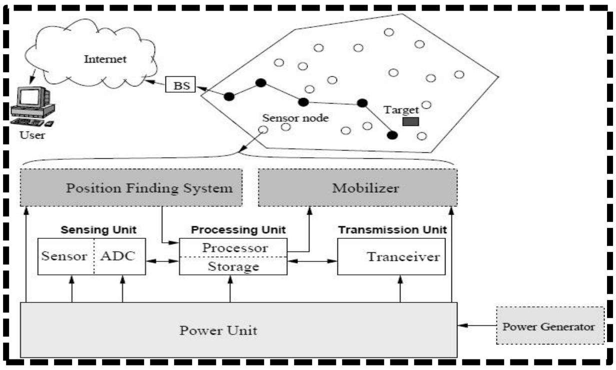

Figure 1: Components of a sensor node [2]

The nodes are connected and send data to the sink/ Base Station. From there the data is forwarded to the user via Internet. WSN provides scalability as it makes the network flexible so as there be nodes added and removed from the network.

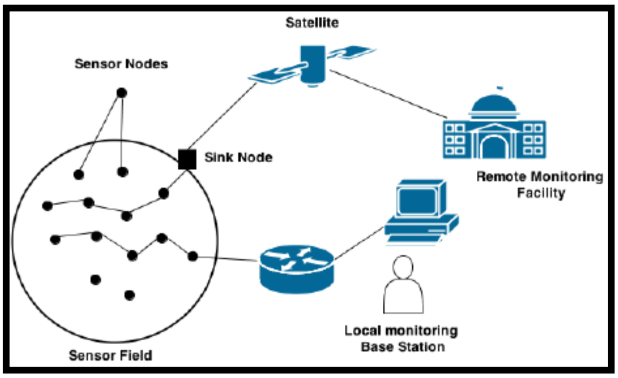

Figure 2: Architecture of Wireless Sensor Network [2]

One of the primary objectives of WSN is to enhance the network lifetime while making the data communication as efficient as possible. By applying energy management techniques, connectivity degradation is prevented. There are various factors that influence the various challenging factors. Further, these factors must be overcome to achieve efficient communication. Routing is a significant factor in enhancing the network lifetime of WSN. There are three types of routing in WSN:

a. Flat Routing – The flat routing is the type of routing in which all the sensor nodes play the same role such as sensing, collecting data and communicating with the sink. It is impractical to issue a global identifier to each node because there are a large number of nodes deployed in the network. So, data centric routing is done where the base station transmits queries to the specific region and waits for reply from the sensor nodes in that specific region. SPIN is an example of such type of routing.

b. Hierarchical Routing – Hierarchical routing is originally designed with various advantages related to efficient communication and scalability. The concept of this type of routing is used to perform energy aware routing in wireless sensor network. In this routing, all the sensor nodes are clustered. Cluster head (CH) is the one of the member nodes of the cluster, but it has the load of forwarding the data to the Base Station (BS). The Cluster Head collects and aggregates the data and checks for redundancy of the data collected, before it is sent to the sink. This saves communication and processing work and also saves energy. LEACH, PEGASIS and TEEN are the examples of hierarchical routing.
c. Location based Routing – All the sensor nodes are addressed by using their locations. Depending upon the strength of the incoming signals, it is possible to calculate the nearest distance of the neighboring node. GAF, GEAR and MECN are the protocols categorized under the location-based routing.

There have been various clustering algorithms developed so far working in the same direction of achieving the high network stability [3]. The CH selection is a NP hard problem as there is always a scope for the optimization of the CH selection by exploring the different dependent factors. This paper focuses on the routing algorithms developed in the heterogeneous network by proposing a new and advanced CH selection. The multi hop communication is much better than a single hop communication in large area network as it avoids the energy depletion due to the long haul communication. However, the hot spot problem arises due to data transmission through relay node [4]. Therefore, the selection of relay node i.e. the relay CH becomes highly significant. The existing clustering strategies [5] have many shortcomings such as low network lifetime compatibility with heterogeneous network [6], poor stability period [7], delay involved [8], problems with large scale WSNs [9], avoidance of factor of residual energy [10], overhead and energy coverage [11] and unbalanced network lifetime [12].

The organization of paper is given as follows. Section 2 discusses the related work done in the heterogeneous WSNs for the CH selection. The problem is defined in section 3. The proposed protocol EOCHR is given in section 4 and the results and discussions are highlighted in section 5. The paper is concluded in section 6 with the directions for future research and thereafter references are listed.

II. Related Work

The sensor network is basically operated in two modes, homogeneous and heterogeneous. In this paper, the energy heterogeneity is taken into consideration; therefore, this literature review mostly focuses on the heterogeneous routing protocols that enhances the CH selection in one or another way. SEP [13] was the first protocol that works for energy heterogeneity at two levels. However, it failed to operate for multi-level. The CH selection was done on the basis of different weights defined for energy factors. DEEC [14] worked with the consideration of ratio of residual energy to the initial energy of the network. Although it improved SEP protocol, it leads to a problem of penalization of advanced node due to their frequent CH selection. DDEEC [15] helped in this context as it only avoided penalization although it improved network lifetime by defining the same threshold concept for every types of nodes. EEHC [16] worked for three levels of heterogeneous nodes by considering the energy factors for CH selection. However, it still faced some shortcomings due to the penalization of higher energy nodes for the same reason as discussed for DEEC at the two levels. BEENISH [17] was introduced for four energy levels heterogeneity and was considered as energy factor for CH selection. Since it faced the same penalization due to the higher energy nodes, it was resolved in I-BEENISH [18], which resulted in the sink mobility in the network for data collection.

The main concern to be emphasized in this paper is that the selection of CH has been mainly on the energy factors. Some of the research works in heterogeneous WSN have focused on the distance factor included in the CH selection [19]. DRESEP [20] considered the distance factor along with the energy for CH selection. It improved stability period better in comparison to the TSEP [21] and SEP protocols. TSEP protocol worked for the event driven application based on some thresholds, termed as the hard and the soft threshold. DRESEP is also an event driven protocol. The CH selection for DRESEP was further improved in the extended version of DRESEP with protocol SEECP documented in another paper [22]. The shortcomings of DRESEP and SEECP are discussed further in Section 3. SEECP basically worked on the deterministic model for the CH selection and it fixed the number of CHs in the network.

III. Problem Definition

Wireless sensor network has been making a tremendous growth in the conservation of energy in the past few years. The limited battery resources have drawn the focus of various researchers on making the routing as efficient as possible. Routing has to be made efficient to utilize the battery resources in the most efficient way. Clustering helps to preserve the battery resources. The most prominent advantage of clustering is the enhanced scalability of the network. There have been various cluster head selection techniques on the various criteria, such as residual energy, distance to the BS and many others. In order to implement dual hop communication in the case of DRESEP and SEECP, the chosen relay CH was based on the nearest CH, ignoring the distance from the BS. It enhances the energy depletion of the nodes. The performance comparison of the DRESEP and the SEECP is given below.

A. DRESEP:

The characteristics of DRESEP protocol are listed as follows:

a. It considers the residual energy and distance from BS for CH selection.
b. It is fully distributed and does not require global knowledge of network.
c. It is scalable due to multi hop communication.

The following are the pitfalls suffered by DRESEP:

a. Stability period is reduced due to the fact that low energy node may become CH.
b. It employs weighted election probability for CH selection, thus normal node may die first, thereby

reducing network lifetime.

c. The high energy variance of nodes in DRESEP leads to improper CH selection, thereby reducing stability period.

B. SEECP

The characteristics of SEECP protocol are listed as follows:

a. It explores deterministic model for CH selection as compared to the threshold-based selection in other protocols, thereby reducing the uncertainties in CH selection.
b. It uses multi hop communication by determining radius R for the region by using geometric theory.
c. The number of CHs has already been predefined with 5% of the total nodes.

The following are the pitfalls suffered by SEECP:

a. The CH selection is entirely based on the residual energy, which is an inefficient approach. The other factors, such as the Distance and the Node Density are not considered.
b. There is no mechanism to determine whether the CH is located outside R that calculates its distance first from the relay CH and BS before sending the data to any of them rather than sending the data to relay CH irrespective of its distance.
c. The radius R is calculated based on geometric theory and it does not consider the random deployment of nodes, making it energy efficient.

IV. Proposed Protocol: Energy Optimized Cluster Based Heterogeneous Routing Protocol (EOCHR)

The protocol considers the three energy levels of nodes; incorporating normal nodes, intermediate nodes and advanced nodes.

A. Working Process

The implementing scenario of EOCHR follows the following steps.

a. The proposed network scenario starts with the deployment of heterogeneous network, including heterogeneous nodes and BS in the middle of the network. The fundamental radio parameters are identical to the ones, which are used in the other routing protocols. In this phase, the energy values are defined to the nodes.
b. To make the network functioning, energy of nodes is checked if it is not zero, otherwise the node is said to be a dead node. Thereafter, the dead nodes are checked: If the number of dead nodes is equal to the total number of nodes taken initially (if it happens), the whole network is said to be dead. Henceforth, the network stops functioning.
c. If the energy of a node is not zero, it goes through the set up and steady state phase. These phases are presented in Figure 3 and explained as following.

B. Setup Phase

In this phase, the selection of Cluster Head is done on some parameters. In the proposed work, the node density parameter is to be incorporated along with the energy and distance.

i. Node density parameter ensures the reduced effective communicative distance between the cluster members and the CH.
ii. As shown in Figure 3, with the use of three parameters, the probabilities are calculated for each type of nodes. Normal nodes, intermediate nodes and advanced nodes will have different probabilities due to their different energy resources. Thereafter, the threshold is calculated for each type of node.
iii. Simultaneously, a random number (Rn) is generated. Then Rn value is compared with the threshold value computed for each node. If Rn<threshold calculated, then a node becomes CH; otherwise, it is a cluster member.

a. Selection of Cluster Head

The main concern has been the changes in the probabilistic formula of CH selection that every researcher has been targeting. D(i) is the distance of a node from the BS. Davg is the average distance of all the nodes from the BS. The CH selection of the proposed protocol follows the following Equations (1-8).

$$D(i) = \sqrt{(D_x(i) - Sink_x)^2 + (D_y(i) - Sink_y)^2} \quad (1)$$

$$Davg = \left(\frac{1}{n}\right) \times \left(\sqrt{(D_x(i) - D_x(j))^2 + (D_y(i) - D_y(j))^2}\right) \quad (2)$$

$$P_N = \frac{P}{(1 + m\alpha + m0\beta)} \quad (3)$$

$$P_{IN} = \frac{P(1+\beta)}{(1 + m\alpha + m0\beta)} \quad (4)$$

$$P_{AN} = \frac{P(1+\alpha)}{(1 + m\alpha + m0\beta)} \quad (5)$$

$$T(n_N) = \left\{ \frac{P_N}{1 - P_N(r \bmod \frac{1}{P_N})} \frac{D(i)}{D_{avg}} \times \left[\frac{E_{CNT}}{E_{MAX}} + (r_s \operatorname{div} \frac{1}{P_N})(1 - \frac{E_{CNT}}{E_{MAX}}\right] \times N_D \right\} \quad (6)$$

$$T(I_N) = \left\{ \frac{P_{IN}}{1 - P_{IN}(r \bmod \frac{1}{P_{IN}})} \frac{D(i)}{D_{avg}} \times \left[\frac{E_{CNT}}{E_{MAX}} + (r_s \operatorname{div} \frac{1}{P_N})(1 - \frac{E_{CNT}}{E_{MAX}}\right] \times N_D \right\} \quad (7)$$

$$T(A_N) = \left\{ \frac{P_{AN}}{1 - P_{AN}(r \bmod \frac{1}{P_{AN}})} \frac{D(i)}{D_{avg}} \times \left[\frac{E_{CNT}}{E_{MAX}} + (r_s \operatorname{div} \frac{1}{P_N})(1 - \frac{E_{CNT}}{E_{MAX}}\right] \times N_D \right\} \quad (8)$$

It is to be noted that in Equation (1-2), the distance of a node from the sink is computed whilst considering the Cartesian coordinates of the corresponding node and sink. The nodes become aware of these coordinates with the help of the Received Signal Strength Indicator (RSSI). Moreover, the sink also broadcasts the IDs received from all nodes to the network.

In Equations (3-5), the probabilities for normal node, intermediate node and advanced node are shown by P_N, P_{IN}, P_{AN} respectively. The threshold formula for normal node, intermediate node and advanced node is shown by $T(n_N)$, $T(I_N)$, $T(A_N)$ respectively, as shown in equations (6-8). These threshold values are compared with the random number. For a node, if the random number is less than the threshold value generated, the node is selected as Cluster Head; otherwise, the node is a normal node.

C. Steady State Phase

In this phase, the data transmission is performed. It follows the following steps.

i. After the selection of CH, the average distance of all the nodes from the BS is computed. On this average distance, which is termed as Radius (R), the communication is decided to be a single hop or dual hop communication.
ii. Thereafter, the distance of CH is computed from the BS. If it is more than R, then the CH forwards the data to the nearest CH that lies within R; otherwise, it sends the data directly to the BS.

D. Network Assumptions

There are some network assumptions, which are taken into consideration while implementing the proposed protocol in the simulator.

i. The network is static i.e. all the nodes and Base station are stationary in nature. Their deployment is random and the battery is irreplaceable.
ii. The nodes are connected to each other and once the battery of any node is drained, a node is said to be dead. At that moment it gets disconnected from the network.
iii. The energy consumption takes place according to the radio energy model, which is used fundamentally in all the routing process of WSN.

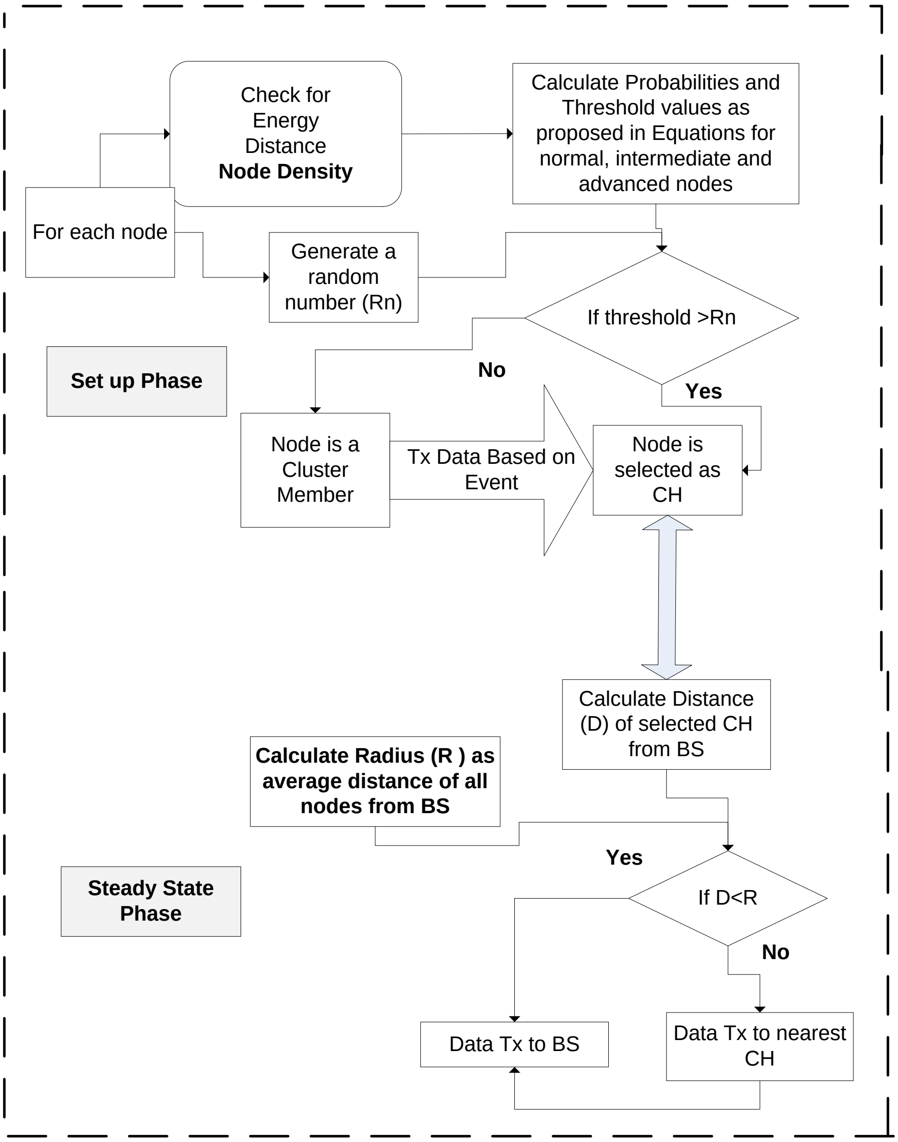

Figure 3: Flow chart for the set up phase and steady state phase

iv. The Base Station has no constraint on its energy resources. It is only the nodes whose energy monitoring is done while data transmission.
v. The other interferences of signal due to obstacles or some other environmental factors are not taken into consideration.
vi. The nodes are location unaware i.e. they do not have GPS installed on their platform.

E. Radio Energy Model

This model deals with the minimum energy dissipation that is encountered when a sensor node communicates with the other node. A sensor node sends the data packet of k bit size by using its transmitter circuitry. The energy being consumed for the data transmission among the nodes is given by the Equations (1) and (2). As the equations indicate that the consumption of energy is directly proportional to the distance between the nodes. Equation (1) gives the equation when the distance is less than a threshold distance.

$$Etx(k,d) = kEelec + kEefsd^2 \text{ for } d<d_o \quad (9)$$
$$Etx(k,d) = kEelec + kEefsd^4 \text{ for } d > do \quad (10)$$

where d is the distance between the two nodes or between node and sink, and the threshold distance is represented by d_o. The reception of message drains the energy by following the Equation (11).

$$Erx(k) = kEelec \quad (11)$$

For merging the m messages, the energy consumed is given by Equation (12).

$$Edx(k) = mkEda \quad (12)$$

In Equations (9-12), E_{tx} is the energy consumed in the transmission of l bit data at distance d, E_{efs} is the energy used in free space model, E_{rx} is the energy consumed in receiving l bit data, E_{da} is the energy consumed in data aggregation and for l bit data and E_{dx} is the represented by m number of packets the total energy consumed in data aggregation. The simulation for the EOCHR is discussed in the following section.

V. Simulation and Discussions

The simulation analysis was done in MATLAB version 2013a. The initial energy of normal nodes was 0.1 J. The advanced fraction used was a=2, fraction of number of advanced nodes was m=0.2 to that of normal nodes and intermediate nodes have energy fraction b=1.5. The number of intermediate nodes are with the fraction of m0=0.2 to that of normal nodes. The considered number of normal nodes was 70 and the advanced nodes were 10 in number containing three times energy to that of E_0. The number of intermediate nodes was 20, which are considered as two times energy to that of the normal nodes.

There are following performance metrics are defined for the EOCHR protocol.

i. Stability period: It is defined as the number of rounds covered or the interval covered until the first node is dead. It confirms the reliability of the network as it gathers data from the network when it is fully functional.
ii. Half Network Dead: It is used to inspect the efficiency of the network. If the network covers more rounds until the 50 nodes are dead, it is said to be more energy efficient.
iii. Network Lifetime: It is defined as the total lifecycle of the sensor nodes while they are in operations or until none of the node is left alive. It is significant for those applications where the data is required for longer interval and some loss of data can be compromised.
iv. Network Remaining Energy: The remaining energy of the network is checked after each round and is traced to check the overall rate of energy depletion.

When the protocol was simulated in MATLAB, the dead nodes analysis is shown in Figure 4 and alive nodes analysis is shown in Figure 5 respectively.

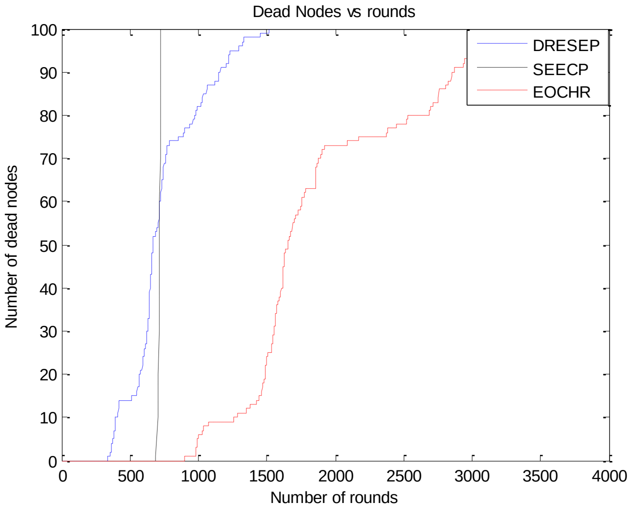

Figure 4: Dead Nodes vs Rounds

It is observed that the EOCHR enhanced the stability period by 31% and 166% as compared to the SEECP and DRESEP protocols respectively. It was due to the node density factor inclusion in the CH selection. Due to which the CH selection was made efficient by reducing the effective distance of nodes from the CH. The remaining energy of the network in the case of EOCHR covered much higher number of rounds as compared to the DRESEP and SEECP protocols, as shown in Figure 6. It was due to the even energy balanced consumption in the network.

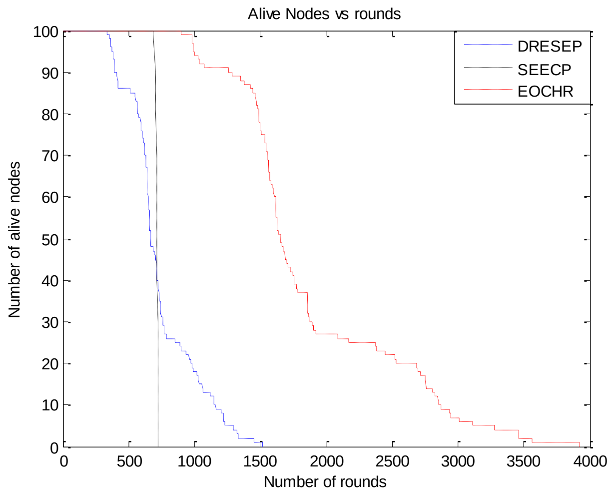

Figure 5: Alive Nodes vs Rounds

The stability period of EOCR was at 898 rounds whereas it was 685 and 337 rounds in case of SEECP and DRESEP protocols respectively as shown in Figure 7 (a). The half network dead was also improved in the proposed protocol as compared to DRESEP and SEECP protocols, as shown in Figure 7 (b). It also enhanced the network lifetime enormously by 440% as compared to the SEECP protocol and 158% to that of DRESEP protocol, as shown in the Figure 7 (c).

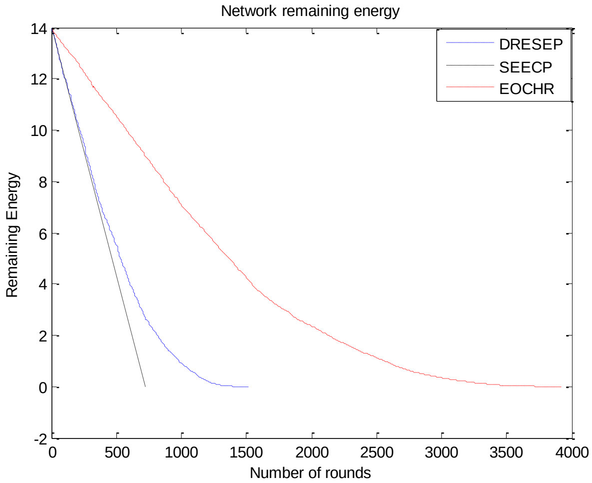

Figure 6: Network's remaining energy

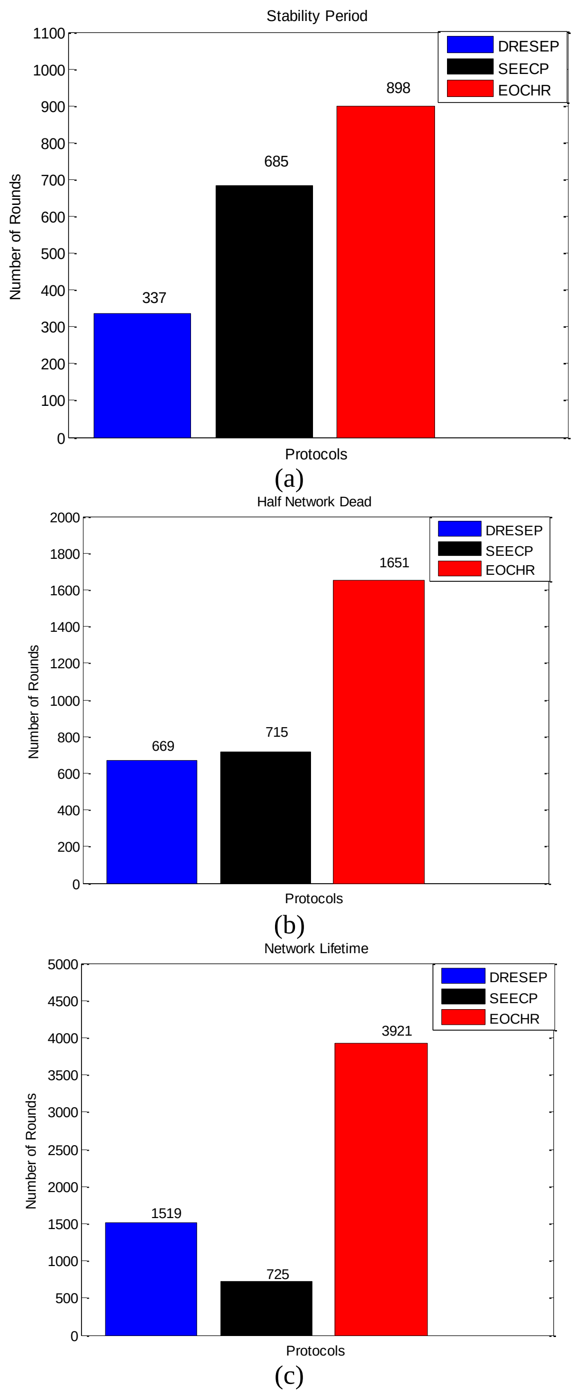

Figure 7: (a) Stability Period, (b) Half Network Dead, (c) Network Lifetime

Table 1
Summarized Analysis of EOCHR, DRESEP and SEECP Protocols

Protocols	EOCHR (Rounds)	SEECP (Rounds)	DRESEP (Rounds)
Stability Period	**898**	685	337
Half Node Dead	**1651**	715	669
Network Lifetime	**3921**	725	1519

Table 2
Percentage Improvement by EOCHR as Compared to Other Protocols

Protocols	SEECP (%)	DRESEP (%)
Stability Period	31.09	166
Half Node Dead	130.9	146
Network Lifetime	440	158.13

In Table 1 and Table 2, the summarized analysis show the number of rounds and percentage improvement covered by the EOCHR as compared to DRESEP and SEECP protocols. It was basically due to the enhanced CH selection and defining the average distance of nodes from the CH as a deciding element for dual hop communication.

VI. CONCLUSION AND FUTURE SCOPE

The energy conservation in WSN is the most prominent concern in developing any routing protocol. Clustering has proved to be much useful for large area network as it balances the load among the nodes for data forwarding by creating hierarchy. In this paper, the clustering is processed in three levels of energy heterogeneity. A cluster head selection is improved by introducing node density factor in threshold formula. Moreover, the dual hop communication is decided by the average distance of nodes from the Base Station despite of some fixed distance topology in DRESEP and SEECP protocols. The simulation analysis shows that stability period was enhanced by 31% due to the energy efficient CH selection and network lifetime was improved tremendously due to optimized load distribution among the clusters. In future, we would like to execute the proposed protocol in real environment to generate accurate results. The work can be further extended by incorporating some optimization techniques in route identification and updating.

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