An Optimal Cluster-Head Selection algorithm for Wireless Sensor Networks

KHUSHBOO JAIN, ANOOP BHOLA
Banasthali Vidyapith, Tonk, Rajasthan, INDIA
khushboojain2806@gmail.com, anupbhola@banasthali.in

Abstract: The energy utilization is one of the most common challenges in Wireless Sensor Network (WSN), as frequent communication between the sensor nodes (SNs) results in huge energy drain. Moreover, optimization and load balancing within the WSN are the significant concern to grant intellect for the extensive period of network lifetime. As a matter of fact, many WSNs are deployed and operating outdoors is exposed to varying environmental conditions, which may further set grounds for severe performance degradation of such networks. Therefore, it is necessary to take into consideration the factors like radio signal strength in order to reduce the impact and to adapt to varying environmental conditions. Since clustering is a topological control technique to reduce the activity of SNs transceivers, it extensively increases overall system scalability and energy efficiency. It selects CH to manage the entire network to achieve longevity in WSN. In this paper, we present an optimal CH selection (OCHS) algorithm which is also based on environmental conditions to achieve energy efficiency and enhanced network lifetime. The originality of this work is that we have taken into consideration the received signal strength index (RSSI) of SNs from the base-station (BS). The OCHS algorithm mainly focuses on maximizing the network lifetime based on RSSI values and residual energy levels of SNs. TheOCHS algorithm is simulated on Cooja Simulator and its performance is compared with existing LEACH and HEED protocols. Simulation analysis and results proved that our OCHS algorithm can effectively enhance the network lifetime by two times and thus it is an energy-efficient way to choose a CH.

Keywords: Cluster Head Selection, Energy Efficiency, Network Lifetime, Residual Energy, RSSI, WSNs

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1. Introduction

A WSN is an extremely intricate distributed system consisting large numbers of SNs and BS. The SNs are usually deployed in a random manner over a large geographical area for event detection and continuous monitoring applications [1]. The WSN gather the sensed value to intend the surroundings with further intellect. Its applications are also crucial for disaster management like forest fire detection, tsunami warning, earthquake monitoring, landslide warning, weather forecasting and air and water quality monitoring. Due to its characteristics like ease of deployment, self-organization and fault tolerance, it has become a promising practice in military applications. Since WSN operates in environment, therefore replacing or recharging batteries is not possible in most of the cases. Even in case of a single SN failure due to energy drain can lead to significant impact on the performance. Therefore the recent trend in WSN is to develop energy efficient design protocols to achieve longevity [2]. The SNs in WSN are arranged into clusters, which are a topological control technique to reduce activity of SN's transceivers. In each cluster, a CH is selected to manage the activities within that cluster. There are three subsequent tasks that a CH has to perform: The first job is to collect sensed value from the SNs of that cluster regularly and aggregates them in-order eradicate duplicity that may exist between the correlated data. The succeeding job of CH is to create a Time Division Multiple Access (TDMA) schedule by which a SN can get a time-slot in order to sends its data. The third job of the CH is to send aggregated values [3] directly to the BS. If a fixed SN performs the entire three tasks, its lifetime will be of very short span. Thus there is a need to change CH regularly and effectively. In this paper we have presented a new CH selection scheme which is based on the residual energy of the SNs and the signal strength between the SNs and BS of that cluster. The proposed algorithm specifies the dynamicity of the CH and determine whether to change the cluster topology is required or not with the residual energy levels. Most of WSNs are deployed and operating outdoors is exposed to varying environment conditions like temperature and humidity, which may further set grounds for severe performance degradation of such networks. Therefore we have to consider factors like radio signal strength for the section of the CH. It has been obvious that RSSI values are significantly affected by environment and multi-path fading. RSSI values changes with the change in environmental conditions and also with the effect of time domain and frequency domain. RSSI

values discrepancy and its strength do not relate with each other but they are individually depended on the environment complexity [4]. RSSI readings are predictable by estimating and measuring the radio signal strength and the majority of IEEE 802.11 and 802.15.4 RF modules sustain for its assessment and measurement.
The rest of the paper is organized as follows: Section 2 describes the related work and motivation, Section 3 presents the network model, energy model and our proposed algorithm (OCHS), respectively. Section 4 presents the performance evaluation and results. Finally, the paper is concluded in Section 6.

2. Related work and Motivation

In recent years, several works have been proposed to improve network life of cluster and energy efficiency during data transmission. In this section we present the valuable prior research accomplished in clustering protocols that are mainly determined towards energy efficiency and thereby improves overall network lifetime.
The authors of paper [5] have proposed an Adaptive Decentralized Re-clustering Protocol (ADRP) which selects a CH and few CHs for subsequent rounds based on residual energy of each SNs and average energy of cluster. In this work, the energy utilization criteria for re-clustering is avoided for next few rounds but SN death from next CH list make the WSN un-balanced.
The authors of paper [6] addressed the issue of suitable CH selection. The proposed approach is implemented by using Fussy Logic with the standard LEACH protocol. The inputs to Fussy inference system are the residue of energy level, location of BS and cluster's centrality. The performance of this approach was enhanced in terms of stability and network lifetime. The Authors of paper [7] have presented HEED protocol with varying level heterogeneity. This enhanced HEED protocol is based on model parameters and demonstrates energy-efficiency with better throughput and increases the packet delivery to the BS.
The author of paper [8] has proposed an EEFL-CH technique by improving the LEACH protocol in-order to reduce the energy utilization by using Fuzzy logic based technique. The enhanced protocol uses parameters like energy-efficiency, distance between SNs and BS and residue energy of SNs for cluster formation. The author of paper [9] had presented a zones based cluster formation in which the sensor field is divided into three equal-sized zones. The CH selection will be dynamic for providing load-balancing and uniform dissipation of energy by the deployed SNs.
The authors of paper [10] had proposed a Fuzzy Logic based Clustering Algorithm for WSN (CAFL) which is an enhancement over CFFL. In this algorithm, they have chosen parameters like residue energy of SNs and proximity to BS for CH selection. For cluster formation they have chosen parameters like proximity to CH of SNs and residue energy of tentative CH is taken into concern for competence. In paper [11], the author has proposed an energy aware protocols in which two BS are located on both the sides of the target field. To maximize the network lifetime, this protocol take into consideration two level of energy heterogeneity. The authors of paper [12] have presented a new protocol Energy Efficient Optimal Chain Protocol (EEOC) for increasing energy efficiency of WSN. The results of simulation is compared with LEACH, PEGASIS, and ACT etc. and concluded that important performance measures are First Node Die (FND), Half Node Alive (HNA) and Last Node Alive (LNA). EEOC outperforms the other protocols and ensure energy efficiency.
The authors of paper [13] have proposed an energy-efficient dynamic clustering technique for CH selection. In this technique each SN approximates on the number of active SNs in real-time and calculates the optimum possibility of becoming a CH by examining its signal strength of the neighbouring SNs. The authors have also proposed and implemented an energy-efficient and power aware (EEPA) routing algorithm. On analyzing and comparing the performance of this with standard AODV, MTE and MRE routing protocols significant increase in network lifetime has been witnessed
The authors of paper [14] presented a cluster based energy efficient forwarding scheme based on binary exponential back off algorithm. This scheme ensures that whenever several SNs of a cluster receive a data packet, then only one SN among them is nominated to send the acceptance. The author of paper [15] has presented energy aware intra-cluster routing techniques based on RSSI. This technique does not take inter-cluster routing into consideration. It is simulated on TOSSIM simulator has shown improvement in energy efficiency.
The above described clustering algorithms takes many important parameters into consideration like location of BS, proximity among the SNs, type of SNs and residual energy of the SNs. In this work we have developed an optimal CH selection (OCHS) scheme which reduces communication overheads and also avoids unnecessary CH selection after every round. The algorithm is simulated to validate the improvement in energy efficiency and network lifetime.

3. Proposed Approach

This section consists of the Network model, energy model and our proposed approach which is a CH selection algorithm and is based on residual energy of the SNs and the signal strength of SNs to BS.

3.1 Network Model

The proposed algorithm assumes a network consisting of SNs which are rando mly distributed with uniform density in a geographical region of size 100*100 m^2 as shown in Figure 1. After deployment the SN is restricted to change its phys ical location. This means that the coordinates of SN remains fixed throughout the netwo rk lifetime. A two level architecture is considered where BS is posit ioned in the centre of the 3D space surrounded by SNs. All SN are considered with equal energy and computational capabilities which may differ in their Signal Strength i.e., RSSI val ue. BS has the responsibility to elect CHs in cluster formation phase and nearby nodes has a responsib ility to join one o f the elected CH. The communication is considered as Multi-hop communication where SN s end their sensed data to their respective CH which i n-turn aggregates all the received data send it to BS.

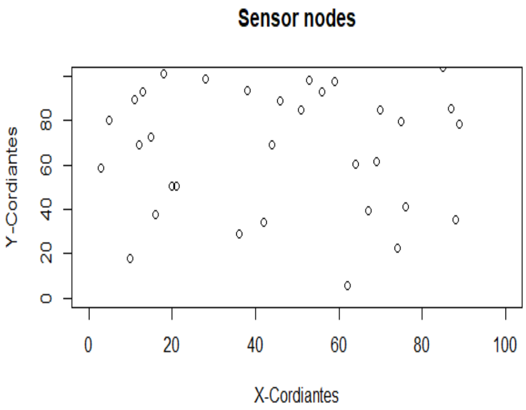

Figure 1 Random Distribution of Sensor Nodes

3.2 Energy Model

There are usually four working system of a SN which are processing unit, sensing unit, radio communication subsystem which includes a receiver, transmitter, amplifier a nd antenna ; an d a energy unit.

The energy dissipation in a SN is depended on t he processing unit, sensing unit and radio unit of the SN. A simple model for the radio communication energy dissipation is assumed in which transmitter fritters energy to run the radio electronics [16].

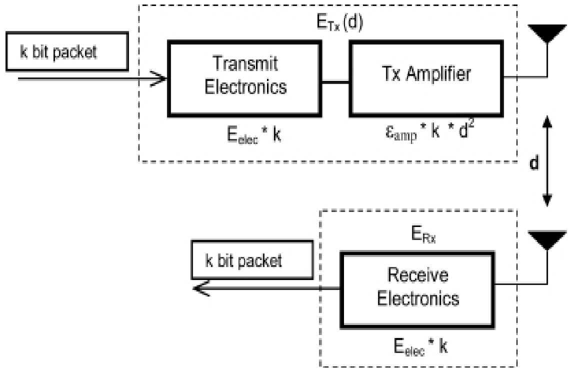

Figure 2: Radio Dissipation Model

This model uses both free-space (fs) and multi-path (mp) fading channels depending on the distance between the transmitter and receiver. A threshold is defined to determine the channel to be used. If the distance is less than the threshold, fs channel is used on the other hand if the distance is greater th an the threshold; the mp channel is used [16]. Th us, to send a k-bit data packet over a distance d, the radio spends:

$$E_{TX}(k,d) = E_{TX\text{-}elec}(k) + E_{TX\text{-}amp}(k,d) \qquad (1)$$

$$E_{TX}(k,d) = \begin{cases} Eelec * k + \varepsilon fs * k * d^2 \text{ if } d < d0 \\ Eelec * k + \varepsilon mp * k * d^4 \text{ if } d \geq d0 \end{cases} \qquad (2)$$

where threshold d_0 is given as

$$d_0 = \sqrt{\frac{\varepsilon fs}{\varepsilon mp}} \qquad (3)$$

To receive the data packet, the radio spends:

$$E_{RX}(k) = E_{RX\text{-}elec}(k) = E_{elec} * k \qquad (4)$$

3.3 Proposed Approach

The optimum CH selection (OCHS) algorithm has following three phases:

3.3.1 Setup and Cluster Formation Phase:

In this phase all SN wi ll communicate with the BS for selection of CHs and Cl uster formation. At the beginning, each SN broadcast an advertisement to the BS. From this advertisement the BS creates th e vector array with SN i ds and their respective RSSI value. The B S then chooses CH on t he basis o f Maximum RSSI value. Thus the li kelihood selecting a first CHs, L _CH[i] are esti mated from the following equation:

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$$L\_CH[i] = \sum_{i=0}^{n} max\ (R[i]) \quad (5)$$

where n is the number of SNs and R[i] is the i^{th} RSSI from the corresponding SN. As the initial energy of all SNs w ould be same, the energy factor is not considered in the setup phase to find the initial CHs. Now the BS broadcasts message to all SNs to inform about the initial CHs, the SN in near proximity will transmit join-request message to CH. The CH will acknowledge them accordingly.

1. Assign random position to SN
2. Construct vector arrays containing of following data for each SN (i=1 to 100)
   a. VX[i]= X coordinate of SN
   b. VY[i]= Y coordinate of SN
   c. E[i]= Energy of SNs and is initialized by E_0
   d. S[i]= Status of each SN (Died=0 or Active=1)
   e. Type[i]=Type of SN(Normal =0 or CH=1)
   f. R[i]= RSSI value
   g. D[i]= Distance from BS/ CH
   h. SN_id[i]= Sensor Node ID
3. Assign a central fixed location to BS.
4. Fix the coordinate of SNs & BS.
5. Compute D[i] of each SN from BS.
6. Send R[i] value of each SN to BS.
7. BS will create lookup-table with node-id and its R[i] value
8. BS will choose CH depending upon max (R[i]) value from equation 5 and acknowledge each SN with 0 or 1(Normal=0 and CH=1)
   a. if SN receive 1, chan ge Type[i]=CH
   b. if SN receive 0, chan ge Type[i]=SN
9. Each SN will send join-request message to its nearby cluster's CH.
10. CH will acknowledge SNs by sending a tuple (SN_id, Response).
    a. If response=1, SN will be longs to that CH
    b. If response=0, SN will be longs to that CH.

3.3.2 Data Communication Phase:

The BS br oadcasts a message to all SNs to update details about the recently selected CHs to all clusters in the WSN. At this instant, a TDMA schedule is allocated by the CH to all SNs of that cluster. Each SN can transmit the sensed d ata to their respective CH in the time slot available to them. CHs will collect the data from SNs and aggregates them. The aggregated data will be then forwarded to the BS.

1. All SNs will send the sensed data t o their respective CH.
2. Energy of SN will change as:
   a. $E[i] = E[i] - E_{TX}$
      (E_{TX} will be computed from equation 1, 2 and 3)
3. CH upon receivi ng the sensed data will aggregate it.
4. Energy of CH will change as:
   a. $E[i] = E[i] - E_{RX}$
      (E_{RX} will be computed from equation 4)

3.3.3 CH Re-election Phase

This phase determines the need of re-election of CHs. By experimentally analyzing varying range of residual energy level of present CH, the threshold value for switching the CH is estimated and is shown in the next section. The CH will broadcast CH_ELECT to all SNs within that cluster, whenever the residual energy E[i] of that CH dr ops to 40% o f its initial energy.

This constitute that the present CH is not having sufficient energy to perform the work of the CH and an instantaneous switching is in need f or extending the lifetime of WSN. On receiv ing this broadcast each SN will sends a parameter S[i] to CH, which is calculated by the summing up of its r esidual energy level E[i] and RSSI value R[i] of all SNs. Now the current CH will evaluate the threshold, S_CH[i] for selecting the next CH. The threshold for selecting the next CH is estimated from the following equation:

$$S\_CH[i] = \sum_{i=0}^{n} \left(\frac{(R[i] + E[i])}{n} \right) \quad (6)$$

where n represents the total SNs in that cluster. The present CH willnow compares S_CH[i] with Si value for each SN. T he SN which has just maximum Si value than the threshold S_CH[i] will be selected as the next CH.

1. if (E[CH] < 40% its initial energy)
   a. CH broadcast a CH-ELECT to BS and all SNs belongs to that cluster
   b. Else Continue to be CH.

2. Upon receiving CH-ELECT, SNs of that cluster will send their R[i] and E[i] to the CH
3. CH will elect the new CH by calculating and comparing S_CH[i] value of each SN with S[i]
4. SN with just higher S[i] value than S_CH[i] will be then selected as a new CH.
5. CH acknowledge each SN with 0 or 1(Normal=0 and CH=1)
6. CH change its Type[i]=CH and other SN will receive 0 and changes their Type[i]=SN.

4.Performance Evaluations

This section describes the simulation environment and performance metrics that we have used to analyse OCHS algorithm. We have also stated the investigational analysis to select threshold for CH selection. Finally we have presented results and demonstrates the proficiency analysis of our OCHS approach.

4.1 Simulation Environment and Performance Metrics

4.1.1 Simulator Used:

ContikiOS [18] is open source operating system for resource constraint hardware devices with low power and less memory. It supports a variety of motes like MicaZ, sky motes, Z1 mote etc. Contiki provides Cooja simulator [17] to simulate the network of SN. We can choose the type of node from any of these three categories: Cooja node, Java node and emulated nodes. Cooja provides simple GUI for easier deployment and configuration of SN. Cooja is a cross level simulator which provides flexibility and extensibility in all levels. As the SNs in WSN are provided with radio frequency which has capabilities of both transmission and receiving a data packet, the RSSI value can be used to approximate the communication distance between the SNs and BS [16]. A total of 100 SN were simulated with varying cluster size in an area of 100m * 100m.

4.1.2 Performance Metrics:

1. Network Lifetime: It is defined as the operational time of the network during which it is capable of performing its dedicated tasks. It can be divided into three categories: First Node Die (FND), Half Node Die (HND) and Last Node Die (LND).
2. Node Death Rate (NDR): It denotes the total number of live SN over the rounds. A lower NDR indicates that the load is balanced over the WSN. The region of NDR can be categorised as stable region and unstable region. All SN are alive in the stable region whereas the unstable region represents the rest of the region.

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Table 1 Simulation Parameters

Parameter	**Value**
WSN area	100m * 100m
No of SN	100
Base Station Location	(50,50)
SN initial energy	2 J
SN distribution	Random
Eelec (for T_x and R_x)	$50 * 10^{-9}$ J/bit
Eamp	$100 * 10^{-12}$ J
Packet header size	25 bytes
Data packet size	100 bytes

4.2 Investigational Analysis to select the threshold for CH selection

We have performed experiments to determine the threshold value for selecting the next CH. The experiment was based on the residual energy level of the current CH. We have tried to establish the relation between the percentage of CH's residual energy and network lifetime. In this experiment, the CH is placed at the centre of 100 m * 100 m sensing field surrounded by 100 SNs. The initial energy of all SN is taken as 2J. So the total energy of WSN will be 200 J.

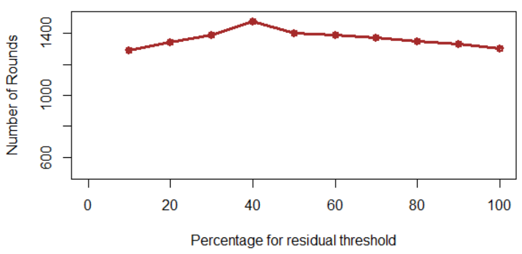

Figure 3 Selection for threshold value for CH

It can be seen from the figure 3 that if 10% of residual energy is taken as threshold, the lifetime of WSN will be about 1140 rounds. On varying the residual energy percentage till 40%, the WSN lifetime reaches to 1476 round s and if we vary residual energy level further the n umber of rounds decreases gradually. Therefore we have taken threshold for selecting new CH to 40% and this value was used for calculation in CH Re-election Phase.

4.3 Results and Discussion

To examine the performance of our OCHS algorithm we have compared its perfo rmance with classical LEACH and HEED for each of the approach. The simulation parameters used during our experimentation for all appro aches are mentioned in Table 1. The performance of our OCHS alg orithm was demonstrated on the basis of four metrics, NDR, FND, HND and LND.

Figure 4 shows the comparison between LEACH, HEED and O CHS in ter m of NDR. It is partitioned into two regions: one is sta ble region and other is unstable region. In stable region, all the SNs are alive and as the SNs starts dying region become unstable. In this figure we ha ve plotted total WSN energy against each round. It is evident from figure 4 that the Node death rate of our approach is always less than that of LEACH and HEED.

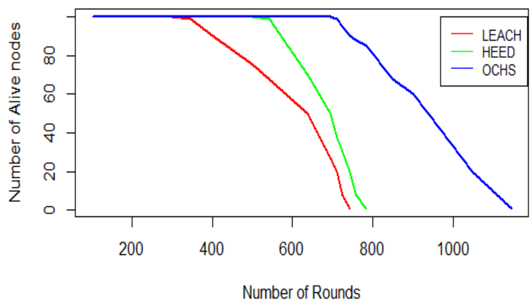

Figure 4 Node Death Rate

We have taken four cluster sizes (5, 10, 20 and 25) to analyze the impact of varying load on CH and to determine overall network lifetime (FND, HND and LND) in all the cases. Table 2 lists the variation in cluster size with a total network size of 100 SNs.

Table 2: FND, HND and LND v alue for various approaches

Protocol	Cluster size	FND	HND	LND
LEACH	-	346	637	744
HEED	-	543	694	783
OCHS	5	712	980	1147
OCHS	10	680	1016	1368
OCHS	20	597	1087	1578
OCHS	25	522	1068	1476

The results of simulation that has been carried out to determine the network lifetime in ter ms of FND o f different algorithms like LEACH, HEED and our proposed OCHS are r epresented in Figure 5. It i s evident that the number of rounds of LEACH, HEED and OCHS with cluster size 5, 10, 20 and 25 take for FND found to be 3 46, 543, 712, 680, 597 and 522 correspondingly. The OCHS algorithm takes more rounds with all cluster sizes for FND in c omparison to other approaches.

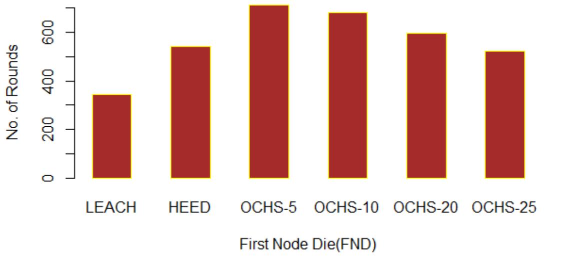

Figure 5 First Node Die

Similarly, the results of simulation carried out between the HND and number of rounds for different approaches LEACH, HEED, and o ur proposed OCHS approach with varying cluster size is represented in Figure 6. It is evident that the number of rounds of LEACH, HEED, and OCHS with cluster size 5, 10, 20 and 25 HND is 637, 694, 980, 1016, 1087 and 1068 corres pondingly. The OCHS algorithm takes more rounds with all cluster sizes for HND in comparison to other approaches.

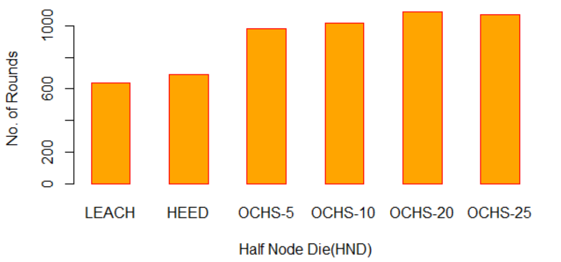

Figure 6 Half Node Died

Similarly, the results of simulation carried out between the LND and number of rounds for different approaches LEACH, HEED, and o ur proposed OCHS approach with varying cluster size is represented in Figure 7. It is evident that the number of rounds of LEACH, HEED, and OCHS with cluster size 5, 10, 20 and 25 LND i s 744, 783, 1147, 1368, 1578 and 1476 corres pondingly. The OCHS algorithm takes more rounds with all cluster sizes for LND in comparison to other approaches.

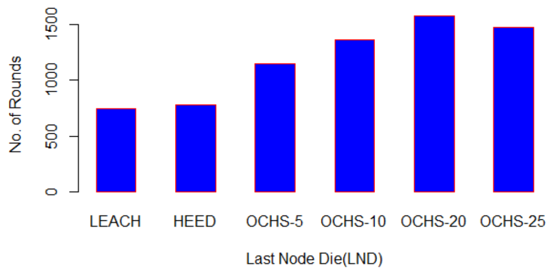

Figure 7 Last Node Die

On the basis of above analysis and results, it has been apparently confirmed that OCHS ensures higher energy efficiency and prolonged network lifetime.

5. Conclusion

In order to improve energy efficiency and enhance network lifetime of a WSN, we have prop osed and simulated an o ptimal CH s election OCHS approach. The OCHS r educes communications overheads and avoids unnecessary selection of CHs. Si mulation results also asser ted that our proposed algorithm has prolonged network lifetime as compared to LEACH and HEED. The algorithm has considerably achieved 35% to 45% efficiency in terms of energy preservation when compared to LEACH an d the number of rounds has increased from around 750 to 1550. Similarly when compared with HEED, OCHS algorithm achieves 25% to 35 % efficiency in terms of energy preservation and the number of rounds has increased from around 800 to 1550. The pr oficiency of OCHS was evaluated on the basis o f NDR and Network lifetime (FND, HND and LN D). It i s evident that the number of rounds of LEACH, HEED and our proposed approach with cluster size 5, 10, 20 and 25 take for FND found to be 346, 543, 712, 680, 597 and 522 correspondingly.
Similarly, the number of rounds of LEACH, HEED, and our proposed approach with cluster size 5, 10, 20 and 25 HND is 637, 694, 980, 1016, 1087 and 1068 correspondingly. And t he number of rounds of LEACH, HEED, and OCHS with cl uster size 5, 1 0, 20 and 25 LND is 744, 783, 1147, 1368, 1578 and 1476 correspondingly. Our proposed algorithm reduces communications overheads and av oids unnecessary selection of CHs in each round and outperforms other standard protocol d uring comparison. The OCHS has uniform energy utilization and thus it has more residual energy available for a large number of rounds. Simulation results also asserted that OCHS algorithm has

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prolonged network lifetime as compared to LEACH and HEED.

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7. Conflict of Interest:

There is no conflict of interest.

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