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Energy Resourceful Distance based Clustering and Routing Algorithm with Competent Channel Allocation Scheme for Heterogeneous Wireless Sensor Networks

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Abstract

Objectives: To implement an effective spectrum access technique using cognitive radio technology with distance based clustering and routing algorithm with in wireless sensor networks and test this algorithm with different scenarios by varying position of the base station. **Methods:** Network region is divided into parts for allocating the spectrum and topology control, by distance based multi hop clustering and routing algorithm which decides cluster forming strategy on the basis of distance from the base station and route the data with less hops. **Findings:** The simulation shows, the proposed algorithm was able to provide a better Network Life time with the same amount of initial energy. Also, election of cluster heads on the basis of distance has helped in increasing the stability. And, with different efficient distance thresholds deciding single hop and multi hop communication. **Application/Improvements:** The proposed algorithm increases the scalability of the network, in comparison to the existing algorithms, by an average of 29%, when the base station is kept at the corner and, by 42.5%, when it is kept away from the corner.

Keywords: Cognitive Radio, Clustering, Energy efficient, Routing, Stability, Wireless Sensor Network (WSN)

1. Introduction

Wireless sensor network finds it application in huge variety of applications such as, bridge health monitoring[1], water environment monitoring[2–4] and plays a crucial role in creating an intelligent environment for such applications. The robustness and easy deployment capabilities make them one of the best choices for keeping eye on the places where the deployment of any other ad-hoc network is quite difficult. The most important concern behind this network is, its ability to harness effectively the amount of energy provided[5], along with, having an efficient channel allocation and avoid congestion[6]. In order to solve such challenges a lot of research has been done to route the packets efficiently to the base station. Initially, wireless sensor networks incorporated Direct Communication for the sensor nodes to interact with the base station and send the information. Although, direct communication follows a simple set of steps and was less computationally complex, it worked well only for the nodes nearer to the BS. For nodes away from the base station, the energy of nodes drained quite fast. So, to impose a restriction on number of nodes communicating with the B.S., nodes were grouped together and the data was transmitted through one of the node in that group. Considering this approach, Low Energy Adaptive Clustering Hierarchy (LEACH)[7] was proposed which is one of the fundamental algorithm in Wireless Sensor Network and, is the base of many clustering algorithms that are present today. It was incorporated on a network containing equally energized nodes. The CH (Cluster Head) selection was done on the basis of the random number generated by the node. The CHs are responsible for a direct transmission to the base station. Although, LEACH increases the Network lifetime as compared to a single hop network but, fails when the area of the network becomes large. It loses scalability for large network causing load imbalance and becomes highly unstable. An advanced version of LEACH known

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as Energy Low Energy Adaptive Clustering Hierarchy (E-LEACH)[8] was proposed, which considered the remaining energy of the node and Energy threshold of the network in the formula for Threshold thus, electing the nodes with higher energy for that round, to become CHs. Since, the nodes had equal amount of energy initially, the decrement in the energy of the nodes was quite similar since, all the nodes got somewhat equal chance of becoming a CH in each round. This algorithm, therefore, was not useful for increasing the lifetime of the network. Hence heterogeneity in the energy amongst the network played an important role in increasing the network life time. The problem of scalability, which could be solved either by increasing the initial energy of some of the nodes and making them CH frequently or, by having a chain based algorithm and increasing the connectivity of the network. With the first option, Stable Election Protocol (SEP)[9] was developed. It consisted of network with a heterogeneous distribution of energy within the nodes. Also, there was a relation between the probability of a CH being elected and the heterogeneity factor of each node and, this protocol was far better than the LEACH algorithm in the terms of network life time and stability. But, still there was deterioration in the performance for large network where the nodes, far away from the base station, die very quickly. In order to deal with this problem an algorithm called Multi hop Clustering and Routing (MCR)[10] was introduced which was a perfect blend of clustering and chain based algorithms, such as Power Efficient Gathering in Sensor Information System (PEGASIS)[11]. Here, level of heterogeneity was chosen to be two i.e., other than the normal node there are two types of nodes namely the active nodes and the super nodes, with energy more than the normal counterparts. The CH selection was similar to SEP but, the interaction between the CH (Cluster Head) and the BS (Base Station) was through the nearby CH, rather than a direct communication to the BS. This strategy was quite helpful in enhancing the scalability of the network by increasing the life of the far away nodes. Since, the clustering was done solely by the weighted election probability without considering the remaining energy of the node, the MCR algorithm was not able to improve the stability of the network. Since, the algorithm is centralized, it reduces the stability of the network because, for making all the nodes aware of the location all CHs broadcast there location which, again becomes detrimental for far away nodes.

To make cluster head election dependent on the energy of node so that, network efficiency could be increased[12,13]. A Distributed Energy Efficient Clustering (DEEC)[14] algorithm was proposed which has a multilevel heterogeneity amongst the nodes deployed, along with an energy efficient optimal CH selection strategy. Here, the CH selection probability was dependent on weighted election probability as well as the current energy of the node and average energy of the all the nodes. It was quite good as per the Network Life time is concerned, but was not efficient in prolonging the life of the network after the first node dies. The main reason behind this was its inability to create more number of CHs when the residual energy of the nodes becomes less. Since the election probability of each node was proportional to the residual energy of the respective node therefore at higher number of rounds, due to deficiency of CHs, the data in the nodes would have to travel longer distances to reach the CH and, this might lead to a rapid decline in the number of nodes alive in the network.

In Energy-Efficient Multilevel and Distance-aware Clustering (EEMDC)[15] algorithm, the CHs were selected on the basis of the nodes distance from the BS and the average distance of all the nodes in the network. In this algorithm, the network was divided into three logical layers on the basis of number of hops each node takes to reach the BS. The routing was done in a multi hop manner. Here, optimal CH selection was done on the basis of its position from the BS to increase the stability of the network since; increasing the CHs near to the BS will surely reduce the cost of sending the data. Although, the major disadvantage of this algorithm was similar to the previously proposed algorithm but here, the reason of decline in number of CH was the constraining distance rather than the energy. For the nodes away from the BS the CH election probability would be substantially less and the ones nearer to the BS would be elected as a CH very frequently. This frequent election of these nodes will lead to a faster depletion of their initial energy and, when these nodes die, the whole network loses connectivity since, the number of CHs in the network reduces drastically.

In order to keep number of CH intact at higher number of rounds along with choosing the nodes as a CHs effectively an algorithm, Energy Efficient Multilevel Heterogeneous Protocol (EEMHR)[16] was proposed which considered multiple level of heterogeneity with a multi hop routing approach and was giving a better stability than the MCR. According to this algorithm, firstly the nodes were provided with weighted election probability on the basis of their heterogeneity. Secondly, instead of introducing the residual energy factor in election probability, they considered number of nodes alive as the factor deciding the CH election. The Ratio of number of nodes alive and total numbers of nodes initially present in the network, was multiplied with the value of threshold. So, whenever the numbers of alive nodes go down, the threshold range of the network decreases hence, the nodes get a fair chance to become a CH even at the higher number of rounds. But, the problem with this algorithm was that, it equally favored the nodes far away from the BS to become a CH which, led to the decline of energy of faraway nodes earlier. Also, it increases the computational burden levied on the nodes to become a CH. A similar but rather inefficient approach was seen in Low Energy Adaptive Clustering Hierarchy with Sliding window (LEACH SWDN)[17] algorithm. Here, instead of changing the WEPs the value of threshold was made dependent on the initial energy of the node and the residual energy of the network. Although the algorithm works fine but the major drawback of this approach is excess burden on the CHs leading to a higher decrement in energy. This burden is due to the fact that, when the cluster members try to send the information about their remaining energy, it has to be done via CHs. Now, since this information is not aggregated by the CH, the amount of energy reduced becomes higher. This reduces the stability of the entire network.

So, to resolve the conflicts between performance and cost by the above algorithms a Distance Based Multi-Hop Communication was proposed. This algorithm carefully brings in the concept of Direct Communication, Multi hop Communication and Clustering together to increase the efficiency of the network. Here, the complete region is divided into three regions based on their distance from the BS. Then on the basis of the distance, it was decided whether, that node has to perform a single hop communication or a multi hop one, to send its packets to the BS. The faraway nodes were preferred for clustering while; the nearer ones were there with single hop communication. Also, in order to avoid packet collision, the regions were demarcated around the BS which was responsible for routing the data by the CHs to the BS, with a specific channel allocation[18]. This algorithm successfully solved the problem of Network Life time, Stability and Scalability, as compared to the previous algorithms but was still lagging behind in election of clusters efficiently. Since, the election probability was dependent on distance and the heterogeneity of the network, there are high chances for a low energy node which is nearer to the BS to become a CH.

This would definitely reduce the stability of the network and also the connectivity of the network[18]. Along with the algorithms discussed above, there is many such vulnerabilities[19–22]. None of them considers the packet loss due to collision that may occur when the nodes are sending the data at the same frequency[23]. Around the BS, a huge amount of data is being communicated by the nodes associated to that BS. Since, in the earlier algorithms the TDMA schedule was followed to transmit the data, there was a huge possibility for a node near to the BS and, the one far away from the BS to have their packets reaching the BS station at the same time and, thus, leading to a collision and data loss. This problem becomes quite serious, when either the network size is increased or, the density of nodes in network increases.

Since, there is a limited amount of frequencies available in the ISM band, hence it is necessary to go for the spectrum that is allocated for commercial telecommunication purposes (Licensed Spectrum). The best way to do so is, by harnessing the cognitive radio technology[24] for an effective usage of the spectrum used by the Primary Users (Licensed Users) for the use of secondary user. The main purpose of cognitive radio technology is, to provide a part of unused spectrum provided to the primary user to, the secondary users. Here, a continuous monitoring is done for the white spaces, given to the licensed users, and the data is transferred using those channels[25–27]. The specialty about this technology is that we can use the unused licensed spectrum without interfering the communication of Primary Users. The approach of using cognitive radio for spectrum allocation not only helps in expanding the spectrum available but, it also helps in avoiding the channel overlapping.

The Cognitive Radio based Sensor Networks (CRSN) have properties and architectural attributes of Cognitive radio. There are four major topologies namely Ad-hoc CRSN, Clustered CRSN, Heterogeneous and Hierarchical CRSN and Mobile CRSN[28] that are followed while considering the allocation of channels to the nodes, present in the network. In case of Ad-hoc CRSN each sensor node is required to sense the frequencies present. It is beneficial in the sense that, it helps in reducing the communication overhead but, problems such as hidden terminal and inaccuracy in, frequencies selection leads to a degradation in performance. While, in case of clustered CRSN the dissemination of information regarding frequency is done by the CH itself. For Hierarchical and heterogeneous approach, actor nodes with renewable source of energy are used for allocation of frequencies. Lastly, in case of Mobile CRSN the only difference is, the mobile nodes which, adds complexity to the procedure of sharing spectrum.

From the text, it is visible that there is a need of an algorithm that has an excellent Network Life time, stands good on scalability factor, has very high stability and incorporates an efficient channel allocation leading to reduced packet collision and, finally, reducing the burden of Cluster head. Therefore, the main aim of this paper is to amalgamate the advantages of previously proposed algorithms with efficiency of multilevel heterogeneity amongst the nodes and effective use of cognitive radio technology for spectrum sharing[29]. To do so, the nodes with cognitive radio properties were made to communicate either directly or through single hop to the BS for which, Ad hoc topology was used for our system. Also, we have considered energy and distance together, as a deciding factor in electing the CH. Following Section gives the network configuration for this algorithm with all the mathematical expressions and the network parameters used. It comprehensively explains the Energy Model used for our algorithm, the optimal probability calculation for election of the CH, and, the regions whose nodes, will be responsible for the transmission of data, using single hop or direct communication and, have cognitive radio technology in their architecture, for spectrum access. Section 3 presents the flow diagram, which explains the proposed algorithm and, discusses about various modifications that were done to the previous algorithms for increasing the performance of our network. And, section 4 compares graphically, the proposed algorithm with previously proposed algorithms, on the basis Network Life time, number of CHs formed per round, the residual energy of the network per round, Network Stability and the round when the death of the first node occurs. Considered parameters helped in forming a better analysis of the proposed algorithm in terms of scalability and connectivity of the network. Then, with Section 5 the work was concluded providing the advantages of the proposed algorithm with respect to other algorithms.

2. Network Configuration

The algorithm was tested in a network with a dimension of 200*200 and containing a total of 100 nodes. For the networks in the region of volcanic eruptions, temperature monitoring etc., it is not possible for us to keep BS at the center, therefore we have tested our approach with the BS at the corner and away from the corner.

2.1 Energy Consumption Model

In Figure 1 the energy model considered is similar to the one proposed in LEACH algorithm.

$$E_{txd}(k,d) = (E_{elect} * k) + (\varepsilon_{ampl} * k * d^{\gamma}) \quad (1)$$

$$E_{txd}(k,d) = \begin{Bmatrix} (E_{elect} * k) + (\varepsilon_{ampl} * k * d^{2}), & (d < do) \\ (E_{elect} * k) + (\varepsilon_{ampl} * k * d^{4}), & (d \geq do) \end{Bmatrix} \quad (2)$$

$$E_{rxn}(k) = (E_{elect} * k) \quad (3)$$

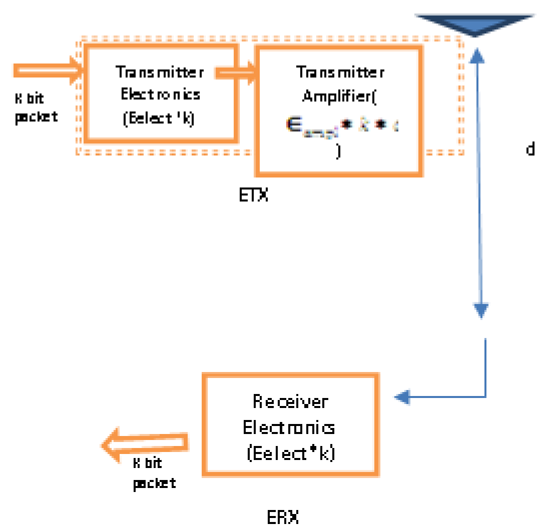

Figure 1. Radio energy model.

2.2 Calculation of Optimal clustering probability

The value of optimal clustering parameter depends upon the path loss factor which is equal to 2 for free space and 4 for multipath scenario, when the base station is at the periphery. Hence, similar to the value of optimal clustering parameter for Path Loss Factor (γ) = 2 is given by k_0, and expected value for d^2_{CH-BS} i.e.,

$$\mathrm{E}\,[d^2_{CH-BS}] = \frac{2}{3}M^2 \quad (4)$$

M*M is the dimension of field where clustering happens. A is the total area. N and n represents total number of nodes in the network. Corresponding to the given path loss factor, value of free space parameter was found to be:

$$k_0 = \sqrt{\frac{n\varepsilon_{fs} A}{2\pi\left(\varepsilon_{fs}\frac{2}{3}M^2 - E_{elec}\right)}} \quad (5)$$

Similarly, when Path loss factor is 4, the expected value for d^4_{CH-BS} i.e.,

$$E\,[d^4_{CH-BS}] = \frac{28}{45}M^4 \quad (6)$$

Correspondingly, the value of multipath environment parameter is given by:

$$k_0 = \sqrt{\frac{45 n\varepsilon_{fs} A}{56\pi\varepsilon_{mp} M^4}} \quad (7)$$

Now, in order to calculate the optimal clustering probability:

$$P_{opt} = \frac{k_o}{N} \quad (8)$$

N is total number of nodes participating in clustering which is applicable for both, multipath and free space environment.

2.3 Calculation of Cluster Head Election Probability for Multilevel Heterogeneous Wireless Sensor Network

In order to calculate the value of cluster head election probability we have considered following 4 parameters

- Average Energy of the network.
- Residual Energy of the node.
- Average Distance of the nodes from the BS (Base Station).
- Position of a node from the BS.

To calculate the average current energy of the network

$$E_{avg}(r) = \frac{1}{N}\sum_{i=1}^{N} E_i(r) \quad (9)$$

Where $E_i(r)$ is the residual energy of ith node in rth round.

With respect to the residual energy and the average energy, the value of new optimal Probability for each node is calculated:

$$P_{opt}(i) = \left(\frac{P_{opt} * E_i(r) * N * (1 + a_i)}{(E_{avg}(r)) * (N + A)}\right) \quad (10)$$

$(1+ a_i)$ is the initial increment factor for the nodes.

In order to calculate average distance from the base station

$$d_{avg} = \frac{1}{N}\sum_{i=1}^{n} d_i \quad (11)$$

Here, d_i is the distance of the ith node from the BS.

Therefore, the probability for selecting the cluster head is given by:

For $d_i > d_{avg}$

$$P_{ch}(i) = \left(P_{opt} * \left(\frac{d_{avg}}{d_i}\right)\right) \quad (11a)$$

And, for $d_i \le d_{avg}$

$$P_{ch}(i) = P_{opt} \quad (11b)$$

Therefore the value of threshold is equal to:

$$T(s_i) = \begin{cases} \dfrac{P_{ch}(i)}{1 - P_{ch}(i) * (r \bmod \frac{1}{P_{ch}(i)})} & if\ s_i \in G \\ 0 & Otherwise \end{cases} \quad (12)$$

If the value of the random variable generated by the node goes below the threshold it will become the cluster head.

2.4 Calculation of Regions for Cognitive Radio Sensor Nodes

In order to provide a better channel allocation in the network, we have equipped some of the nodes in the network with cognitive radio property of channel sensing and allocating.

Considering, the node density to be constant around the base station, we have calculated the Radius of the two quarter concentric circular regions where cognitive radio sensor are to be placed as follows

$G1 = Area\ of\ region\ 1$

$G2 = Area\ of\ region\ 2$

$G3 = Area\ of\ region\ 3$

Let,

$$\frac{G1+G2}{G3}=\frac{2}{8} \tag{13}$$

And $G1=G2$ (14)

Since $Gi=\frac{\pi * Ri^2}{4}$ (15)

Therefore, from Equation (13), (14) and (15) the value of R1 and R2 are 71 and 101 respectively. The sensor nodes in region 1 and region 2 will follow a single hop approach while, the nodes in region 3 will follow clustering and multi hop routing approach.

2.5 Spectrum Allocation for Region 2 and Region 3 Nodes

Region 1 and region 2 are responsible for allocating channels to the data received from the cluster heads and the nearby nodes from region 3, as well as sending the data to the base station. In order to do so following spectrum allocation strategy was incorporated:

- If the node density of region 2(D2) is greater than node density of region 1(D1) than D1 number of nodes from region 2 will transmit the data to the base station using the channel of D1 region 1 nodes. Rest D2-D1 nodes from region 2 will send the data directly to the base station.
- If the node density of region 1(D1) is greater than node density of region 2 (D2) than n2 nodes of region 2 will transmit through D2 nodes of region 1 and rest D1-D2 nodes of region 1 will directly transmit without any reception.

3. Proposed Algorithm

The proposed method is clearly described by the given flow diagram, Figure 2.

Firstly, a network with nodes, having parameters given in Table 1 was created followed by, the calculation of the initial energy and distance from the base station. The calculation of distance was done by the broadcast signal by the base station and processor installed in each sensor node which calculates the distance of each node from the base station. In order to incorporate our algorithm we have considered some assumption such as:

- All nodes have limited amount of energy.
- All nodes are aware of their location.
- Nodes are near to immobile in position.
- We have considered a random distribution of nodes.

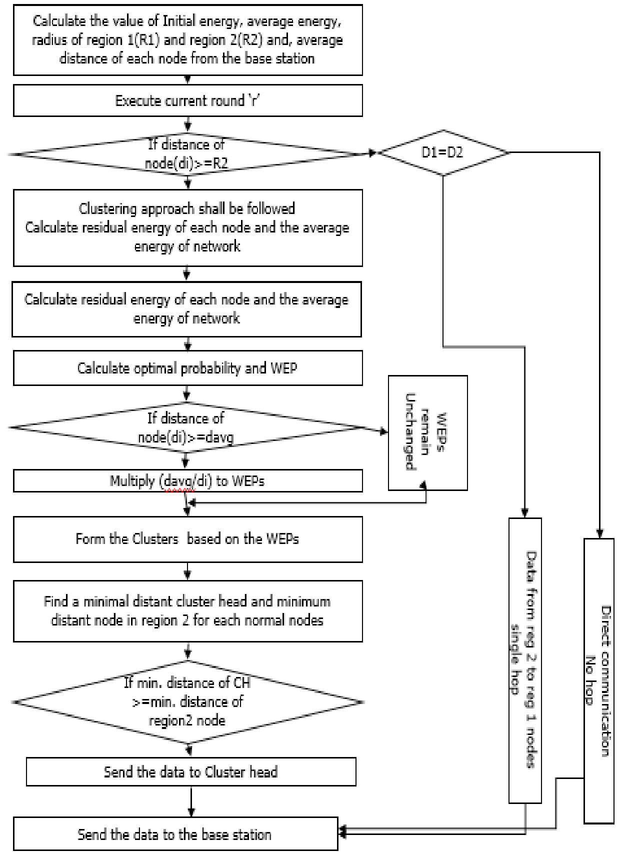

Figure 2. Proposed algorithm flow.

Table 1. Simulation parameters

Parameter	Value
No. of Nodes	100
Size of Network	200*200
Location of B.S.	(200,0) & (-30,230)
Data Aggregation Energy	5nj/bi/round
Packet Size	50 bytes
ε_{amp}	0.0013pj/bit/m^4
ε_{fs}	10pj/bit/m^2
Initial Energy	0.25J

Now, the node will check its distance from the BS and if it is greater than the radius of region two then clustering is performed otherwise the data transmission follows the method described in subsection 5 of last section. The nodes in region 1 and region 2 will intimidate all the other nodes about their location.

While performing clustering, the nodes calculate the value of optimal probability using Equation (10), followed by calculation of average distance. Nodes distance is then compare with the average distance of all the nodes and then accordingly using Equation (11a) and Equation (11b) the cluster head election probability is chosen. They send the data, without any hop, to the BS.

4. Results and Discussion

The proposed algorithm was simulated using MATLAB software with the parameters mentioned in Table 1.

All the observations were done with respect to the two scenarios; one, when the base station was at the corner and the other, when the BS is located away from the network;

It is clearly visible from the Figure 3 that the proposed algorithm was able to increase the Life of the Network.

a. **Scenario 1:** Base station at the Corner

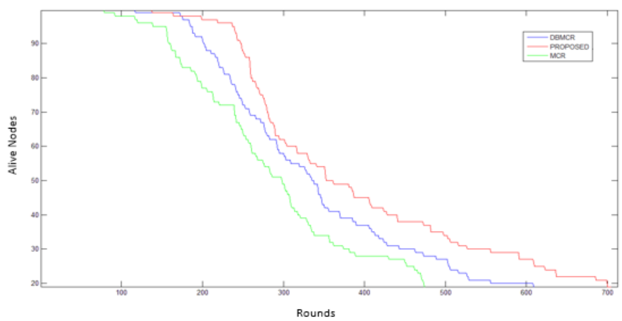

Figure 3. Nodes alive versus current round when B.S. is at (200, 0).

Here, we have considered the stability's definition as number of rounds that had occurred from the First node death till the 80% of the node dies. In that respect, there was an increment of 43.7% in the stability for the proposed algorithm with respect to MCR and, 13.9% with respect to DBMCR.

Also, having the same initial energy, the rate of decrement was reduced by with respect to MCR as well as with respect to DBMCR as seen in Figure 4.

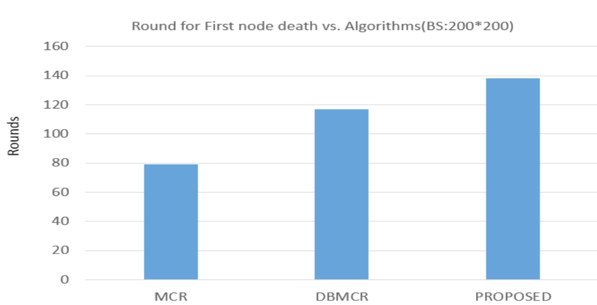

Figure 4. Rounds when the first node dies for different algorithms when B.S. is at (200, 0).

The proposed algorithm was able to hold the network without any dead nodes till 138th round which is 74.68% higher than the MCR algorithm and 17.9% higher with respect to DBMCR algorithm Figure 5.

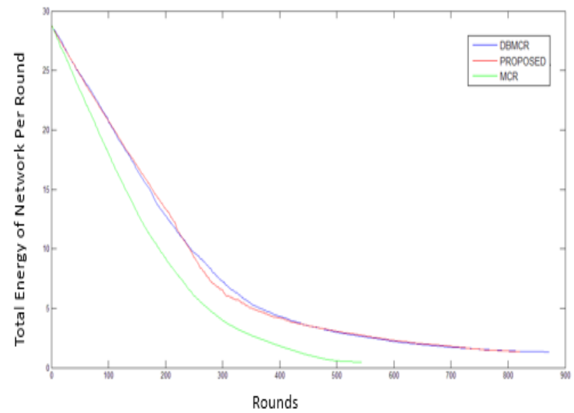

Figure 5. Residual energy with respect to number of rounds when B.S. is at (200, 0).

Also, there was an optimum number of cluster head per round Figure 6 hence, increasing the scalability of the network was increased.

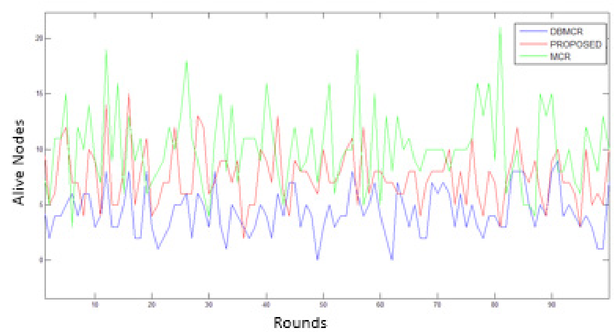

Figure 6. Number of cluster heads with respect to number of rounds when B.S. is at (200, 0).

In this case, as expected the first node death was early, for the proposed algorithm, as compared to the previous scenario Figure 7. But, the stability has increased quite impressively. Here, the stability of proposed algorithm was 40.5 percent higher than the DBMCR and was 45.45% higher than MCR algorithm Figure 8.

A similar trend was seen in case of residual energy Figure 9 whereas for First node death, the proposed algorithm was able to prolong it till 84th round which is greater than the DBMCR and MCR algorithms by 48 and 71.42 percent respectively.

a. **Scenario 2:** Base Station away from the corner

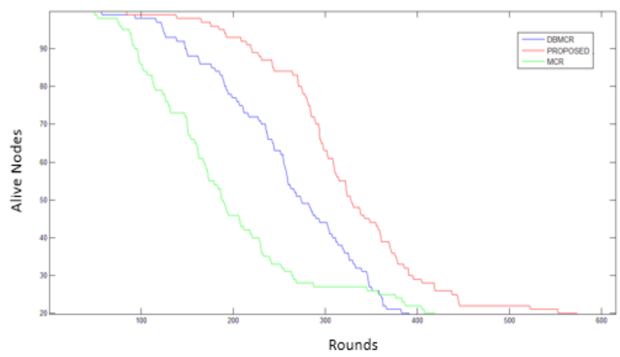

Figure 7. Nodes alive versus current round when B.S. is at (-30,230).

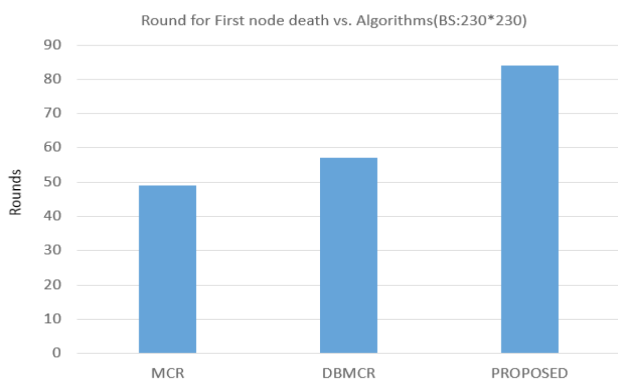

Figure 8. Rounds when the first node dies for different algorithms when B.S. is at (-30,230).

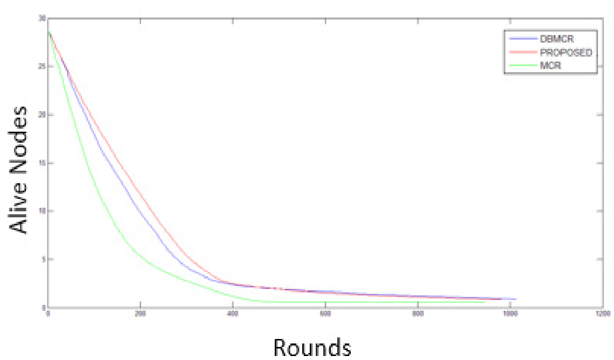

Figure 9. Residual energy with respect to number of rounds when B.S. is at (-30,230).

Here also, the main reason behind the scalability and stability of the network was optimum number of cluster heads per round Figure 10.

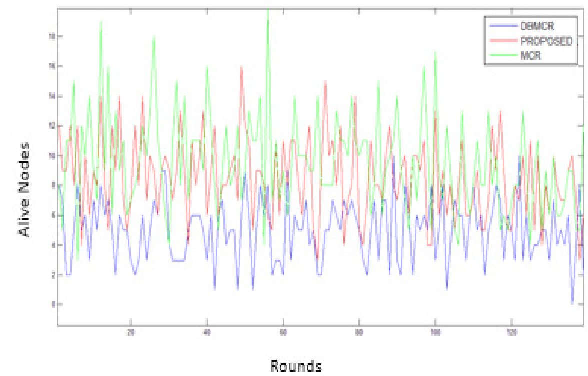

Figure 10. Cluster heads with respect to number of rounds when B.S. is at (-30,230).

Next, the reasons behind the increased efficiency of the network by the proposed algorithm are:

- The cause behind the increased stability is the optimal clustering done by incorporating current energy and average energy of the nodes in the network for choosing the CH election probability.
- One more advantage of this algorithm is its multilevel heterogeneity. The main reason behind this is the ease of introducing new node in between the rounds. They will automatically adapt to the algorithm irrespective of their energy level.
- Moreover, instead of having same initial energy the proposed algorithm was able to outperform the other two because, it was efficiently to circulating the CH on the basis of the distance from the base station and there heterogeneity factor. The main reason behind this is having sufficient amount of cluster heads per round which is done efficiently by our proposed algorithm.

5. Conclusion

The give algorithm was checked with two different scenarios and was found to be more efficient as compared to MCR and DBMCR algorithms in terms of Network stability, Residual energy per round, Number of Cluster heads per round and number of rounds for the first node to die.

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