
An optimal RSSI-based cluster-head selection for sensor networks

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Abstract: Wireless sensor networks (WSNs) are becoming a very auspicious key to better address reliability to constant, accurate environmental monitoring. Although energy utilisation is one of the most common challenges, frequent communication between the sensor nodes (SNs) results in a huge energy drain. Moreover, load balancing and optimisation within the WSN are the significant factors for the extensive period of network lifetime. In fact, many such networks are deployed and operating outdoors is exposed to varying environmental conditions, which may further set grounds for severe performance degradation. Therefore, it is necessary to take into consideration factors like radio signal strength index to reduce the impact and to adapt to varying environmental conditions. In this paper, we propose an optimal RSSI CH selection (ORCHS) algorithm that is also based on environmental conditions to achieve energy efficiency and enhanced network lifetime by effectively managing energy levels within the network.

Keywords: cluster head selection; energy efficiency; network lifetime; residual energy; RSSI; wireless sensor networks; WSNs; node death rate; ContikiOS; ORCHS.

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1 Introduction

Wireless sensor networks (WSNs) are becoming progressively a ubiquitous mechanism to monitor over a large geographical area for event detection and continuous monitoring applications (Bhola et al., 2017). The WSN gather the sensed value to intend the surroundings with further intellect. Its application are military and civil applications including environmental monitoring, home automation, surveillance and reconnaissance, fault analysis and diagnosis, precision agriculture, bio-medical applications, portfolio control, entity tracking. Its applications are also essential for disaster management like forest fire detection, tsunami warning, earthquake monitoring, landslide warning, weather forecasting and air and water quality monitoring. Due to their placement in hard-to-reach locations, it is usually problematic and expensive to or recharging or replacing batteries is not possible in most of the cases. Therefore, the recent trend in WSN is to develop energy-harvesting techniques that utilise ambient energy to elongate the network lifetime of sensor nodes (SNs) (Gupta and Sikka, 2015).

The SNs can be organised into clusters, which is a topological control technique to reduce activity of SN's transceivers. In each cluster, one or more CHs are 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 (Jain and Bhola, 2018) 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 work, we have proposed an optimal received signal strength index (RSSI) 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 considers 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 (mp) 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 (Wu et al., 2008). 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 organised as follows: Section 2 describes the related work and motivation, Section 3 presents the network model, energy model and our proposed algorithm (optimal received signal strength index CH selection – ORCHS), respectively. Section 4 presents the simulation and performance evaluation followed by the results. Finally, the paper is concluded in Section 5.

2 Related work and motivation

Clustering which is a topological control technique plays an imperative role in energy management in the sensor network. Selecting a CH can suitably balance load and effectively manage data transmission by reducing energy depletion and improving sensor network lifetime. 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.

A cluster-based energy efficient forwarding scheme is presented in Adeel et al. (2010) 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. Bajaber and Awan (2011) have proposed an adaptive decentralised 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 utilisation criteria for re-clustering is avoided for next few rounds but SN death from next CH list make the WSN un-balanced.

A scalable energy efficient clustering hierarchy (SEECH) is proposed in Tarhani et al. (2014), which selects CHs and transmits separately on the based on SN suitability. In this algorithm high degree SNs are classified and CHs and low degree SNs are employed as relays. SEECH uses a new distance-based algorithm to deliberate uniformity of CHs to balance clusters. The proposed algorithm when is compared with LEACH and TCAC method depicts enhanced performance of SEECH protocol in terms of sensor network lifetime. Nayak and Devulapalli (2016) had addressed the issue of suitable CH selection. The proposed approach is implemented by using fuzzy logic with the standard LEACH protocol. The inputs to fuzzy 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.

Singh et al. (2016) 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. A new protocol energy efficient optimal chain protocol (EEOC) for increasing energy efficiency of WSN is proposed in Agarwal et al. (2016). The results of simulation is compared with LEACH, PEGASIS, and ACT, etc. and concluded that important performance measures are first node die (FND), HNA and LNA. EEOC outperforms the other protocols and ensure energy efficiency.

El Alami and Najid (2016) has proposed an EEFL-CH technique by improving the LEACH protocol in-order to reduce the energy utilisation 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. Mehra et al. (2017) 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.

El Alami and Najid (2017) 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. A simple yet effective clustering algorithm is presented in Padmanaban and Muthukumarasamy (2018) known as energy efficient structured clustering algorithm (EESCA). The algorithm uses average communication distance and remaining energy for selecting the CHs. Further the CHs are rotated based on the CTNR parameter. The analysis is performed on the basis of simulation time, load balancing, scalability, FND and CUDP. Simulation results are compared with LEACH and SEECH protocols and proved to be advantageous for environmental monitoring.

A priority-based weighted clustering algorithm for ad hoc networks presented in Pathak and Jain (2019). It uses three different stages to CH changes and clustering overhead. In first stage, the algorithm selects the CHs based on their initial priority of SN inside cluster. The second stage aids in cluster maintenance. In addition, in third stage the new CH is automatically selected without any delay when residual battery life of previous CH reaches to minimum threshold value. Experimentation and simulation of the proposed algorithm proved the validity of the work and confirms the theoretical claims. Zeng et al. (2019) have proposed an energy-coverage ratio clustering protocol (ECRCP) to minimise the energy depletion and to utilise the coverage ratio. They have designed an energy model, which determines optimal number of clusters on the principle of 'minimum energy depletion' and selects the CH on the principle of 'coverage maximisation'. Experimentation with the proposed model proved to attain elongated network lifetime, load balancing and lower energy consumption in the environment of heterogeneous sensor network.

Behera et al. (2019) focuses on an efficient CH selection algorithm, which rotates the CH position among the SNs with higher energy intensity as compared to other. The proposed scheme is based on the initial energy, residual energy and an optimum number of CH to select the next group of CHs for the network that is beneficial for IoT applications such as environmental monitoring, home automation, surveillance, fault analysis, precision agriculture. Experimentation proved that the proposed scheme outperforms the LEACH in terms of throughput, network lifetime and residual energy.

Jain et al. (2020) focus the research on improving sensor network lifetime. Instead of changing cluster heads for dynamic clustering at every round of communication, they develop an optimal CH threshold function and an energy threshold function to propose the dynamicity of cluster head based on the current energy intensities, thus improves the network's lifetime.

3 Proposed approach

This section consists of the network model, energy model and our proposed approach which is an ORCHS algorithm and is based on residual energy levels of the SNs and the signal strength of SNs to BS.

3.1 Network model

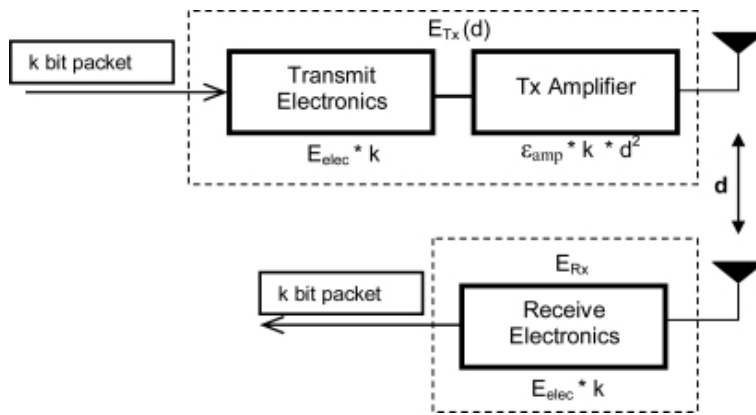
The proposed algorithm assumes a network consisting of SNs which are randomly distributed with uniform density in a geographical region of size $100 * 100 \text{ m}^2$. After deployment the SN is restricted to change its physical location. This means that the coordinates of SN remains fixed throughout the network lifetime. A two-tier architecture is considered where BS is positioned 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 value. BS has the responsibility to elect CHs in cluster formation phase and nearby nodes has a responsibility to join one of the elected CH. The communication is considered as multi-hop communication where SN send their sensed data to their respective CH which in-turn aggregates all the received data send it to BS.

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 and antenna; and a energy unit. The energy dissipation in a SN is depended on the 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 (Heinzelman et al., 2002).

Figure 1 Radio dissipation model



This model uses both free-space (fs) and 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 than the threshold; the mp channel is used (Heinzelman et al., 2002). Thus, to send a k -bit data packet over a distance d , the radio spends:

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

$$E_{TX}(k, d) = \begin{cases} E_{elec} * k + k\epsilon_{fs}d^2 & \text{if } d < d_0 \\ E_{elec} * k + k\epsilon_{mp}d^4 & \text{if } d \geq d_0 \end{cases} \tag{2}$$

where threshold d_0 is given as

$$d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \tag{3}$$

To receive the data packet, the radio spends:

$$E_{RX}(k) = E_{RX-elec}(k) = kE_{elec} \quad (4)$$

3.3 ORCHS algorithm

The proposed ORCHS algorithm has following three phases.

3.3.1 Setup and cluster formation phase

In this phase all SN will communicate with the BS for selection of CHs and cluster formation. Therefore, each SN broadcast an advertisement to the BS. From this advertisement the BS creates the vector array with SN ids and their respective RSSI value. The BS then chooses CHs on the basis of Maximum RSSI value. Thus the likelihood selecting a first CHs, $LC_H[i]$ are estimated from the following equation:

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

where n is the number of SNs and $R[i]$ is the i^{th} RSSI from the corresponding SN. Originally, energy of all SNs would be same, therefore the energy factor is not considered in the setup phase to select 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.

3.3.2 Data communication phase

The BS broadcasts 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 data 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.

3.3.3 CH re-election phase

This phase determines the need of re-election of CHs. By experimentally analysing 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_SELECT to all SNs within that cluster, whenever the residual energy $E[i]$ of that CH drops to 40% of 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 for extending the lifetime of WSN. On receiving this broadcast each SN will sends a parameter $S[i]$ to CH, which is calculated by the summing up of its residual energy level $E[i]$ and RSSI value $R[i]$ 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 will now compares $S_CH[i]$ with S_i value for each SN. The SN which has just maximum S_i value than the threshold $S_CH[i]$ will be selected as the next CH.

Algorithm: ORCHS

Procedure: Initialise: Construct vector array containing the following data for each SN.

$V_X[i], V_Y[i], E[i], S[i], Type[i], R[i], D[i], SN_{ID}[i]$

Parameters:

- 1 $V_X[i]$ ← Vector of X-coordinate of SN
 - 2 $V_Y[i]$ ← Vector of Y-coordinate of SN
 - 3 $E[i]$ ← Energy of SNs and is initialised by E_0
 - 4 $S[i]$ ← Status of each SN (died = 0 or active = 1)
 - 5 $Type[i]$ ← Type of SN(normal = 0 or CH = 1)
 - 6 $R[i]$ ← RSSI value of SNs
 - 7 $D[i]$ ← Distance from BS/CH
 - 8 $SN_{ID}[i]$ ← Sensor node ID
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Algorithm 1 Setup and cluster formation phase

- 1 Assign random position to SN
 - 2 Assign a central fixed location to BS.
 - 3 Compute $D[i]$ of each SN from BS.
 - 4 Send $R[i]$ value of each SN to BS.
 - 5 BS will create lookup-table with $SN_{ID}[i]$ and its $R[i]$ value
 - 6 BS will choose CH depending upon max $R[i]$ value from equation (5) and acknowledge each SN with 0 or 1 (SN = 0 and CH = 1)
 - a if SN receive 1, change $Type[i] = CH$
 - b if SN receive 0, change $Type[i] = SN$
 - 7 Each SN will send join-request message to its nearby cluster's CH.
 - 8 CH will acknowledge SNs by sending a tuple ($SN_id, Response$).
 - a if $Response = 1$, SN will belongs to that CH
 - b if $Response = 0$, SN will not belongs to that CH.
-

Algorithm 2 Data communication phase

- 1 All SNs will send the sensed data to their respective CH for each successive round of communication
 - 2 Energy of a SN will change as:
 - a $E[i] = E[i] - E_{TX}$
 [E_{TX} will be computed from equations (1), (2) and (3)]
 - 3 CH upon receiving the sensed data will aggregate it.
 - 4 Energy of a CH will change as:
 - a $E[i] = E[i] - E_{RX}$
 [E_{RX} will be computed from equation (4)]
-

Algorithm 3 CH re-election phase

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1  if ( $E[CH] < 40\%$  its initial energy)
    a  CH broadcast a CH-ELECT to BS and all SNs belongs to that cluster
2  else
    a  Continue to be CH.
3  Upon receiving CH-ELECT, SNs of that cluster will send their  $R[i]$  and  $E[i]$  to the CH
4  CH will elect the new CH by calculating and comparing  $S\_CH[i]$  value of each SN with  $S[i]$ 
5  SN with just higher  $S[i]$  value than  $S\_CH[i]$  will be then selected as a new CH.
6  CH acknowledge each SN with 0 or 1 (SN = 0 and CH = 1)
7  CH change its  $Type[i] = CH$  and other SN will receive 0 and changes their  $Type[i] = SN$ .

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4 Simulations and performance evaluations

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

*4.1 Simulation environment and performance metrics**4.1.1 Simulator used*

ContikiOS (Dunkels et al., 2004) 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 (Österlind et al., 2006) 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. A total of 100 SN were simulated with varying cluster size (5, 10, 20 and 25) in an area of 100 m * 100 m.

4.1.2 Performance metrics

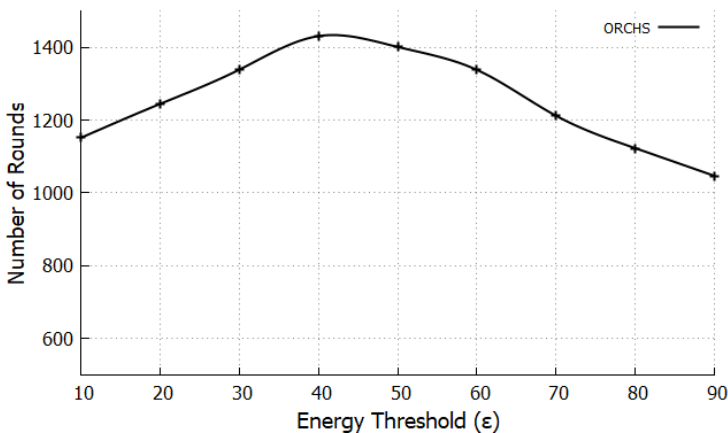
- 1 Network lifetime: It is defined as the operational time of the network during which it is capable of performing its dedicated tasks. It can be divided into three categories: FND, half node die (HND) and last node die (LND).
- 2 Node death rate (NDR): It denotes the total number of live SN over the 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.

4.2 Investigational analysis to select the energy threshold for CH selection

We have performed experiments to determine the energy threshold value for selecting the next CH. The experiments were based on the residual energy level of the current round of CH. We have tried to establish the relation between the percentage of CH's residual energy and network lifetime to determine an optimum value of energy threshold. In these experiments, 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 2 J. So the total energy of WSN will be 200 J.

In our analysis, we have vary the residual threshold energy for re-election of the CHs. We have performs for experiments with threshold ranging from 10% to 90% and fixed the cluster size to be 10 to determine the network lifetime. It can be seen from Figure 2 that if 10% of residual energy is taken as threshold, the lifetime of WSN will be about 1,152 rounds. On varying the residual energy percentage until 40%, the WSN lifetime reaches to 1,431 rounds and if we vary residual energy level further the number 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.

Figure 2 Selection for optimal threshold value for CH



4.3 Results and discussion

To examine the performance of our ORCHS algorithm we have compared its performance with classical LEACH (Nayak and Devulapalli, 2016) and SEECH (Tarhani et al., 2014). The simulation parameters used during our experimentation for all approaches are mentioned in Table 1. The performance of our ORCHS algorithm was demonstrated on the basis of following metric: network lifetime (FND, HND and LND) and NDR. We have taken four cluster sizes (5, 10, 20 and 25) to analyse 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 1 Simulation parameters

<i>Parameter</i>	<i>Value</i>
WSN area	100 m × 100 m
Total no. of SNs	100
Protocols	LEACH, SEECH, ORCHS
BS location	(50, 50)
SN initial energy	2 J
Total energy	200 J
SN distribution	Random
Eelec (for T_x and R_x)	$50 * 10^{-9}$ J/bit
Eamp	$100 * 10^{-12}$ J
Aggregation energy	5 nJ/bit/s
Packet header size	25 bytes
Data packet size	100 bytes

Table 2 FND, HND and LND value for various approaches

<i>Protocol</i>	<i>Cluster size</i>	<i>FND</i>	<i>HND</i>	<i>LND</i>
LEACH		406	697	789
SEECH		654	703	891
ORCHS	5	801	1,021	1,265
ORCHS	10	792	1,125	1,431
ORCHS	20	653	1,284	1,671
ORCHS	25	602	1,267	1,541

The results of simulation that has been carried out to determine the network lifetime in terms of (FND, HND and LND) of different algorithms like LEACH, SEECH and our proposed ORCHS are represented in Figure 3. It is evident that the number of rounds of LEACH, SEECH and ORCHS with cluster size 5, 10, 20 and 25 take for FND found to be 406, 654, 801, 792, 653, 602 correspondingly. The ORCHS algorithm takes more rounds with all cluster sizes for FND in comparison to other approaches. Similarly the HND is 697, 703, 1,021, 1,125, 1,284 and 1,267 correspondingly. The ORCHS algorithm takes more rounds with all cluster sizes for HND in comparison to other approaches. Correspondingly, the LND is 789, 891, 1,265, 1,431, 1,671 and 1,541 respectively. The ORCHS algorithm takes more rounds with all cluster sizes for LND in comparison to other approaches.

Figure 4 shows the comparison between LEACH, SEECH and ORCHS in term of NDR. It is partitioned into two regions: one is stable 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 have plotted total WSN energy against each round. It is evident from results that the NDR of our approach is always less than that of LEACH and SEECH.

Figure 3 Network lifetime

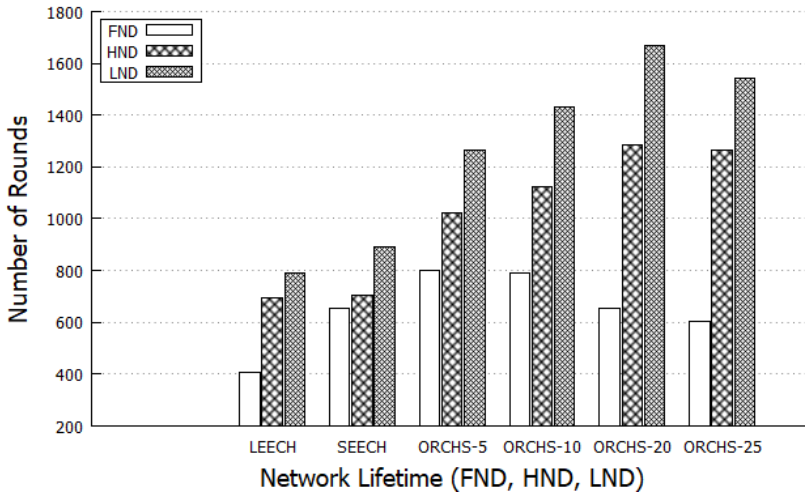
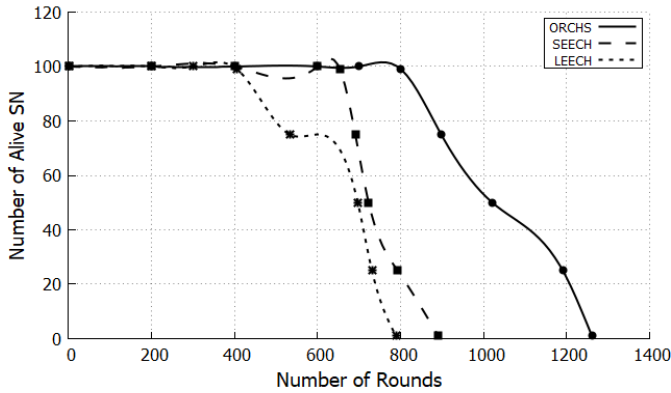


Figure 4 Node death rate



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

5 Conclusions and future aspect

In order to improve energy efficiency and enhance network lifetime of sensor network, we have proposed and simulated an optimal RSSI CH selection ORCHS approach. The ORCHS has uniform energy utilisation and thus it has more residual energy available for a large number of rounds. It reduces communications overheads and avoids unnecessary selection of CHs after every round of communication. Simulation results also asserted that our proposed algorithm has prolonged network lifetime as compared to LEACH and SEECH. The algorithm has considerably achieved 35% to 45% and 30% to 35% efficiency in terms of energy preservation when compared to LEACH and SEECH

respectively and the number of rounds has increased from around 789 to 1,671 in case of LEACH and from 891 to 1,671 in case of SEECH. Future work will be dedicated to inculcate scalability in the proposed work.

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