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Energy Reckoning Distance Based Clustering for Spectrum Aware Cognitive Radio Wireless Sensor Networks

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Abstract: Implementing cognitive radio sensor nodes in wireless sensor networks introduced a smart combination called cognitive radio sensor network (CRSN) which creates new challenges in the design of network topology. Conserving the nodes energy helps to extend the lifetime of the network. This stands as an important criterion while designing any algorithm. In order to achieve the same, two important criteria are to be considered – the communicating distance between the nodes or node to base station and proper spectrum sharing technique. In the proposed work, Energy Reckoning Distance-Based Clustering (ERDBC) algorithm, both the criterion is taken into consideration and designed in order to increase the lifetime of a cognitive radio sensor network. In the ERDBC algorithm, the whole network area is divided into three regions according to the distance and the cluster heads are elected based on energy, distance and common channel creates a greater impact on retaining the nodes energy. Also, implementing multi-hop routing using proper spectrum sharing technique helps to avoid data collision and retransmission thereby; the energy consumption of the nodes are reduced to a greater extent. The performance of the proposed ERDBC algorithm is measured on the basis of residual energy, throughput, channel usage, first node death, last node death, and network lifetime, and compared with the already existing LEACH, CogLEACH, LEAUCH and CEED algorithms. Thus the network lifetime of the proposed ERDBC algorithm is 78.18% more than LEACH, 73.6% more than CogLEACH, 29.88% more than CEED and 17.98% more than LEAUCH algorithms.

Keywords: Cognitive LEACH, Cognitive radio sensor network, Low energy clustering, Spectrum aware clustering.

I. INTRODUCTION

Wireless sensor networks (WSN) which works on energy limited sensor nodes gets over crowded due to its vast applications and die out very fast. A sensor node with Cognitive Radio (CR) capability, deployed in a WSN brought Cognitive radio sensor network (CRSN) into existence.

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This helped the WSN to operate over idle licensed band, which reduced the probability of channel collision and communication delay with an increase in network throughput [1]. It also helped to enhance the energy conservation of nodes and extend the network lifetime. Preserving the energy of the nodes and extending the lifetime of the network stand as an important criteria while designing any protocol. This depends on two important criteria – the communicating distance between the nodes or between the node and base station and proper spectrum sharing techniques. There are various clustering and routing protocols designed in order to increase the lifetime of a network. In all these protocols the sensor nodes, which are battery limited sense, collect, aggregate and transmit the information to the nearby base station. The amount of energy spent by a node to compute the information seems very less compared to the energy spent in transmitting [2]. This is mainly due to the distance between the nodes and base station. Also, the communication among nodes depends on the proper utilization of the spectrum.

In CRSN, utilizing the unused licensed band opportunistically helps to increase the communication dependability and energy efficiency. Opportunistic access of the licensed band by the secondary users (SUs) without interfering the primary users (PUs) transmission plays a crucial role[3]. They bring about a lot of challenges in spectrum sharing and utilization. Many works have been done on spectrum sharing and allocation, but in all these not much of importance is seen in nodes energy conservation. Similarly the clustering protocols which are designed for improving energy efficiency[4] do not look for minimizing the spectrum scarcity problem. Hence, in order to overcome the above challenges, an Energy Reckoning Distance Based Clustering (ERDBC) algorithm for a CRSN has been designed.

The proposed ERDBC algorithm divides the network area into three different regions according to distance and creates clusters according to the calculated probability which depends on the energy and distance in the outermost region alone. Later, the formed clusters collect and aggregates the data and transmits them effectively without any collision or packet drops using spectrum sharing technique. By doing so, the energy of the nodes is sustained and this enhances the stability and lifetime of the network. The performance of the proposed ERDBC algorithm is measured on various metrics like like residual energy, channel usage, throughput, stability(FND and LND) and network lifetime, and is compared to LEACH, CogLEACH, CEED and LEAUCH protocol.

The rest of the paper is structured as follows. Section 2 provides the related works and section 3 explains the network model used and the design of the proposed algorithm. Section 4 gives the simulation parameters used. Section 5 gives the diagrammatic flow of the proposed algorithm. The simulation results and comparison of the performance of the proposed algorithm with respect to various metrics is given in section 6 and sections 7 concludes the paper and provides future research directions.

II. RELATED WORK

Low-energy adaptive clustering hierarchy (LEACH) [5] is the most primitive and also a basic algorithm for designing all clustering and routing protocols. This algorithm is designed for WSN where the concepts of CR techniques could not be brought about. The operation of LEACH is divided into two phases – set-up phase and steady-state phase.

During the set-up phase the cluster head(CH) selection and cluster formation takes place. For a total of 'N' nodes taken, the cluster heads are selected using distributed algorithm where all nodes become cluster head once in (N/k) rounds on average, where 'k' is the expected number of CH nodes in that round [5]. The energy of the nodes is also taken into consideration in electing the CH. The elected CHs advertise message to all other nodes using non-persistent CSMA(carrier sense multiple access) MAC protocol [6] declaring them to be the CH. Based on the received signal strength (RSS) of the advertisement, the other non-CH nodes try to find it nearby CH and become cluster members(CM). When the cluster is fully formed, the CH sets a TDMA(time division multiple access) schedule and send to all its CMs in order to exchange the information collected. The data is finally aggregated by the CHs. Next begins the steady-state phase where the data are transmitted to the base station in frames using fixed spreading code and CSMA. In all the above process, the burden imposed on CH is unequal and they create a load imbalance among all CH. Also, working on fixed channels, the data collision or overlapping of transmission occurs more which thereby reduces the energy of the nodes to a greater extent.

In Ex-LEACH (extended LEACH)[7], which is also similar to LEACH, works on two phases. The CH are selected here using a threshold value T(n) and the CM is elected according to a cluster constraint size[5]. This threshold value T(n) calculated depends only on the initial energy of the node and the present energy of that node in the particular round, helps to increase the network lifetime. Even though they increase the network lifetime, similar to LEACH algorithm, this algorithm also consumes increased energy for the nodes that are quite farther away from the BS than the near ones. Hence, they have uneven balance in the energy distribution, leading to load imbalance too. This analysis proved that the distance of the nodes also plays a vital role in cluster formation and routing.

A new algorithm called LEACH-DT [8] was proposed, considering the distance of the node from the base station as a criteria for CH selection. In this algorithm, the BS initially calculates the distance of all nodes from the them based on the received signal strength. They use this value as a component in the probability equation of LEACH algorithm, in order to elect its own CH. This algorithm also brought multi-hop communication for the nodes which are quite far away from the BS and proved it to be better than a normal LEACH algorithm. Since WSN nodes were deployed, the multi-hop routing technique lead to higher data collision rate and thus the nodes started declining in energy levels quickly.

To avoid data collision and redundant information exchange, an extended version of tree-based clustering(TBC) protocol called General Self-Organized Tree-Based Energy-Balance routing protocol (GSTEB) [9] protocol was designed. Here in this they have four phases - initial phase, tree building phase, self-organized data gathering and broadcasting phase, and information exchange phase. Initially, BS selects a root node and convey its ID and the coordinates to all sensor nodes. Later the tree path is built by each node by calculating the path route from BS to parent node, where the root node remains in the vicinity of parent node. Then they gather and start transmitting the data. Even though this algorithm increases the network lifetime, it is calculated only with respect to the first node death alone. Also, the information regarding the neighboring nodes' position is recorded continuously in order to form the tree. This consumes lots of memory for data storage.

Based on the distance another routing protocol called Centralized Energy Efficient Distance (CEED)[10] was proposed in order to improve the network lifetime by balancing the energy among all nodes. Here the optimum number of CHs is elected in every round based on the three dissipated energies for CH selection, cluster creation and routing. Also the distance which is taken into consideration for analysis are the distance of a CH from BS, CH to its members, the ratio of the distance of each node in a cluster to the BS to the distance of the farthest node from the BS and the average distance among all CH to the BS. By considering all the above criteria and using multi-hop routing technique, CEED proved to be more efficient than LEACH and LEACH-DT. This protocol again works only with WSN nodes. Hence the properties of spectrum management could not be introduced which could further enhance the lifetime of the network.

By introducing CR concept a new protocol named Cognitive LEACH (CogLEACH) [11] was introduced. The CHs was selected based on the channel availability. This helps in increasing the throughput of the nodes, which indirectly aids in increasing the lifetime of the network. Even though this algorithm overtook all the drawbacks of WSN, still it lagged behind because the distance between the CH to BS was not taken into considering for analysis. Hence, the nodes which remain far from the base station die out fast. CogLEACH looks into the vacant channel list for electing its CH. In order to enhance this selection criteria a improved algorithm called CogLEACH-C [12] was proposed. In CogLEACH-C algorithm the CH selection was based on considering both the residual energy of the node and the number of vacant channels. This also helped in increasing the network lifetime, but the limitation that exists for the far away nodes was not met with.

Considering the inadequacy faced in the above algorithm, a new Low-Energy adaptive Uneven Clustering hierarchy (LEAUCH) [13] was proposed. This algorithm brought the uneven clustering technique in the whole network. The channel allocation was done and the nodes with more idle channels were elected as the CHs.

They used multi-hop routing technique in which the residual energy of the node with their distance from BS was considered to elect them as the next hop node for data transmission. This helped them to balance the load among all CHs and provide a better performance in terms of network lifetime.

Later, an improved version of CogLEACH known as Cognitive Improved LEACH (CogILEACH) [14] was proposed. In this two level heterogeneity of energy was brought about.

In this, the CH were selected by considering the ratio of the present residual energy with the initial energy of a node, and multiplying with the square root value of the number of its neighbouring nodes. This increased the network lifetime, but did not consider the spectrum allocation techniques for their analysis.

From all the above analysis, it is clearly seen that the introduction of CR nodes, bringing energy level heterogeneity among nodes and considering the distance of nodes from BS together with spectrum assignment, all considered together could help in further increasing the lifetime of a CR network. Taking all the above parameters into consideration the new energy reckoning distance-based clustering (ERDBC) algorithm for a CRSN has been designed. Here the whole network is divided into different regions according to the distance and further analyzed in order to improve the network lifetime.

III. PROPOSED ERDBC ALGORITHM

Increasing the lifetime of the nodes depend mainly on the proper way of electing cluster heads, cluster members formation and lossless data transmission to the base station. This requires a proper clustering and spectrum aware multi-hop data routing scheme between nodes. Hence the following contributions are considered in designing the proposed ERDBC algorithm.

i) Dividing the network into three regions based on distance.

ii) Applying clustering to R3 region alone by electing the optimized CH.

iii) Applying the spectrum aware clustering technique to elect the CM.

iv) Applying multi-hop routing technique for data transmission.

A. Network model and energy calculation of nodes

Consider a network of ‘M*M’ area, with ‘N’ CR nodes deployed randomly. The BS is located at the center of the network as could be seen in Fig.1. These nodes have energy level heterogeneity among them. They have three levels of energies and are classified as normal nodes, advanced nodes and super nodes. Consider ‘E_0’ to be the initial energy of all nodes. In order to bring the heterogeneity in energy among these nodes we consider ‘m_0’ to be the percentage of advanced nodes with ‘α’ amount of additional energy from ‘N’ normal nodes. Similarly for super nodes, consider ‘β’ amount of energy to be higher for ‘m’ percentage of nodes. The following calculation using (1), (2), (3), (4) and (5) as from [15] [16] is used for calculating the number of nodes and the initial energy.

Let, for example

$m_0 = 0.5$, $m = 0.3$, $\alpha = 1$, $\beta = 2$, $N = 100$ and $E_0 = 0.5J$

Energy of advance nodes,

$$E_{adv} = (1 + \alpha) * E_0 = 2 * 0.5 = 1.0J \quad (1)$$

Number of advanced nodes ,

$$T_{adv} = N * m_0 - N * m_0 * m = 35 \quad (2)$$

Number of super nodes,

$$T_{sup} = N * m_0 * m = 15 \quad (3)$$

Energy of super nodes,

$$E_{sup} = (1 + \beta) * E_0 = 3 * 0.5 = 1.5J \quad (4)$$

Number of normal nodes,

$$Tnrm = N - (Tadv + T\ sup) = 50 \quad (5)$$

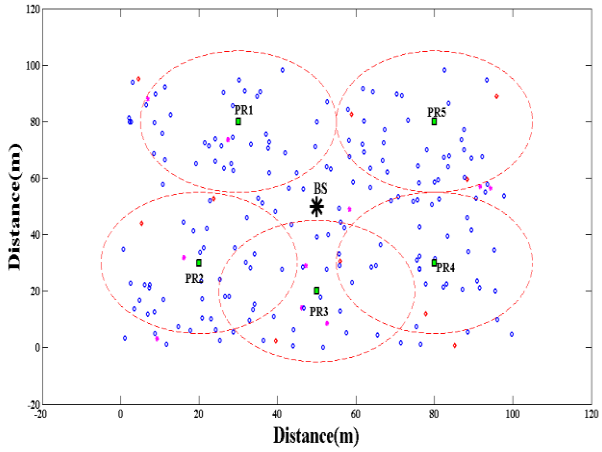

Fig. 1. Deployment of nodes, base station (BS) and primary radio(PR) channels

B. Energy Model

The 1st order radio model used in LEACH algorithm is also used here in this algorithm [2] . The set of equations (6), (7) and (8)are considered for calculating the energy consumption.

$$E_{rxd}(k,d) = (E_{elect} \text{ x } k) + (\varepsilon_{ampl} \text{ x } k \text{ x } d^{\gamma}) \quad (6)$$

$$Etxd(k,d) = \begin{cases} (E_{elect} \times k) + (\varepsilon_{ampl} \times k \times d^2),\ (d < d_0) \\ (E_{elect} \times k) + (\varepsilon_{ampl} \times k \times d^4),\ (d \geq d_0) \end{cases} \quad (7)$$

$$E_{rxn}(k) = E_{elect} \text{ x } k \quad (8)$$

Here E_{elect} is the energy required to elect CH, E_{avg} is the average energy of the network, E_{txd} is the energy required for transmission of data, E_{rxd} is the energy for reception of data, ε_{ampl} is the amplification factor, d is the distance between CH and BS and d_0 is the cross over distance. Each node will use the above mentioned energies for transmitting and receiving `k' bit packets using free space path loss model. Fig.2 shows the design of the first order radio energy model.

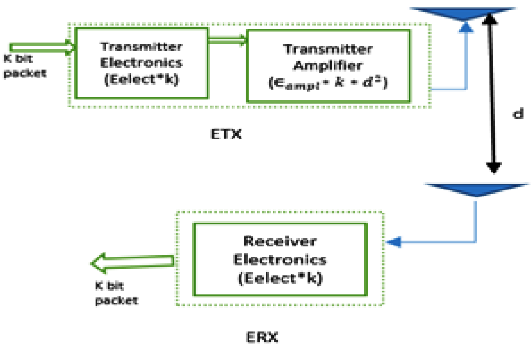

Fig. 2. First Order Radio Model

C. Division of network region

The data transmission consumes more energy than the data gathering process in these networks. So in order to reduce this cost, many authors have designed the clustering only by calculating the distance between the BS and CH. But the effective region where the clustering takes place also plays a vital role. The nodes which are nearer to the BS, can transmit the gathered data directly to them without forming clusters. This reduces a considerable amount of energy used for clustering of these nodes. Also, the nodes that are quite far away, can use the nearby nodes as gateway nodes to communicate the information to the BS. Hence, the whole area of the network is divided into three regions as per the analysis below.

The whole area of the network 'M*M' with BS located at the center, is divided into three regions as R1, R2 and R3 according to (9) and (10) with a radius of R1 and R2 to be r_{R1} and r_{R2} respectively[16]. Consider, R_1 = Area of region1 ; R_2 = Area of region 2; R_3 = Area of region 3 and r_{R1} = radius of R1; r_{R2} = radius of R2.

$$\text{Here, } \frac{R_1 + R_2}{R_3} = \frac{2}{8} \quad \text{with} \quad R_1 = R_2 \tag{9}$$

$$\text{Also the radius, } \frac{{r_{R1}}^2}{{r_{R2}}^2 - {r_{R3}}^2} = 1 \tag{10}$$

The sensor nodes in R1 and R2 will follow a single-hop transmission while, the nodes in R3 will follow clustering and multi-hop routing technique. Fig.3, gives the network configuration after dividing the network into three regions.

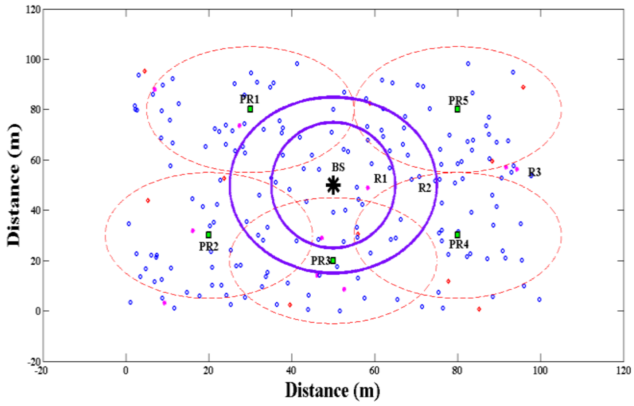

Fig. 3. Division of network into three regions(R1, R2 and R3)

D. Probability of CH selection

On dividing the area into three regions, the node density varies in each region. BS broadcasts an advertisement message to all nodes which helps in finding the number of nodes in each region according to the distance. Since clustering takes place only in region R3, the number of nodes 'N_{R3}' present in the third region alone would participate in clustering. Hence the optimum number of nodes being elected as cluster heads per round would decrease to 'k_{R3}' and '$k_{R3_{opt}}$' be the optimum number of CH elected in a region R3 which has 'N_{R3}' number of nodes in it. This is calculated similar to the LEACH algorithm as given in (11) below.

$$k_{R3_{opt}} = \frac{\sqrt{N_{R3}}}{\sqrt{2\pi}} \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \frac{M}{d^2_{toBS}} \tag{11}$$

As per LEACH algorithm, the probability $P_{R3}\,(i)$ of a node to become a cluster head is given in (12). But in the proposed ERDBC algorithm the CH election probability depends on the available idle channels, the normalized energy of the node, the number of CH elected in that round and the normalized distance of the node to a node in region R2.

$$P_{R3}\,(i) = \frac{k_{R3opt}}{N_{R3}} \tag{12}$$

Let 'C_{ni}' be the available idle channel for a node among the total channels 'C_T'present. 'E_{ni}' be the normalized energy of the node as calculated below in (13). Here 'E_{value} ' is the remaining energy of the node in that particular round, 'max E_{value} ' is the maximum remaining value and the 'min E_{value} ' is the minimum energy value of all one-hop nodes around the particular node. Let 'E_T' be the initial energy of that node.

$$E_{ni} = \frac{(\text{org } E_{value} - \min E_{value})}{(\max E_{value} - \min E_{value})} \tag{13}$$

The normalized distance of the node to the BS '$d_{ni\text{-}BS}$' is calculated using (14) where 'd_{value}' is the distance of the particular node from BS, 'max d_{value}' is the maximum distance and 'min d_{value}' is the minimum distance of all one-hop nodes around the particular node. Later '$d_{ni\text{-}BS}$' is subtracted from the radius of region 2 'r_{R2}' as given in (15) in order to elect them as cluster heads.

$$d_{ni-BS} = \frac{(\text{org } d_{value} - \min d_{value})}{(\max d_{value} - \min d_{value})} \tag{14}$$

$$D_{iR3} = d_{ni\text{-}BS} - r_{R2} \tag{15}$$

Calculating all the above parameters, the new probability of a node to become a CH as is given by (16).

$$P_{R3}\,(i) = min\left(N_{R3} * k_{R3_{opt}} * D_{iR3} * \frac{C_{ni} * E_{ni}}{C_T * E_T}, 1\right) \tag{16}$$

Also, in order for the proper balance, the energy consumption among all nodes, a threshold value according to LEACH [5] is calculated using the proposed probability value $P_{R3}(i)$ as given in (17) below for the node to be elected as CH in that round.

$$T_{r,i} = \begin{cases} \frac{P_{R3}(i)}{1 - P_{R3}(i)\left(r \bmod \left(1/P_{R3}(i)\right)\right)}, & if\ C_{H,i} = 1 \\ 0, & if\ C_{H,i} = 0 \end{cases} \quad (17)$$

E. Allocation of primary user radio model

In the proposed model all CHs are assumed to be the PUs. Hence Semi-Markov ON-OFF process is assigned and they follow the time intervals as two independent variables 'qi' and 'pi' respectively as designed by the authors in [13] for the Fig.4.

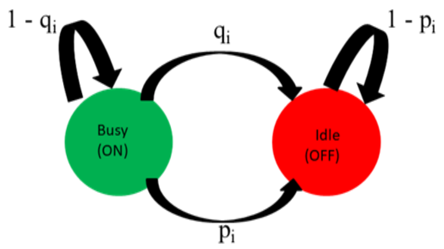

Fig. 4. Semi-Markov ON-OFF Process

They also calculate the stationary probability 'p_f' for a channel 'i' by (18).

$$p_f^i = \frac{q_i}{q_i + p_i} \quad (18)$$

According to the work in [14], if all channels are assumed to have the same 'p_f', they follow a binomial distribution as given in (19), where the probability of a node which has 'I' number of idle channels out of the 'm' number of total channels is,

$$P_r[N = I] = \binom{m}{I} p_f^I (1 - p_f)^{m-I} \quad (19)$$

Since in the proposed method only spectrum similarity radio model [11] is considered, the channels of a single PU will have the same p_f while different PUs have different p_f. The coverage of the radio range is shown in Fig. 5, below.

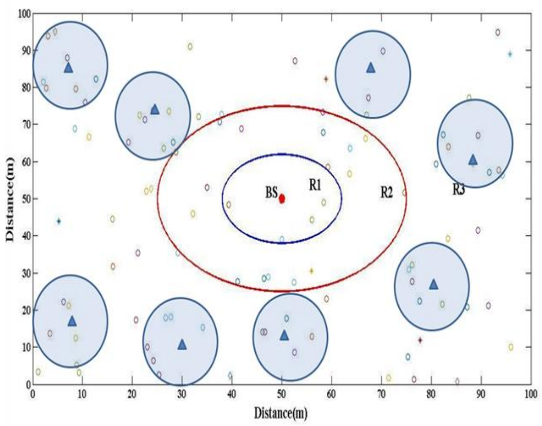

Fig. 5. Spectrum similarity model with Primary radio range

F. Cluster formation

Once the CH has been elected, according to spectrum similarity model, all the nodes that come under the CH's primary radio range can be accepted as its members according to figure 6. Hence the CH broadcast an advertisement (ADV) message to all nodes regarding its ID and its common control channel(CCC) [17]. The nodes which receive this message will check for the distance between them and the CH. The node which satisfies the above two conditions will become its CM immediately. Else, if a node receives ADV from two CH, then it would check for the distance between the node and the CHs. The node which has less distance and has the common idle channel of CH to be one of its idle channels, then it will reply back an acknowledge (ACK) signal to the requested CH. This helps the CH to elect its CM effectively.

The nodes which are not elected as CM, will act independently and communicate to the CH which has one idle frequency channel common among them. This turn out the particular node to be an elected CM for the particular CH which helps in collecting the data and transmitting the same to the BS through these CH. This helps to include the nodes which are not participating in the clustering process. Similar to LEACH algorithm, the TDMA scheduling is scheduled and sent among all the cluster members for data transmission to the CH.

G. Routing the aggregated data to base station

In LEACH this phase is called the steady state phase. The CH aggregate all the data from its CM by creating a TDMA schedule in order to avoid inter-cluster interference among them. Also, in order to transmit the collected data and to help the nodes that are quite far away from BS and region R2, multi-hop routing has been used. This helps the far away node to retain its residual energy.

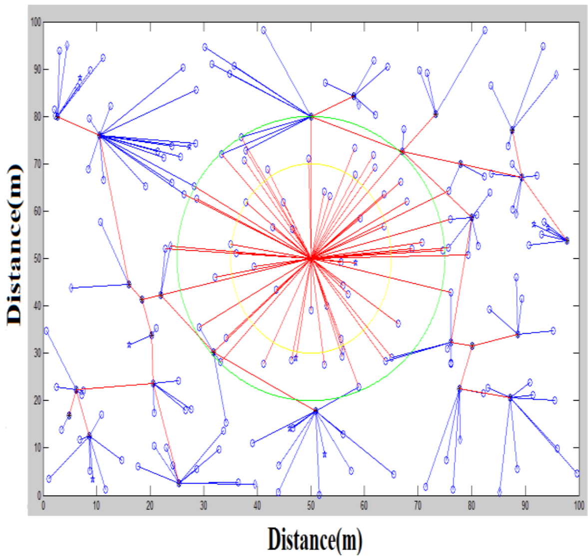

Fig. 6. Clustering and routing of data to BS

The CHs that are within the nodes' transmission range, transmit the data directly to the nodes in region R2 using its PR channel and those nodes to carry over it to the BS. The CH that are quite far away from R2 region,

look out for a nearby CH that share the same idle channel and is at the minimum distance to them.

This helps them to avoid energy loss due to long distance transmission and intra-cluster interference too. Once all the data are transmitted, the cluster disintegrate and the algorithm go for the next round of cluster formation and data collection. Fig. 6. below shows the clustering and data transmission occurring in the proposed ERDBC algorithm.

IV. FLOWCHART

The diagrammatic flow of the proposed algorithm is given as a flowchart in Fig.7.

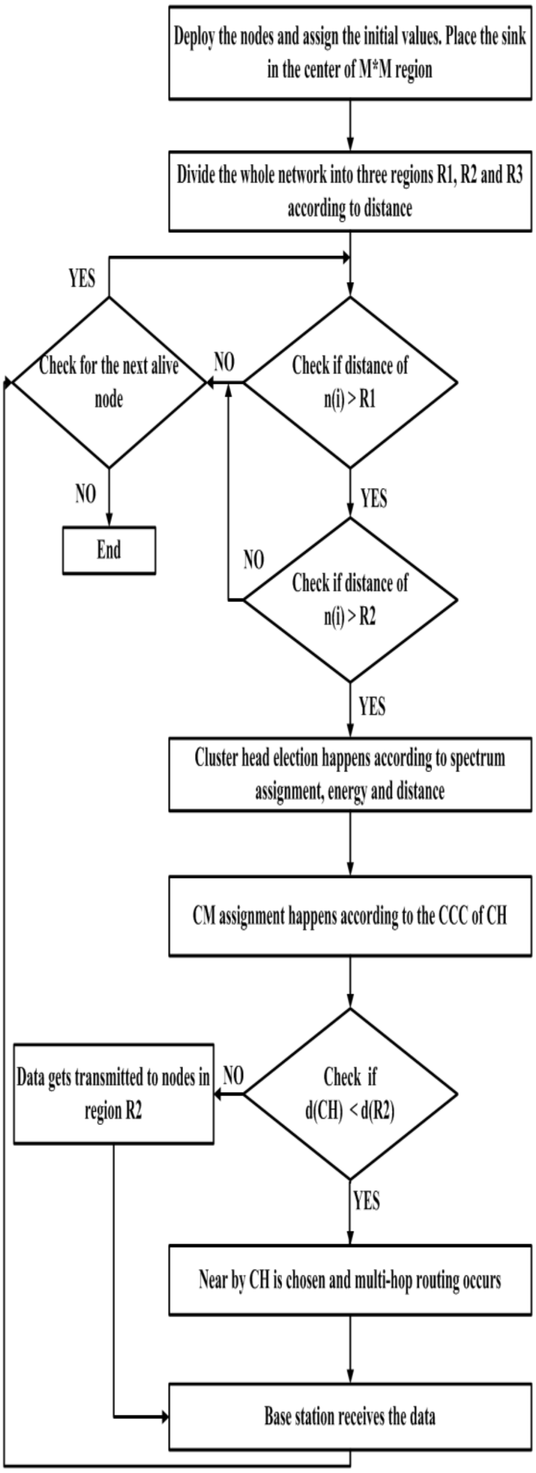

Fig. 7. Flowchart of ERDBC algorithm

V. SIMULATION PARAMETERS

The parametric values used for analyzing the proposed ERDBC algorithm are given in table 1. In order to have a uniform comparison, all the already existing algorithms like LEACH, CogLEACH, CEED and LEAUCH are also simulated using the same parameters and the resultant values are taken for result analysis.

Table-I: Simulation Parameters

Parameter	Values
Initial energy of nodes	0.5 J
E_{TX} / E_{RX}	50nJ
E_{DA}	5nJ
E_{fs}	10pJ/bit/m^2
E_{amp}	0.0013 pJ/bit/m^4
Energy for channel switching (J_{sw})	40mJ
Network area(M*M)	100 x100 m^2
Number of nodes	100
Sink location	(0,50)
Node range(r)	10 to15 (m)
Control Packet size	200bits
Data Packet size	4000bits
PR range (R_R)	25m
Number of Channels	5
% of advanced nodes (m_0)	0.5
% of super nodes(m)	0.3

VI. RESULT ANALYSIS

The simulation of LEACH, CogLEACH, CEED, LEAUCH and ERDBC is done using MATLAB. The residual energy of the nodes, throughput, number of CH generated, channel usage, the first node death(FND), the last node death(LND) and the network lifetime are taken into consideration for the analysis.

A. *Residual Energy*

The amount of energy that is left behind in nodes after each round of execution is called the residual energy. Fig. 8. and Table-II gives an idea of the increase in residual energy of the proposed ERDBC algorithm in comparison to all other algorithms.

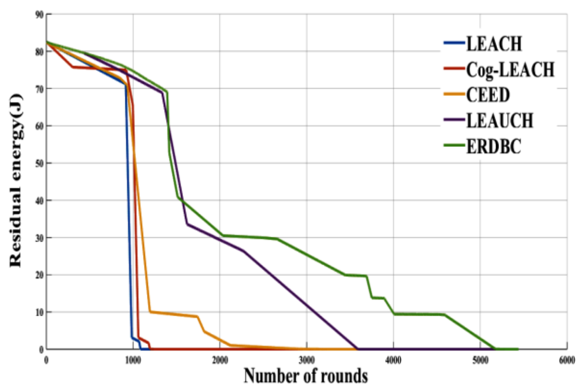

Fig. 8. Residual energy of the network

Since LEACH and CEED works on WSN nodes, the CR techniques could not be incorporated and hence they face a lot of data collision.

This ultimately leads to repeated data transmission and gradually the nodes die out fast.

In CogLEACH and LEAUCH, even though they incorporate CR techniques like spectrum sharing and channel allocation, they too fail since they don't look into the nodes which are quite far away from BS, which looses their energy due to long distance communication that happens between the nodes and BS. In the proposed the division of region helps to reduce the clustering range.

Table-II: Residual energy at specific rounds

Round	LEACH (J)	Cog LEACH (J)	CEED (J)	LEAUCH (J)	ERDBC (J)
0	82.380	82.380	82.380	82.380	82.380
500	76.340	75.510	76.770	78.790	79.100
1000	2.900	66.470	53.080	73.000	74.700
2000	0.000	0.000	2.470	29.310	31.230
3000	0.000	0.000	0.028	11.790	25.380
4000	0.000	0.000	0.000	0.000	9.630
5000	0.000	0.000	0.000	0.000	2.880

Also taking into account the normalized energy and distance of the nodes from R3 region to BS, and minimization of the transmission range to region R2, reduces the energy of the node spent for long distance communication. Hence it is seen that the proposed algorithm has high residual energy and helps to keep the nodes alive for longer duration than the other algorithms.

B. *Channel Usage*

The amount of control and data packet exchange that happens in each channel is calculated and analyzed here. Fig.9. gives an analysis of the channel usage of all the algorithms.

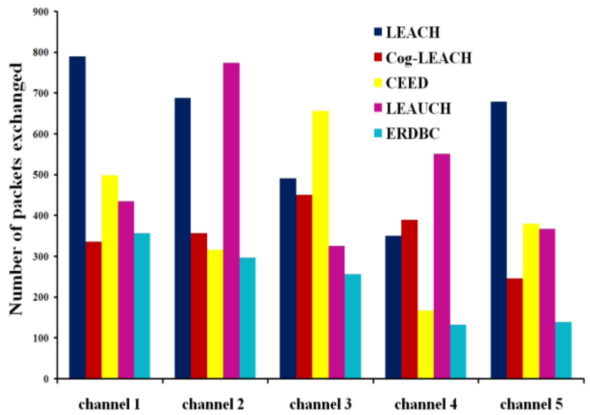

Fig.9. Number of packets exchanged per round

The analysis shows the number of packets exchanged in each channel during one single round when all the nodes are alive. From the analysis, it is clearly seen that the proposed ERDBC algorithm has less channel usage for both control and data packet exchange due to the implementation of distance based clustering which reduces the number of nodes that take part in clustering. This reduces the amount of control signal exchange and the spectrum aware technique help is reducing data retransmission. Hence, the proposed algorithm gives an optimized usage of channels compared to other algorithms.

C. *Number of Cluster head elected*

The number of CH generated in each round is given in Fig.11. below. It shows that the proposed algorithm ERDBC has stable CH generation till the first node dies and later it starts to gradually decrease.

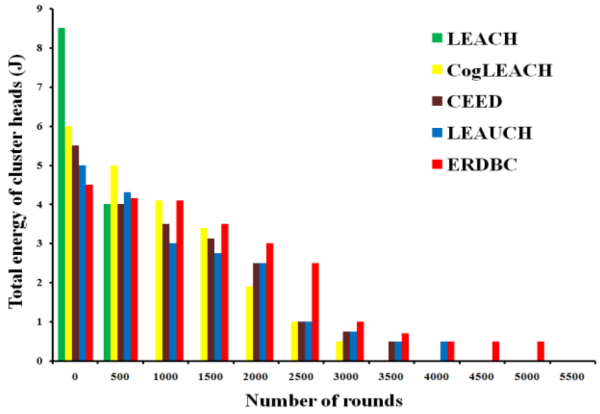

Fig. 10. Amount of energy consumed by the cluster head

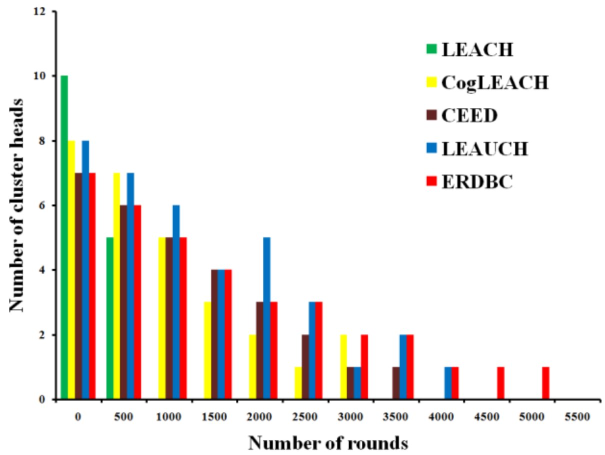

Fig. 11. Number of Cluster Head generated per rounds

Table-III: Number of cluster heads generated

Rounds	LEACH	Cog LEACH	CEED	LEAUCH	ERDBC
0	8	10	10	9	8
500	5	7	6	7	6
1000	2	5	7	6	5
1500	0	3	5	4	4
2000	0	2	3	5	3
2500	0	1	2	3	3
3000	0	2	1	1	2
3500	0	0	1	2	2
4000	0	0	1	1	1
4500	0	0	0	1	1
5000	0	0	0	0	1
5500	0	0	0	0	0

In comparison, it is evident that the proposed ERDBC has a relatively less CH selection. Due to the division of regions the nodes which takes part in clustering reduces, which thereby reduce the number of CH elected. Also, by decreasing the distance of data transmission for CH's, the energy spent on long distance data transfer is also retained. Thus the sensor nodes retain their energy for quite a longer duration. Fig. 10 gives the total amount of energy consumed by the CH generated.

The resulting analysis shows that the proposed algorithm consumes less energy compared to the other algorithms and the cluster remains alive for longer duration since they follow spectrum sharing technique for data collection and transmission.

D. *Throughput of the network*

It is the amount of data being transmitted by the number of alive nodes to the BS, in every round. From Fig.12., it is inferred that the number of data bits transmitted for the proposed ERDBC is better compared to all other algorithms.

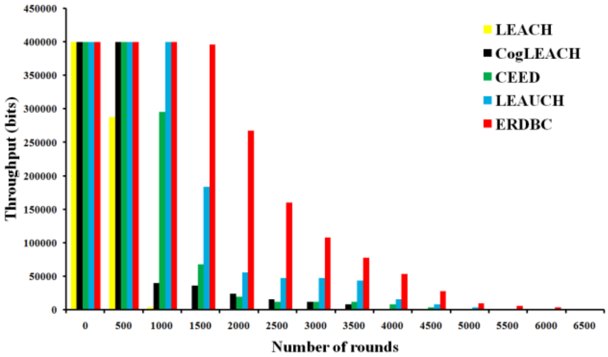

Fig. 12. Throughput of the network

This is mainly due to the selection of CHs using common control channel and also transmitting the aggregated data to the BS, through a selected primary channel among all CHs. In LEACH and CEED, the WSN nodes face lot of data collision. Hence the throughput, reduces greatly. In CogLEACH even though it follows CR concepts still it lags behind due to the distance that the far away CHs need to cover in order to transmit the data to the BS.

E. *Network lifetime and Stability of the network*

The lifetime of the network is defined as the rounds till which the nodes stay alive and help in keeping the network working for capturing and transmitting the data. Fig. 13 shows the simulation analysis of the lifetime of the network.

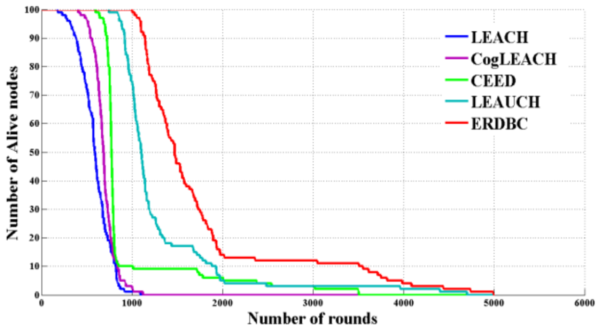

Fig. 13. Lifetime of the network

Table-IV: Round at which FND and LND occur

Algorithm	Round at FND occurs	Round at LND occurs
LEACH	200	1091
CogLEACH	402	1320
CEED	598	3506
LEAUCH	642	4101
ERDBC	1001	5000

The stability of the network in this work is calculated on the basis of the rounds at which the first node death(FND) and the last node death(LND) occurs. Table-IV and Fig.14, gives the rounds at which the FND and LND occur. From Table-IV, it is inferred that the number of rounds gets increased for FND by 801 rounds for LEACH, 599 rounds for CogLEACH, 403 rounds for CEED and 359 rounds for LEAUCH. Also the LND gets increased by 3910 rounds for LEACH, 3681 rounds for CogLEACH, 1495 rounds for CEED and 901 rounds for LEAUCH.

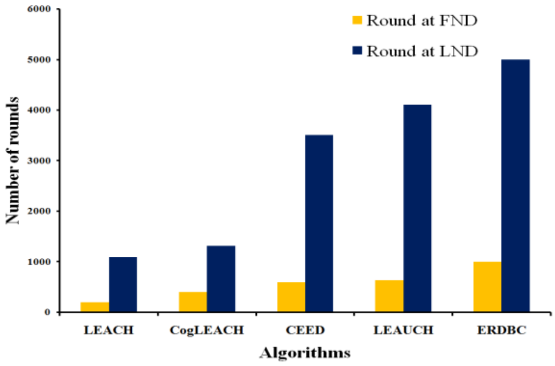

Fig. 14. Result of FND and LND

From Fig.14. it is clearly seen that the stability of the proposed ERDBC network is clearly increased. FND of the proposed ERDBC algorithm is 80.02% more than LEACH, 59.84% more than CogLEACH, 40.25% than CEED and 35.86% than LEAUCH. This is mainly due to the amount of energy being dissipated by each node for clustering and routing, is very less in the proposed ERDBC compared to LEACH, CEED, CogLEACH and LEAUCH algorithms.

VII. Conclusion

The division of the network area into different regions based on the distance of the nodes from the base station, electing cluster heads based on energy, distance and common channel, and using multi-hop routing with spectrum sharing technique helps the proposed ERDBC algorithm to perform better than other existing algorithms. The reduction in packet loss and retransmission, helps in increasing the nodes residual energy and sustain the network lifetime for a longer duration. Experimental analysis also proves the proposed ERDBC algorithm outperforms the other algorithms like LEACH, CEED, CogLEACH and LEAUCH, in terms of residual energy, throughput, cluster head count, FND, LND and network lifetime. Thus, the network lifetime of the proposed ERDBC algorithm is 78.18% more than LEACH, 73.6% more than CogLEACH, 29.88% than CEED and 17.98% than LEAUCH. The work could be further enhanced by introducing mobile sink and the further challenges by implementing them could be analysed.

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