Bosupally NandaKumar, et. al. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 13, Issue 10, October 2023, pp 107-117

RESEARCH ARTICLE OPEN ACCESS

Energy-Efficient Multihop Clustering Routing Protocol for Cognitive Radio Sensor Networks

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ABSTRACT
In Cognitive Radio Sensor Networks (CRSNs), Sensor nodes are energy constrained and creates an energy depletion problem which in turn diminishes the network lifetime. Clustering is found as one of best solution which unequally distributes the traffic on Sensor Nodes and enhances the network lifetime. However, a uniform clustering results in quicker energy depletion of network. Hence, this paper proposes a new non-uniform clustering mechanism called as Energy-Efficient Clustering Routing Protocol (EECRP) for CRSNs. EECRP considers three parameters namely Distance, Energy Consumption and Chanel Utilization rate for the selection of optimal next hop neighbour node in multi-hop routing. Extensive Simulation experiments have been carried out on the proposed EECRP model and the performance is analyzed through three metrics namely Number of Alive nodes, Packet delivery ratio and Control overhead. Further, the comparison between proposed and existing methods proves the superiority in terms of overhead reduction and network lifetime improvisation.

Keywords - Cognitive Radio Sensor Networks (CRSNs), Energy, Channel Availability, Clustering, Routing Protocol.

Date of Submission: 04-10-2023 Date of acceptance: 16-10-2023

I. INTRODUCTION

The combination of Cognitive Radio (CR) Technology and Wireless Sensor Networks (WSN) formed an intelligent network called as Cognitive Radio Sensor Network (CRSN) [1]. In CRSN, CR Technology allows a sensor node to detect an unused spectrum or spectrum holes which was not occupied by Primary Users (PUs) and it can access the unused spectrum dynamically without interrupting the PUs usual communication [2]. Generally, the sensor nodes which were present in the CRSN are not capable of enough energy and mostly they operate on batteries and deployed in resource constrained environment. In this case, it is too difficult or even impossible to recharge their batteries. Further, due to the multiple operations such as spectrum sensing, dynamic spectrum access was performed by the CR consumes additional energy and it implies energy consumption problem [3]. Further, the energy consumption increases when the sensor nodes are deployed in large monitoring areas and they are far away from the sink node due to multihop data transmission. To address this issue, few researchers have been suggested clustering technique as one of the solutions for multihop CRSNs.

Clustering minimizes the energy consumption by reducing the number of data packets t b transmitted using data compression and accumulation methods [4], [5] such that the network lifetime increases. In uniform clustering, Cluster Heads (CHs) nearer to the sink node exhibits more inter-cluster data communication tasks than the far CHs. Uniform Clustering cannot balance the residual energy among the nodes and they create energy hole problem in the multihop CRSN [6]. To address the energy-hole problem in Multihop CRSNs, past research studies suggested non-uniform clustering mechanisms where the CH balances the residual energy and minimizes energy consumption by varying cluster radius. Even though non-uniform clustering extends the network lifetime, they have few limitations [7] in terms of multihop communication, dynamic channel accessibility, specific network configurations include node density, network size, and maximum transmission range, and energy consumption of data transmission. In order to handle all these issues, this work proposes a new Energy-Efficient Clustering Based Routing Protocol for CRSNs. The entire methodology is accomplished in four phases; they are (1) Spectrum Sensing (SS), (2) Cluster Formation, (3) CH selection, and (4) Multi-hop Routing for data transmission. Therefore, the major contributions of this work are outlined as follows;

1. To minimize the overall network energy consumption, this work proposes non-uniform clustering and CH selection mechanism based on available energy and channel utilization rate.
2. To improve the network lifetime, this work proposes energy efficient routing protocol which considers the distance and energy metrics.

The remaining paper is organized into four sections. Section 2 describes the related past works relevant to the CRSNs, section 3 elaborates system model and proposed methodology, section 4 demonstrates the simulation experiments to validate the performance of proposed methodology, and finally section 5 explores the conclusion of this work.

II. RELATED WORKS

Clustering based routing protocol is one of the prominent solutions for energy balancing in CRSNs. This section explores the past related works of clustering in CRSNs. Yadav *et al.* [8] suggested an optimal cluster number to build up their energy-aware cluster-based routing protocol. Here, the optimal number of clusters was derived based on the energy consumed in an intra-cluster communication related to an information collecting phase in each cluster, and the energy consumed while transmitting data in inter-cluster from each CH to the BS in a single-hop transmission. But they were not concentrated on multihop communication. Mortada *et al*. [9] focused on a clustered CRSN where the CH performs SS, gathers the data, and sends it toward a central base station by adopting an ad hoc topology with in-network data aggregation (IDA) capability. In such networks, when the number of clusters increases, the consumed energy by the data transmission decreases, while the total consumed energy of SS increases, because more CHs need to perform SS before transmitting. Further, to select the best number of clusters, a study is derived aiming to extend the network lifespan, taking the SS requirements, the IDA effect, and the energy consumed by both SS and transmission into consideration. However, the dynamic nature of PUs is not considered, so that inaccurate paths may get selected and it increases energy consumption.

Xiaoyan Li *et al.* [10] proposed a combination weighted clustering algorithm to reduce the communication overhead of the distributed cognitive network and to maintain the stability of the network structure. First, a clustering algorithm formulated based on the available channel, geographic location, and experienced data (used for collecting the behavior of secondary users (SUs) in the network and the evaluation on it) of SUs is put forward through analyzing the characteristics of the idle channels in cognitive network. Three factors, namely, average channel capacity, stability, and channel quality, are converted into quantifiable values. Then, CH is determined on the basis of these three factors. Further, the cluster members and gateway nodes are determined using the weighting formula and the location information of the CH. They majorly concentrated on data transmission but energy is drastically depleted when the nodes are distant from the sink node.

To ensure stability, scalability, efficient spectrum management, and reduce communication overhead, Santhosh kumar *et al.* [11] suggested a localized clustering scheme. Here, each node computes its weight and shares with its one hop neighbors, and a node with maximal weight becomes the CH. Subsequently, the neighbor node sharing the channel(s) with a CH joins it to form a cluster. To provide fault tolerance, vice-cluster head is also selected along with CH. Even though, they reduced the communication overhead, they didn't concentrate on path selection through which the data reaches the sink node.

J. Wang and C. Liu [12] proposed an imperfect spectrum sensing-based multi-hop clustering routing protocol (ISSMCRP) to alleviate the impact of imperfect spectrum sensing on network performance. CH and relay selection criteria are defined based on detection level of available channels with high spectrum sensing capability. Idle detection accuracy based intra-cluster and inter-cluster channel selection criterion is proposed to promote successful intra-cluster and inter-cluster data delivery. In addition, control overhead introduced by CHs selection and cluster formation is strictly controlled, and reasonable cluster radii are set to manage the range of control information exchange, so as to reduce the energy consumption caused by control overhead. However, the authors didn't consider the dynamics of clusters which increases the energy consumption of the network.

To solve the problems of low spectrum utilization and channel congestion caused by the static division of spectrum resource, Ye, H. and Jiang, J [13] proposed an optimal linear weighted cooperative spectrum sensing for clustered-based CRNs. Here, different weight values were assigned for cooperative nodes according to the SNR of cognitive users and the historical sensing accuracy. In addition, the cognitive users are clustered and the users with the better channel characteristics are selected as CHs for gathering the local sensing information. They achieved better detection probability but network lifetime was reduced due to static weight values assignment for CH selection.

L. V. R. C. Prasad *et al.* [14] suggested weighted clustering parameter based adaptive clustering algorithm to prolong the network lifetime by balancing the energy consumption among the CHs. The parameters for CH selection are considered in the algorithm are node coverage, spectrum availability, queue length, and residual energy. The cluster stability is improved using an optimal selection of reliable CHs for each cluster. The Cluster Head Weight (CHW) parameter for each node is determined and the CHs are chosen using the CHW parameter. An optimal relay selection method is also incorporated in the proposed method based on fuzzy logic (FL) to select the quality relay node for intra- and inter-cluster communications. The parameters like channel quality, link error rate, and traffic index are considered as input in the fuzzy system for relay selection. The dynamic nature of PUs is not considered, so that inaccurate paths may be selected and it consumes additional energy.

Surajit Basak and Tamaghna Acharya [15] used a convex optimization framework to determine the closed form expression for each transmitting node's optimal transmit power. Routing algorithm called as Spectrum Aware-Minimum Outage Intelligent Cooperative Routing (SA-MOICR) method is proposed which chooses a minimum outage path and determines the number of nodes and a unique PU channel to transmit along the path for each hop. However, the channel state information is not included in the routing process.

To provide efficient spectrum management, minimized communication overhead, better stability, and scalability Kumar *et al.* [16] proposed a novel technique known as localized clustering. Cluster formation is accompanied using the channels which share with the CH for neighbor nodes. A vice CH is chosen to provide fault-tolerance along with the CH. However, this method lacks of efficient data aggregation. No efficient relay or forwarder node selection mechanism and fault tolerance during data communication is addressed. Anil Carie *et al.* [17] proposed a technique for integration of sensor nodes with the nodes of CR for routing the data to sink based on licensed channels. For the clustering of CR and sensor nodes, they considered energy efficiency of nodes. However, the channel state information is not included. Next, to minimize the energy consumption and to improve the network lifetime, G. A. Safdar *et al.* [18] proposed an energy efficient fuzzy logic-based clustering (EEFC) algorithm. EEFC uses a set of fuzzy input parameters to select the CH. Unlike most of the other probabilistic as well as fuzzy logic-based clustering algorithms, EEFC increments the fuzzy input parameters from three to four to obtain improved solutions employing the Mamdani method for fuzzification and the Centroid method for defuzzification. However, the fuzzy logic increases the computational complexity and decreases network lifetime.

A. Verma *et al.* [19] introduced CHEF is a distributed clustering algorithm that uses both a probabilistic approach and parameters to select CHs. CHEF does not require the BS to gather all the characteristics of the sensor nodes. Interim CH candidates are selected based on the probabilistic approach of LEACH and then fuzzy logic is implemented which utilizes the fuzzy input parameters such as residual energy and local distance to calculate the output parameter chance as to which interim CH candidate will become the CH. However, the major drawback is that the local distance is not a suitable parameter for selecting efficient CHs and hence resulted in re-clustering overhead in every round. Shakhov *et al.* [20] Proposed an Efficient Clustering Protocol for CRSNs. They considered the remaining energy and the quality of available common channels for CH selection. In addition, the security issues are alos considered to develop an efficient clustering protocol. Further, the weighted clustering metric introduced by Wang. T *et al.* [21] includes temporal–spatial correlation, confidence level, and residual energy. They assume the Euclidean distance between any two nodes in the network is known and does not change. Furthermore, the channel state was also ignored.

M. Zheng *et al.* [22] suggested a Stability-Aware Cluster-Based Routing (SACR) protocol for CRSNs. In the aspect of cluster formation, they considered the spectrum dynamics and energy consumption for clustering. The resulting clustered architecture is stable and thus avoids large communication overhead due to high clustering frequency. For data routing, SACR adopts an opportunistic forwarding scheme which selects a unique CH by accounting for its cluster size, number of available channels, and hop distance to the gateway. However, they didn't utilize a dedicated common control channel and they didn't consider the cluster dynamics.

E. Pei *et al.* [23] proposed heterogeneous nodes based Low Energy Adaptive Clustering Hierarchy (HLEACH) algorithm. Here, the sink node first updates the global information including the optimal number of clusters and average cluster radius and then broadcast it. Each cognitive node calculates its competition radius after receiving the broadcasting information and then starts the competition for CHs based on the proposed competition rules. The selected CHs are finally censored targeting the optimal number of clusters to optimize the distribution of final CHs. In clusters' formation stage, non-CH cognitive nodes and sensor nodes synthetically consider the distance and the connection degree of CHs such that the distribution of CNs among clusters and the energy consumption among CHs can be energy efficiently balanced. Even they achieved better energy balancing among the nodes, the dynamic nature of PUs is not considered and resulted in inaccurate path selection.

III. PROPOSED APPROACH

3.1 System Model

Here, we consider N number of Sensor Nodes with CR capability are randomly deployed in a circular shaped region and *M* number of primary users can access the spectrum opportunistically which are distributed stochastically in the monitoring region. Next, Semi-Markov ON/OFF state model is considered to observe the dynamic behavior of PUs [24]. Specifically, each licensed or primary user operating in two states such as ON and OFF whose time durations are distributed exponentially. Moreover, these two States are independent each other. Once the SNs are deployed their location is fixed and they have unique ID.

One sink node is deployed at the center of the monitoring region and it has the provision of unlimited power supply and the processing capability [25-26]. Here, each SN obtains its own remaining energy, geographical location, available channels, and other relevant information. The Euclidian distance between SN and sink node ensures the minimum data transmission delay and the entire monitoring region is partitioned into few angular layers. Each angular layer has equal radius which is equal to the maximum transmitting sensing range of SN i.e., R_{max}. The layer nearer to the sink node is assumed as layer 1 and if the distance from sink node increases then the number of layers also increases. Each SN can obtain its layer number ($R_l(i)$) among the number of layers such as $l \in 1,2,...p...P$, where P represents maximum number of layers. Based on the Euclidian distance between the sink node and the SN i the $R_l(i)$ is calculated as,

$$R_l(i) = \frac{d_i^{\sin k}}{R_{\max}} \qquad (1)$$

where, $d_i^{\sin k}$ represents the Euclidean distance between the SN i and sink node. The sensor nodes which are present in the same layer p $(p \neq 1)$ form clusters by exchanging the local information. Cluster Members (CMs) forwards the collected data to CH and then the CH transfers it to sink node through multiple hops.

3.2 Energy Consumption Model

It is commonly used to evaluate the energy consumption during the data transmission in CRSNs. This work uses free space or multi path propagation model and these models are employed based on the distance between the sender and receiver node *(d)*. The threshold distance (d_{Th}) is used to decide the type of propagation model (d^2 or d^4) [27]. The free space energy model (d^2 power loss) is used when the distance between the sender and the receiver node is less than or equal to d_{Th}, otherwise, multipath energy model (d^4 power loss) is used. Generally, the energy consumption at each SN is evaluated based on four states: transmitting, receiving, idle and sleep. Among these four states, Idle and sleep states consume negligible amount of energy. Therefore, we consider energy consumption during transmitting and receiving states only. The amount of energy consumed to transmit a packet of *b*-bit length [27] over the distance *d* is given by,

$$E_{trandmitting}(b,d) = \begin{cases} b\times E_{el} + b\times \varepsilon_{fs} \times d^2, \ if \ \mathrm{d} \le \mathrm{d}_{Th} \\ b\times E_{el} + b\times \varepsilon_{mp} \times d^4, \ if \ \mathrm{d} \le \mathrm{d}_{Th} \end{cases} \quad (2)$$

where E_{el} signifies the energy consumption at the transceiver to transmit or receive 1-bit of information, and ε_{fs} and ε_{mp} signifies the energy consumption coefficients of power amplifier in free space and multipath propagation environments respectively. Additionally, $d_{Th} = \sqrt{\frac{E_{fs}}{E_{mp}}}$ denotes the threshold distance. The amount of energy consumed to receive a packet of *b*-bit length [27] is given by the following:

$$E_{receiving}(b) = b \times E_{el} \quad (3)$$

3.3 Proposed Energy-Efficient Clustering Routing Protocol (EECRP)

The proposed model is designed to reduce entire network's energy consumption by balancing the energy in each layer. It is accomplished in four phases; Spectrum Sensing, CH selection and cluster formation, route establishment and data transmission. In phase 1, each SN *i* independently sense the channel availability at its own location through spectrum sensing, and then determines its available channel information C_i which is used for CHs selection, cluster formation, and intercluster routing path selection. Here $C_i = [C_{i_1}, \mathrm{C}_{i_2}, ..., \mathrm{C}_{i_c}, ..., \mathrm{C}_{i_N}]$, where *N* denotes total number of licensed channels, C_{i_c} denotes channel identifier indicating that whether the channel at node *i* is available or not and $1 \le C_{i_c} \le N$. If sensed channel is idle then $C_{i_c} = 1$, otherwise $C_{i_c} = 0$. In phase 2, sensor node in each layer except 1st layer computes the weight and determines whether that node become CH by comparing its weight value with neighbor nodes' weight value. Further, each non-CHs node selects its CH and requests to join the cluster. In phase 3, each CH in the outer layers (p ≠ 1) cannot directly reach the sink node and it routed through selected multiple hops for inter-cluster communication. In phase 4, the aggregated data is forwarded towards sink node through selected CHs. Like the above, at each and every phase the energy is optimized efficiently by determining channel availability information, selecting appropriate CHs and forming an energy efficient cluster, route selection, and data transmission.

A. CH Selection and Cluster Formation

The channel availability information is used to select the appropriate CH. Here, the layer 1 nodes are independently acts as CHs [28] to acquire the following benefits; i) No additional energy is consumed when they exchange control information to compete for CHs and formulate clusters. ii) When the number of CHs increases for inter-cluster data communication tasks sharing and it prolongs the network lifetime by minimizing the energy consumption. A node in each layer in the CR sensor network exchange the information related to geographical location (x_i, y_i), residual energy ($E_R(i)$) and channel availability information (C_i) with other nodes within cluster radius R_{cl}. After obtaining the information, a node *i* computes its weight value $W_{CH}(i)$ using Eq. (4) and compare with neighbor nodes' weight values. If node *i* acquires highest weight value than the remaining node's weights, then node *i* is nominated as CH and broadcasts a notification message as CH within R_{cl}. After receiving notification message as CH then non-CH nodes *j* broadcasts a quit message. The other non-CH nodes within the radius of *j* receive the quit message and delete *j* from their CHs competitor list.

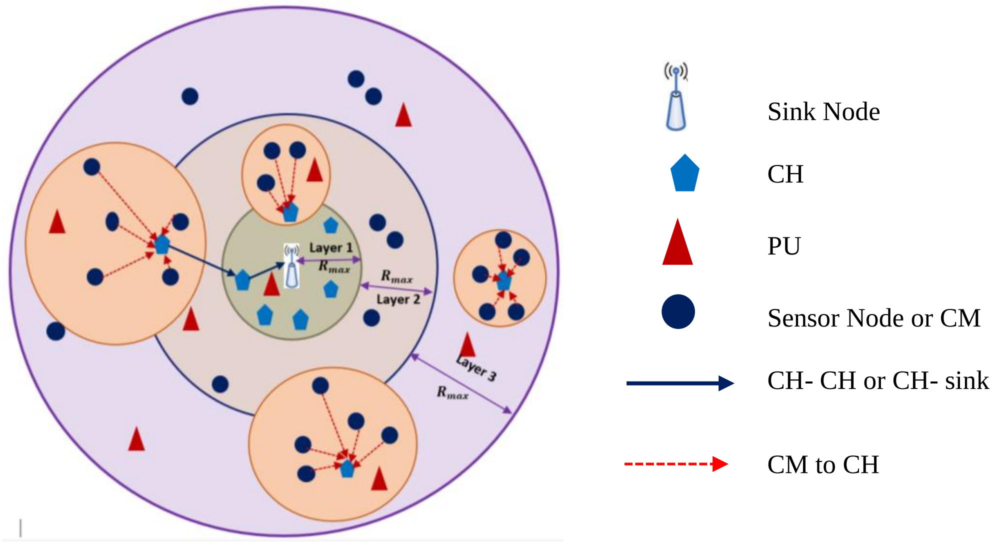
$$W_{CH}(i) = \alpha \times E(i) + \beta \times C_{uti}(i) \quad (4)$$

where, α and β represents the weight coefficients of energy and channel utilization rate respectively, *E(i)* represents the energy related term and

$E(i) = \frac{E_R(i)}{E_{Avg}(i)}$, where $E_R(i)$ denotes the residual energy of a node i, $E_{Avg}(i)$ denotes the average energy consumption of a node i. $C_{utl}(i)$ represents the channel utilization ratio of node i. The average energy consumption of a node i, $E_{Avg}(i)$ is given by

$$E_{Avg}(i) = E_D(i) + E_C(i) \tag{5}$$

where $E_D(i)$ denotes the energy consumed due to data packets and $E_C(i)$ denotes the energy consumed due to control packets.



They are mathematically expressed as

$$E_D(i) = \frac{[(|n_n(i)|+1)(E_{el}+E_{CD}) + \varepsilon_{fs}(d_i^{\sin k})^2] \times S_d}{|n_n(i)|} \tag{6}$$

and

$$E_C(i) = \frac{[(|n_n(i)|+1)(E_{el}+\varepsilon_{fs}(R_{cl})^2] \times 3S_c}{|n_n(i)|} \tag{7}$$

where, $n_n(i)$ indicates list of neighbor nodes of i within the radius of R_{cl}, E_{CD} indicates energy consumed during data accumulation, S_d and S_c indicates data and control packet size respectively. Further, the available channel utilization rate denotes the communication capability of a node i which is derived from physical proximity and joint spectral perspectives. Therefore, the available channel utilization rate ($C_{uti}(i)$) is given by

$$C_{uti}(i) = \frac{\sum_{j \in n_n(i)} C_i.C_j}{|n_n(i)| \times C} \tag{8}$$

where, $C_i.C_j$ represents the available channel information for node i and j respectively, C represents the number of available channels. Upon selecting the CH using Eq. (4) then cluster formation is done using Eq. (9). According to that Eq.(9), the non-CH node j choses a node i with highest weight as CH (CH_i) based on energy and channel utilization rate. After that, node j sends the join request message to (CH_i). Upon receiving the request message by CH_i it joins the node j as CM. If node j cannot receive any notification message which is broadcasted by CH, then node j becomes a CH

automatically. Therefore, the weight function for $CM(W_{CM}(j))$ is given by

$$W_{CM}(j) = \frac{C_{CH_i}.C_j}{E_{Transmit}} = \frac{C_{CH_i}.C_j}{E_{el} + \varepsilon_{fs}(d_j^{CH_i})^2 \times S_d} \tag{9}$$

where, $d_j^{CH_i}$ is the Euclidean distance between the node j and CH_i. After CH selection and cluster construction process, there should be a common channel for information exchange.

The common channel selection is done by CH and it is common for CH and CMs. If there is no availability of common channel for information exchange, then the CH selects random channel and assign it as a common channel for CMs in the corresponding cluster.

B. Multihop Routing and Information Transmission

With the limitation in the node transmission range, the CHs in outer layer $(p \neq 1)$ forwards their accumulated data to the sink node through multiple adjacent inner layer CHs which in turn called as inter-cluster data transmission. Here, the route selection process is initiated after the layer 1 and the CHs of layer 1 can directly send their data to the sink node. But, the CHs which are present above the layer 1 can broadcasts their messages including geographical location, residual energy, and available channel information within the node transmission range R_{max}. Then, CH_j in the layer above the layer 1 prepares a candidate relay set and choses appropriate CH based on the energy and distance. Further, Eq. (10) is used to find out the next-hop relay node to transfer the information to the sink node and it's mathematical expression is given by

$$Route_i(j) = \begin{cases} \dfrac{E_R(CH_i) \times E_T(CH_i, CH_j)}{E_T(CH_i, \text{sink})}, & if \ C_{CH_i}.C_{CH_j} > 0 \\ 0, & otherwise \end{cases} \quad (10)$$

where, $E_R(CH_i)$ represents the residual energy of CH_i, $E_T(CH_i, CH_j)$ represents the total estimated energy consumption during the data transmission between the CH_i, and CH_j and $E_T(CH_i, sink)$ represents the total estimated energy consumption to transfer the information from CH_i, to the sink node. According to the Eq.(10), the ratio of $E_R(CH_i)$ and $E_T(CH_i, sink)$ signifies the communication capacity of CH_i in concern with the energy. Therefore, $E_T(CH_i, CH_j)$ and $E_T(CH_i, sink)$ is given by

$$E_T(CH_i, CH_j) = \left(2E_{el} + \varepsilon_{fs}(d_{CH_j}^{CH_i})^2\right) \times S_d \quad (11)$$

$$E_T(CH_i, \text{sink}) = \begin{cases} (E_{el} + \varepsilon_{fs}(d_{CH_j}^{\text{sink}})^2) \times S_d, & if \ d_{CH_j}^{\text{sink}} \le d_{Th} \\ (E_{el} + \varepsilon_{fs}(d_{CH_j}^{\text{sink}})^4) \times S_d, & \text{otherwise} \end{cases} \quad (12)$$

According to the Eq. (10), CH_j unicasts its routing related message to the selected relay and that selected node receives the message and transfers the data to the sink node. If CH_j cannot find its relay from the inner CHs, then it select the CM node which is nearer to the sink node to transfer the data. In this manner, the route selection process continues till the accumulated data reaches the sink node.

After selecting the efficient route, each CH follows TDMA schedule to collect the data from the CMs in the specified time slot. Then the data collected by the CH is getting aggregated and transmitted to the next-hop relay. This process continuous until the collected data reaches sink node. As network operation goes on, CHs changes among nodes in layer $p(p\neq 1)$. In addition, by selecting proper next-hop relays, the inner CHs in layer p. $(p\neq P)$ will act as relays and forward the data packets from outer layers to the sink. Such kind of process can balance the residual energy among nodes in the same layer and improves the network lifetime.

IV. SIMULATION EXPERIMENTS

This section describes the proposed work's experimental analysis. Simulation carried out by varying the number of rounds mentioned for data transmission. Totally three performance metrics are used to assess the performance of proposed approach, they are Number of Alive nodes, Packet Delivery Ratio (PDR) and Control Overhead. In the current section, initially we explore the details of simulation setup and then the details of performance metrics.

A. Simulation Setup

This sub section explains the simulation setup required to validate the performance of proposed method. Here, the proposed method is compared with the state-of-the-art methods such as WCM-SAC [21], ISSMCRP [12]. The performance is evaluated for two layered and three-layered networks by fixing the number of alive nodes as 40 and 80 respectively.

Table 1 Setup for different network layers

Number of Network Layers	Radius of the Network	Total number of sensor nodes in the CRSNs
Two-Layered CRSN	100m	40
Three-Layered CRSN	150m	80

Table 2 Simulation Set Up

Parameter	Value
Initial Energy of each sensor node	0.5J

energy consumption at the transceiver to transmit or receive 1-bit of information (E_{el})	50nJ/bit
Energy consumption coefficient of power amplifier in free space (ε_{fs})	10pJ/bit/m^2
Energy consumption coefficient of power amplifier in multipath propagation environment (ε_{mp})	0.0013pJ/bit/m^4
Energy consumed during 1-bit of data accumulation (E_{CD})	5nJ/bit/packet
Control packet size (S_C)	100bit
Data packet size (S_d)	1000bit
Number of Primary users (M)	5
Threshold Distance (d_{Th})	87.7m
Maximum transmission range of sensor node (R_{max})	50m

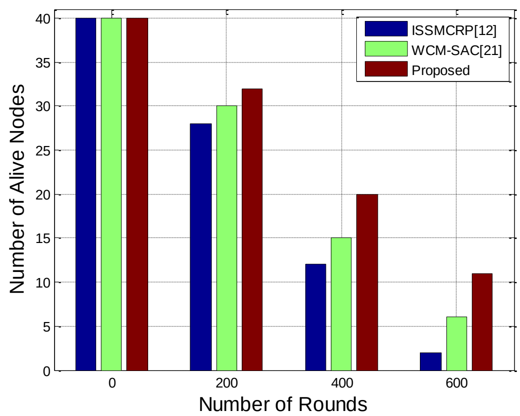
The sink node is located at the center of the network, the number of sensor nodes with various network radius as shown in the Table-1 and the remaining simulation parameters are tabulated in Table-2. further, to evaluate the clustering routing protocols, we considered the performance evaluation metrics such as number of alive nodes, packet delivery ratio, and control overhead. The following sub sections explores the performance metrics of proposed method.

B. Number of Alive Nodes

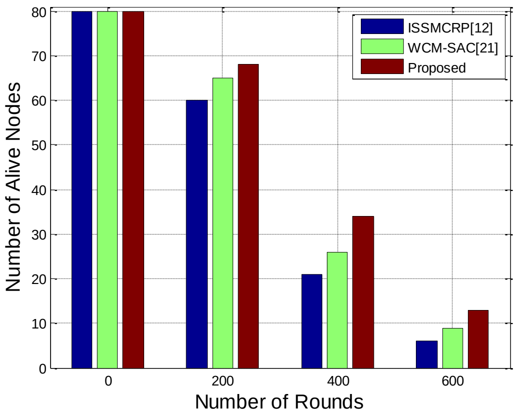
In the proposed method, the sensor nodes that are present in the layer 1 are directly transmit their data to the sink node where as the nodes in the layer 2 and above can take multiple hops to transmit the data to the sink node. Figure.2(a) and Figure.2(b) represents the number of alive nodes for varying number of rounds for two-layered and three-layered networks respectively. By observing the Figure.2(a) and Figure.2(b), as number of rounds increases then the number of alive nodes decreases. But the proposed method's number of alive nodes decrement is lesser than the existing methods' decrement due to efficient CH selection, cluster formation, and routing for data transmission.

For example, the number of alive nodes for proposed method, WCM-SAC [21], and ISSMCRP [12] are approximately 20, 15, and 12 respectively for two-layered CRSN for 400 number of rounds as shown in the Figure.2(a). Whereas, as shown in the Figure.2(b), the number of alive nodes for proposed method, WCM-SAC [21], and ISSMCRP [12] are approximately 33, 25, and 21 respectively for three-layered CRSN for 400 number of rounds. In the proposed method, the layer 1 nodes can transmit the data directly through single-hop to the sink node which can reduce the number of control messages exchanging and minimizes the energy consumption for CH selection and cluster formation for the upper layers due to varying cluster radius. Whereas, the existing methods like ISSMCRP and WCM-SAC consumes more energy for cluster formation, CH selection, and continuous broadcasting of control information exchange.

From the Figure.2(a), we can observe that on an average the number of alive nodes for proposed method are approximately 29, for WCM-SAC are 23, and for ISSMCRP are 20 in two-layered CRSN. Further, From the Figure.2(b), on an average the number of alive nodes for proposed method, WCM-SAC, and ISSMCRP are approximately 49, 45, and 42 respectively in three- layered CRSN. Hence, the proposed method achieves good performance in terms of number of alive nodes for varying number of rounds than the existing methods.



(a)

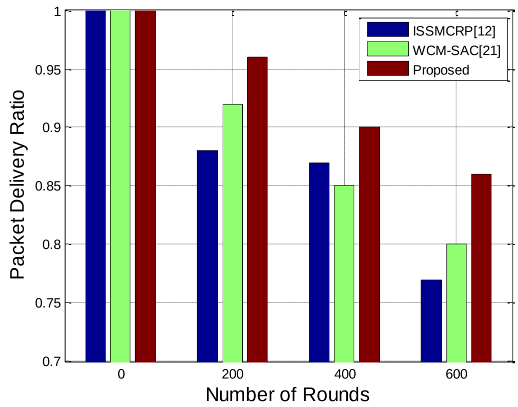


(b)

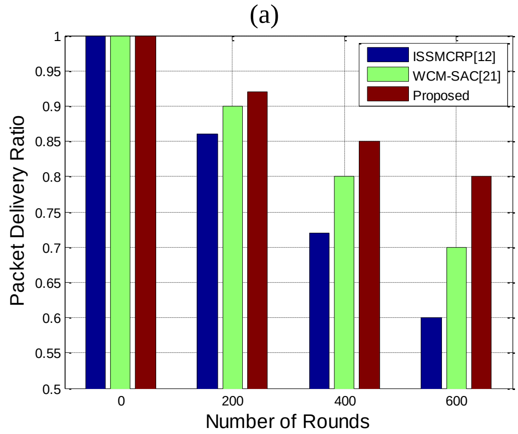
Figure.2 Number of alive nodes comparison at (a) Two layered CRSN and (b) three-layered CRSN

C. Packet Delivery Ratio

Here, the packet delivery ratio is defined as the total number of sensor nodes that are successfully transmitted to the sink node to the total number of alive sensor nodes in the CRSN. Figure.3(a) and Figure.3(b) shows the packet delivery ratio for varying number of rounds in two-layered and three-layered CRSNs respectively. According to the Figure.3(a) and Figure.3(b), as number of rounds increases the packet delivery ratio decreases for all the methods. The packet delivery ratio for proposed method is higher than the existing methods at each round due to random accessing of channels to transmit the data. If the multiple channels are available to the nodes in the cluster in proposed method, then it will select the common channel for all the nodes randomly such that less energy is consumed to transfer the data and for frequent channel switching. So, the random channel selection can improve the data transmission capability. Whereas in existing methods there is no enough channel availability information, limited transmission range, and huge number of CM nodes then there are a smaller number of packets to be delivered to the destination. From the Figure.3(a), we observe that on an average packet delivery ratio for proposed method, WCM-SAC, and ISSMCRP are approximately 0.94, 0.89, and 0.87 respectively for two-layered CRSNs. Further, we observe that on an average packet delivery ratio for proposed method, WCM-SAC, and ISSMCRP are approximately 0.89, 0.85, and 0.81 respectively for three-layered CRSNs.



(a)

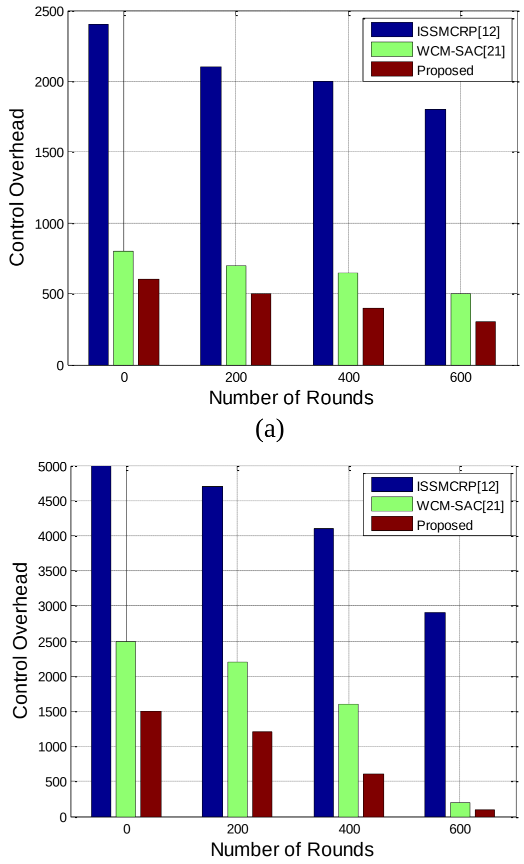


(b)

Figure.3 Packet Delivery Ratio comparison at Two layered CRSN and (b) three-layered CRSN

D. Control Overhead

Practically, in, CRSNs, the channel accessing competition will results in neighbor nodes collision. These collisions force all the nodes to transmit their information repeatedly to the sink node and it causes additional energy consumption and control overhead. The less control overhead consumes less energy due to a smaller number of control information exchange. In the proposed method, all nodes in the layer 1 are directly send their information to the sink node without control information exchange and with less energy. Moreover, the proposed method uses a smaller number of control information messages for the CH selection and cluster formation. Figure.4(a) and Figure.4(b) shows the control overhead with varying number of rounds for two-layered and three-layered CRSNs respectively. As shown in the Figure.4(a) and Figure.4(b), the number of rounds increases the control overhead for all routing protocols decreases. For example, the control overhead for the proposed method in two-layered CRSN is approximately 500 where as it is of 650 for WCM-SAC, and it is of 2100 for ISSMCRP at number of rounds equal to 200 as shown in the figure 4 (a).



(b)

Figure.4 Control Overhead comparison at (a) Two layered CRSN and (b) three-layered CRSN

Further, the control overhead for proposed method, WCM-SAC, and ISSMCRP is approximately 1200, 2200, and 4650 respectively for three-layered CRSN at number of rounds are 200. Therefore, the performance of proposed method is better than the existing methods due to their smaller number of control information exchange for CH selection and cluster formation. Moreover, the proposed routing protocol directly sends the layer 1 nodes' information to the sink node and it consumes less energy than the existing routing protocols.

V. CONCLUSION

This paper mainly aimed at the improvisation of network lifetime in CRSNs and proposed an non-uniform clustering protocol called as EECRP. EECRP is a multi-hop clustering protocol which forms the clusters based on two attributes namely available energy of each SN and channel utilization rate. Further, the routing process includes distance metric which helps in determining the shortest path for every communication node pair in CRSN. Simulation experiments explore the efficacy of proposed approach. Particularly, the proposed EECRP achieved better performance compared with other protocols by maintaining more number of alive nodes even after several rounds of communication. Further, it also gained an improved packet delivery ration and reduced control overhead than the state-of-the-art methods

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