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Dynamic Cluster Configuration Protocol (DCCP) for Cognitive Radio Ad-Hoc Networks

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Abstract: *Now a day's cognitive radio is one of the valuable research areas in wireless communication. The cognitive radio (CR) is a technology that is used to share the spectrum or bandwidth efficiently. In Cognitive Radio Network (CRN), the absence of primary user; the secondary user can use the spectrum efficiently. But how to access the available spectrum effectively without interference the primary user is a main challenge in CRN. A large number of cluster based MAC protocol have been proposed to solve this problem. To solve this type of problem, in this paper we have motivated to design an approach named as Dynamic Cluster Configuration Protocol (DCCP) for Cognitive Radio Ad Hoc Networks (CRAHNs). The cluster-based structure is efficient for guaranteeing system performance, reliable routing and reducing communication overhead in variable network environment. In this approach secondary users are clustered based on their available channels that maximize the network throughput and maintain the cluster topology stability. The simulation results shows that our protocol provides better performance in terms of cluster formation and throughput.*

Keywords – *Cluster Based, Cognitive Radio Network, Primary User, Rendezvous, Secondary User*

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I. Introduction

Cognitive radio (CR) is an intellectual transceiver, adaptive and network apparatus, which can be configured with significant property. It has ability to automatically detect free or available channels from wireless spectrum and change its transmission parameters enabling more communications to run concurrently [1]. It is known that, currently ISM (Industry, Science, and Medical) wireless band is 2.4 to 2.48 GHz and 5 GHz [1, 2]. In wireless communication this ISM band is used by all the wireless devices such as WLAN (Wireless Local Area Network), WPAN (Wireless Personal Area Network), WBAN (Wireless Body Area Network), WSN (Wireless Sensor Network) and Wi-Fi (Wireless Fidelity) network users. But in practical, numbers of wireless users are increasing rapidly. It is predictable that within a very shorter period of age this 800 MHz bandwidth will not be sufficient to provide better support for the wireless users in terms of quality of service (QoS), throughput, energy consumption and delay. Hence, the ultimate solution is to find out some alternative. Cognitive Radio Network (CRN) is one of the possible solutions. The CRN is a well-organized approach to share the spectrum or bandwidth [3]. In CRN at the absence of primary user (PU), the secondary user (SU) can access the available channels of license bands opportunistically. This is in-fact exactly how the wireless communication works today, wireless devices are only allowed to use a certain frequencies (i.e. ISM band) which are getting crowded. Through the cognitive radio technology SUs can use all of the available frequencies or channels even those are dedicated by the PUs. The intelligent devices (i.e., cognitive radio) negotiate in order to use the whole radio spectrum in the most efficient way. In CRN, SUs are permitted to utilize free of licensed channels without any harmful interference to PUs [4], [5]. Cognitive radio could understand the language of any radio. This combined with new simple radio embedded in any object. It allows interaction any physical object to provide communication. In CRN the rendezvous of two or among SUs is crucial task due to primary user activities. A general CRN network model is illustrated in Fig. 1[4]. CRN is composed of both the SU (i.e., Laptop, Smart Phone, Wi-Fi, Wireless Sensor Devices etc.) and PU (i.e., Mobile Network, TV Channels, and Radio Channels etc.), where SUs consists of CR-enabled radios and the PUs whose radios need not to be CR-enabled [1]. Cognitive capability means the ability to sense opportunities in spectrum where and when channels are not utilized by PUs. As a result the main challenges for the CRNs are (i) Ensuring channel rendezvous between SUs (ii) To keeps continuing data transmission between SUs without interference the PUs. It is observed that a large number of MAC protocols have been designed to make channel rendezvous between two SUs. Cluster based MAC approach is one of possible protocol to rendezvous between two SUs. Clustering is one of good numbers of extensively innovated solutions for scaling down ad hoc network. Cluster includes information for arranging secondary users (SUs) into logical groups with the goal of decreasing the signaling overhead required for network communication while maintenance the network connectivity. It is noted that, there are different cluster based MAC approaches exist for channel rendezvous. *Firstly,* in *Cluster-based MAC* approach [3], clustering is formed based on reserved values of neighbour nodes. In this protocol three factors such as capacity, stability degree and quality of each link among the neighbours are used to compute reserve values. It is the channel centric and common control channel (CCC) based protocol [3]. However, this approach is comparatively very complex to form cluster and inter cluster communication is impossible due to lack of gateway node(s). *Secondly,* in *Clustering Scheme for Spectrum Sharing* approach [5], cluster is formed

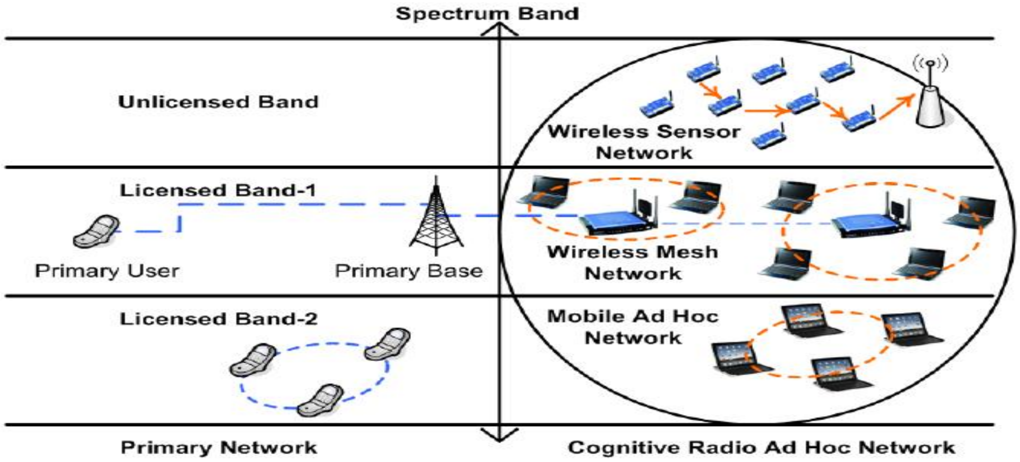


Figure: Cognitive Radio Network Architecture

according to their geographical location and shared information. However, in this approach, node to node communication is not presented and cluster formation process is quite difficult. *Thirdly,* in *Event-driven Spectrum-Aware Clustering* approach [6] cluster is formed according to the spectrum awareness of the nodes. However, in this approach, cluster formation process is complex and inter communication is not possible due to lack of gateway node(s). As a result, overall throughput is decreased and rendezvous rate is increased due to cluster formation complexity. *Fourthly,* in Dynamic Cluster Based Architecture approach [7] describe hypothetical concept of cluster formation. In this approach cognitive terminals (CTs) are connected with a dynamic cluster base station (DCBS) and the station maintains the communication operation. However, in this approach lack of DCBS communication is not possible and extra memory space is required for communication between two SUs. As a result communication performance as well as throughput is decreased and increased rendezvous delay. *Fifthly,* in Distributed Clustering Approach [8] used distributed clustering algorithm based on soft-constraint affinity propagation message passing model. However, in this protocol re-clustering process is very difficult. In As a whole our proposed work makes the following contributions:

1. Design a new approach to make the cluster efficiently and more robust to PUs dynamic activities.
2. Proposed a new cluster formation algorithm based on available channel and adjacency nodes. Cluster formation is dynamically according to adjacency matrix of the available channels which are used in maximum and same common channel for inner cluster structure.
3. Target to minimize number of cluster formation, maximize throughput and minimize rendezvous delay

II. Related Work And Problem Statements

In this section we describe different types cluster based approaches those have been proposed for Cognitive Radio Ad Hoc Networks (CRAHNs) to solve the channel rendezvous problem such as- *Cluster-Based MAC approach[3], Novel Clustering Scheme for Spectrum Sharing approach [5], Event-driven Spectrum-Aware Clustering approach [6], Dynamic Cluster Based Architecture approach [7], Distributed Clustering approach [8].*

2.1 Cluster-Based MAC Approach

In the Cluster-Based MAC approach [3], uses two round neighbors discovery in which each round includes several super frames [3] such as (1) Beacon Period (2) Spectrum Sensing Period (3) Intra Communication Period (4) Inter-intra Communication Period and (5) Data Transmission Period/ Neighbor Discovery. *Firstly,* a node gathers neighbors' information from the first round of neighbor discovery, then computes reserved value and a node exchanges the reserved values for links with its neighbors at the second round of neighbor discovery.

Then nodes form clusters according to the updated reserved value, experienced statistics and finally cluster initialize themselves and connect with each other. In this protocol three factors such as capacity, stability degree and quality of each link among the neighbours are used to compute reserve values. However, this approach is comparatively very complex to form cluster and inter cluster communication is impossible due to lack of gateway node(s). The structure of Cluster-based MAC approach is shown in Fig. 2 [3].

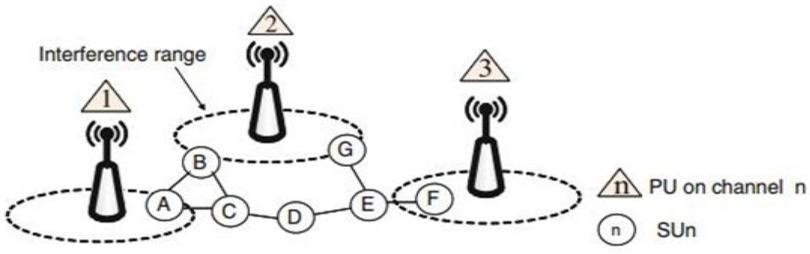


Figure 2: The structure of cluster-based MAC approach

2.2 Novel Clustering Scheme for Spectrum Sharing Approach

Another cluster based approach is a novel clustering scheme for spectrum sharing in multi-hop ad-hoc cognitive radio networks [5]. In this approach, in order to manage the spectrum identification and exploitation in multi-hop ad-hoc CRNs, it proposed to cluster the SUs best on their geographical location and their occurring order, where cluster is assigned a spreading code different from the other cluster. However, in this approach, node to node communication is not presented and cluster formation process is quite difficult. The clustering process is illustrated in the Fig. 3 [5].

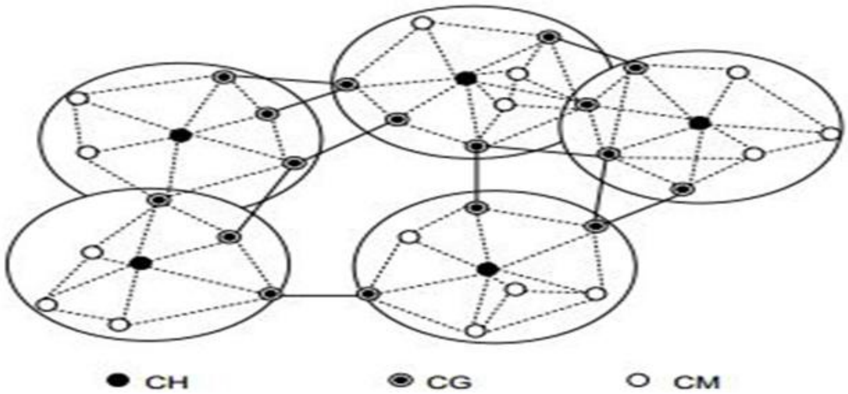


Figure 3: Novel clustering scheme for spectrum sharing approach

2.3 Event-driven Spectrum Aware Clustering Approach

Event-driven Spectrum Aware Clustering Approach [6] in cognitive radio sensor networks is spectrum aware clustering approach. In this approach the authors are described their protocol in two phases. The first phase is used to determine the eligible nodes as well as the second phase is used to form cluster according to the spectrum awareness of the nodes. However, in this approach, cluster formation process is complex and inter communication is not possible due to lack of gateway node(s). As a result, overall throughput is decreased and rendezvous rate is increased due to cluster formation complexity. Event-driven Spectrum Aware Clustering approach operation is illustrated in the Fig.4 [6].

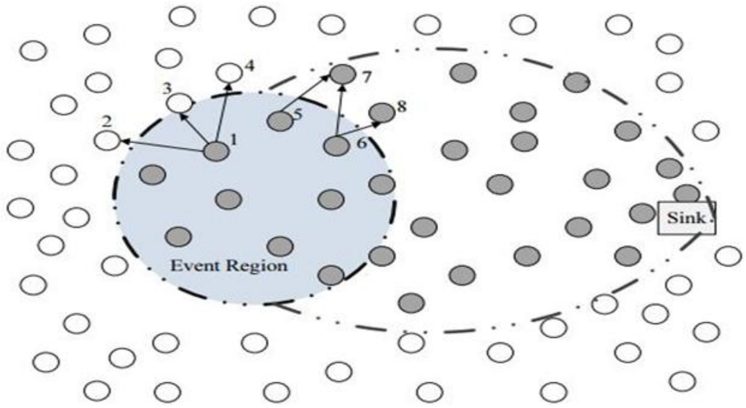


Figure 4: Operation of Event-driven Spectrum Aware Clustering Approach

2.4 Dynamic Cluster Based Architecture Approach

Dynamic Cluster Based Architecture approach [7] for CRN is designed for creating architecture for CRN. In this approach authors are proposed dynamic cluster architecture but can't describe how the cluster is formatted and maintenance. It is a hypothetical approach. In this approach only assumes that cognitive base station (CBS) acts as a dynamic cluster base station (DCBS). After formation of cluster cognitive terminals (CTs) are completed their communication via DCBS. Cluster heads (CHs) are responsible for all communication. One of the main limitation of this approach is it requires extra memory to store the *Set of Accessible Channels (SAC)* list. Calculating the home channel, from the SAC list, is also an operational surplus for the network. However, in this approach lack of DCBS communication is not possible and extra memory space is required for communication between two SUs. As a result communication performance as well as throughput is decreased and increased rendezvous delay. Dynamic Cluster Based Architecture approach configuration is illustrated in Fig. 5 [7].

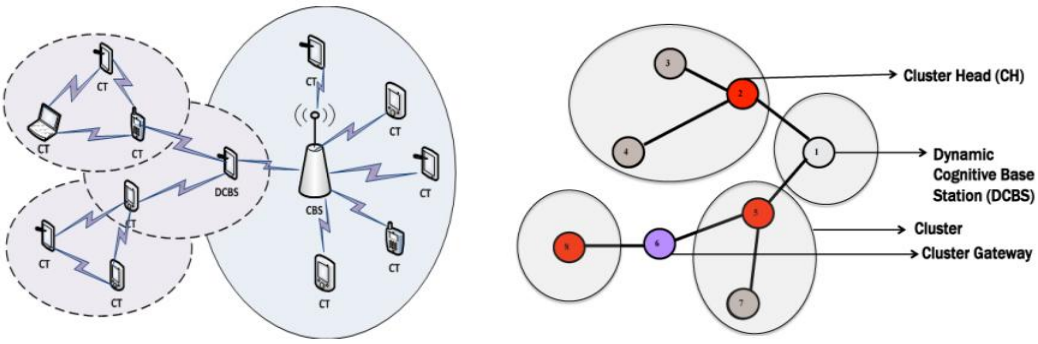


Figure 5: Hypothetical scenario of dynamic cluster based architecture approach

2.5 Distributed Clustering Approach

Another fashionable cluster based approach is Distributed Clustering approach [8] is designed for cognitive radio ad-hoc networks. Distributed technique is used for cluster formation in this approach. In this approach the authors are proposed a distributed clustering algorithm based on soft-constraint affinity propagation message passing model (DCSCAP). In this approach, without dependence on predefined common control channel (CCC), DCSCAP relies on the distributed message passing among CRs through their available channel, making the algorithm applicable for large scale networks. However, in this approach re-clustering process is quiet difficult. As a result, this approach may be fallen in time complexity problem and decreased the communication performance as well as maximize the rendezvous delay. The operation scenario of Distributed Clustering approach in CRN is illustrated in Fig. 6[8].

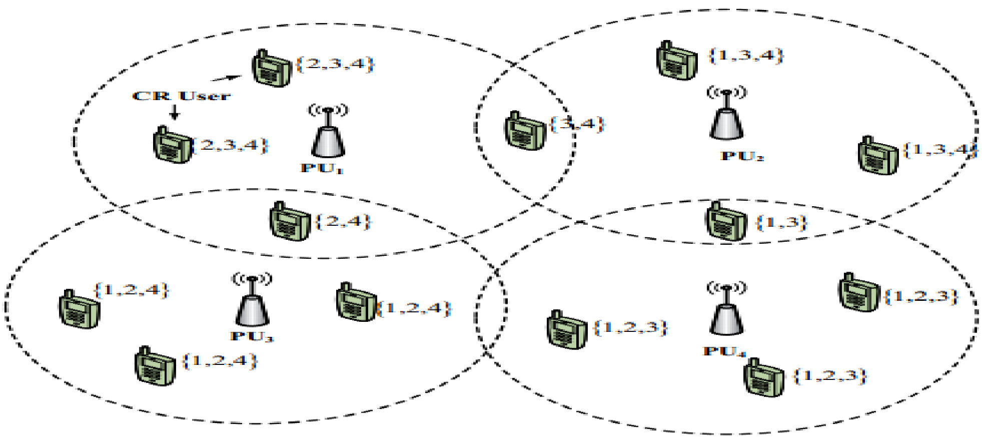


Figure 6: Operation of distributed clustering approach

III. Proposed DCCP Approach

3.1 System model

In our system model we assumed that, there are N number of channels and total number of M secondary users (SUs). Each secondary user is equipped with single half-duplex transceiver. At a given time, Secondary Users (SUs) can only sense a finite portion of the spectrum and generate the available channel list. In CRAHNs, two SUs are said to be 1-hop neighbors if they are within a cluster and they are turned to the same channel [1]. On the other hand, 2-hop neighbors are described when it's being at other cluster which communicates with cluster gateway. We assume that the mobility of node is slow, and the channel availability at each node changes at a relatively low rate, such that the network topology does not change during cluster formation process [10].

3.2 DCCP Approach overview

3.2.1 Cluster Formation Technique

After sensing the spectrum the all SUs create an Available Channel List (ACL), and then, firstly, produce an *Adjacency Matrix (AM)* with respect to ACL. Then find the channel which is available in maximum nodes from *AM*. According to maximization produced a cluster. Again find second maximum usable channel, but it must be omitted which nodes are already used in cluster are not use in another cluster instead of that nodes which have same common channel that will be used in cluster gateway. Similarly all nodes are search the *AM* with same process. According this procedure nodes are formed clusters and then a random *Cluster ID (CL_ID)* will be generated when cluster is formed.

Let, there are 10 secondary users such as *A, B, C, D, E, F, G, H, I,* and J and their *Available Channel Lists (ACL)* is shown in Table 1.

TABLE 1: Available Channel List of Secondary User Nodes

Secondary User (SU) Node	**Available Channels**
A	{1, 2}
B	{2, 3, 4}
C	{1,2,3}
D	{4}
E	{5}
F	{1,5}
G	{2, 3}
H	{4, 5}
I	{4,5}
J	{2,3,4}

According to *Available Channel List (ACL)* all nodes are created the following adjacency matrix for cluster formation which is shown in Table 2 as follows:

TABLE 2: Adjacency Matrix for Cluster Formation

Channels	**Secondary Users (SUs)**									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
1	1		1			1				
2	1	1	1				1			1
3		1	1				1			1
4		1		1				1	1	1
5					1	1		1	1	

From the *AM* it is seen that, channel 2 is common for the nodes *A, B, C, G and J* respectively and the value in row in the matrix is maximum. So Cluster_1 is produced first and cluster members are *{A, B, C, J, G}*, where *J* is the Cluster Gateway (CG), and according algorithm the node *B* is selected as Cluster Head (CH). So node B is the controller of the Cluster_1. Furthermore, according to cluster formation process another two cluster are formed with nodes *{D, I, H, J}* and *{H, E, F}* where *H* and *J* are CG respectively and *I* and *F* are the CH respectively. In Fig. 7 is illustrated the cluster formation according to proposed protocol algorithm.

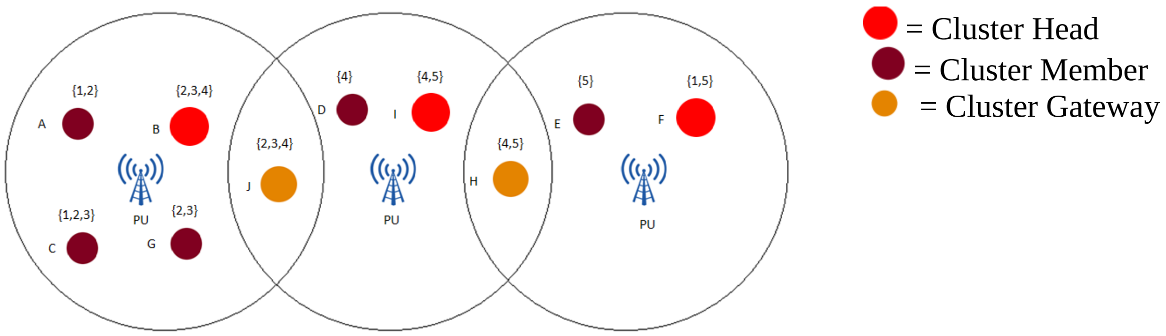


Figure 7: Proposed dynamic cluster formation architecture

3.2.2 Cluster Formation Algorithm

Proposed cluster formation algorithm is shown in Table 3 as follows:

TABLE 3: Cluster Formation Algorithm

```
BEGIN
Create structure str
        Channel and value;
st[];
Boolean operator less strA and strB
        Return value A less than value B
Vector v[]
Initialize k,I,j,b,count,ary[][],node
    channel,check,checkary[],channelvalue;
For I :=1 to node
    Input channel and node
        For j:=1 to channelvalue
            Ary[][]:=1
            End for
End for
Print adjacency Matrix
  For i:=1 to channel
      For j:=1 to node
          Print ary[][].
      End for
End for
For i:=1 channel
      Count:=0
         For j:=1 to node
            If ary[][]:=1 Then
               Count:=count +1
               End if
            End for
    St[].value:=count
    St[].channel:=i
End for
Sort(st,st+channel)
Count:=1
Check:=0
For k:=0 to less than channel
    Check:=0
    I:=st[].channel
       For j:=1 to node
          If ary[]:=1 Then
             If checkary[]:=0 Then
                If check:=0 Then
                   Count:=count+1
                   Check:=1
                End if
                Checkary[]:=1
                Vector v.push_back
             End if
          End if
       End for
End for
End
```

3.2.3 Cluster Head

In cluster network, every cluster have a Cluster Head (CH). CH is the controller of a cluster which has all the information's of the cluster members and their behavior. It is responsible for the intra-cluster communication. CH is selected according to cluster head selection algorithm. CH selection algorithm is shown in Table 4.

TABLE 4: Cluster Head Selection Algorithm

1. Firstly, select one-hop neighbor for the node which be a cluster head.
2. Then select the common channel which used by maximum one-hop neighbor
3. Select two-hop neighbor using that channel.
4. Then calculate the weight of each node by using the following formula:

   $W_k = [CC_k] * [CN] * [2HN_k]$……………….(1)

   Here,

   CC_k= Common channel of node k

   CN= one hope neighbor Cluster node of common channel

   $2HN_k$ =Maximum two-hop neighbor used by channel.
5. Again, find the second maximum one-hop neighbors and union previous channels overlap node for selecting next two-hop neighbor using through overlap node. Then calculate the weight again using formula 1.
6. Similarly, calculate all the nodes weight and find the maximum weight of each node of a cluster.

7. The node which contain maximum weight it would be cluster head.
8. If any cluster has only one node then the node is the cluster head.
9. If there are only one cluster is formed after sensing then finds the node that has the maximum one-hop neighbor to be cluster head.

To find out the CH, for example, we can randomly select a node, say, node *B* from Cluster_1. The ACL of *B* is{2, 3, 4} and calculate one hop neighbors, so maximum one-hop neighbors of node B are *{A, C, J, G}* through the channel 2, but there is no two-hop neighbor of node B using channel 2. Fig. 8 is illustrated the cluster head selection scenario.

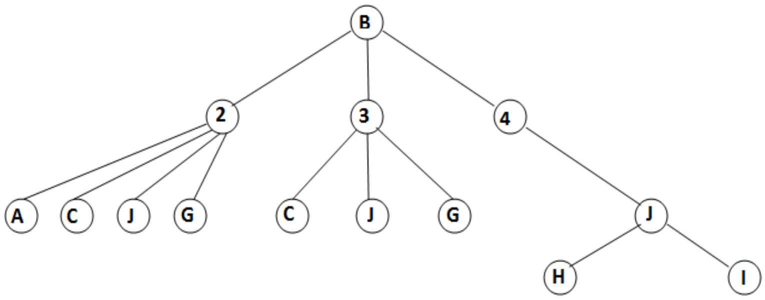


Figure 8: Cluster head selection scenario

Then, the second maximum one-hop neighbor through the channel 3 are *{C, J, G}* and union of channel 2 and 3 getting overlap node are *{C, J, G}* but there is no two-hop neighbor also. Now, find the overlap node using union of channels 2, 3 and 4 again. Then the maximum overlap node is *J* only. Then find out the two-hop neighbors. Now two hop neighbors are *H* and *I* through channel 4 using node J. The full process is illustarted in Table 5.

TABLE 5: Cluster Head Selection Process (Iteration Table to Finding CH)

No. Iteration	CC[k]	CN[k]	CD[k]	W[k]
i=1	{2}	{A,C,G,J}	0	0
i=2	{2,3}	{C,G,J}	0	0
i=3	{2,3,4}	{J}	{H, I}	6

Calculating all nodes weights using the similar process the maximum weight of Cluster_1 is contain node B. For this case *B* is selected the final CH of Cluster_1. Similarly, node *I* will be the CH of Cluster_2 and node *F* also CH of Cluster_3.

3.2.4 Cluster Gateway

Gateway nodes are responsible for the inter-cluster communication. A node which is responsible to complete the communication among the clusters is called Cluster Gateway (CG) node. For selecting CG nodes follow the *AM*. Firstly identify the CH and find the available channels in inner cluster and outer cluster. Find the maximum available common channel(s) among the clusters nodes and then find the sequence of order of available channels. In this case, the node which has more common channel in a cluster and has maximum two-hop neighbors is called the CG. There may have more than one gateway node in a cluster. For instance, in Cluster_1, node *J* has the available channels are {2, 3, and 4} and channel 2 is available in Cluster_1 and channel 4 also common in Cluster_2. So node *J* can complete the communication the entire inner cluster nodes using channel 2 and also can communicate as a two-hop neighbor in inter-intra cluster using channel 4. For the overall discussion, the node *J* is the CG in Cluster_1. Similarly node *J* and *H* are the CG of Cluster_2 and *H* is also CG of Cluster_3.

3.2.5 Neighbor Discovery

According to clustering technique, every node has two states: In cluster (node has already joined in cluster) and searching-cluster (node searches a cluster to join) [1]. Both states have a basic action that is called neighbor discovery. If the node in cluster then it finds its one hope neighbor for transmitting data controlled by CH. After spectrum sensing when the node is not joined in a cluster firstly it senses the CH and finds the cluster formation channel, if the channel is available for that node then it can join the cluster. If there has not available common channel it will wait for re-clustering. If there have no cluster then node formed a new cluster with his own available channel(s).

3.2.6 Data Communication Phase

Data communication between nodes may be two types such as (i) Intra-cluster communication and (ii) Inter-intra cluster communication. The operations are described below.

3.2.6.1 Intra-Cluster Communication

When nodes of same cluster are communicating with each other, this is called intra-communication. If a node in a cluster, has data packet, and it wants to send data to its receiver. In this situation at first, node sends control information to the CH for sending its data to its corresponding receiver node. Then CH finds the available channel(s) for data transmission between two nodes. If there have more than one cluster common channel, then the CH sends a message to the both nodes. Firstly, the transmission occurred in cluster common channel. If the cluster common channel is more busy for transmitting data when multiple transmission occurred in a channel then CH suggest the nodes for transmitting data into other common channel for better transmission efficiency. The intra-cluster communication process between nodes to node is illustrated in Fig. 9(a). Suppose the node *A* sends a request to CH for transmitting data to node *C* at the same time node *G* sends a request to CH for transmitting data to node *B* also. Then CH checks the available channel list among those nodes where available channel(s) list given in Table 6 below:

TABLE 6: Nodes and ACL for Intra-cluster Communication

Secondary user Node	Available Channel List(ACL)
A	{1, 2}
C	{1, 2, 3}
G	{2, 3}
B	{2, 3, 4}

After checking the available channel(s), CH suggest to node *A* and *B* for transmitting data into channel 2, CH also suggest the node *G* and *B* for transmitting data into channel 2 if overhead of nodes are existed in channel 2.If the overhead is higher than limit then the CH suggest to the nodes *G* and *B* to go to channel 3 for data transmission. And also suggest to node *C* and *A* to channel 1 which is shown in Fig. 9(b).

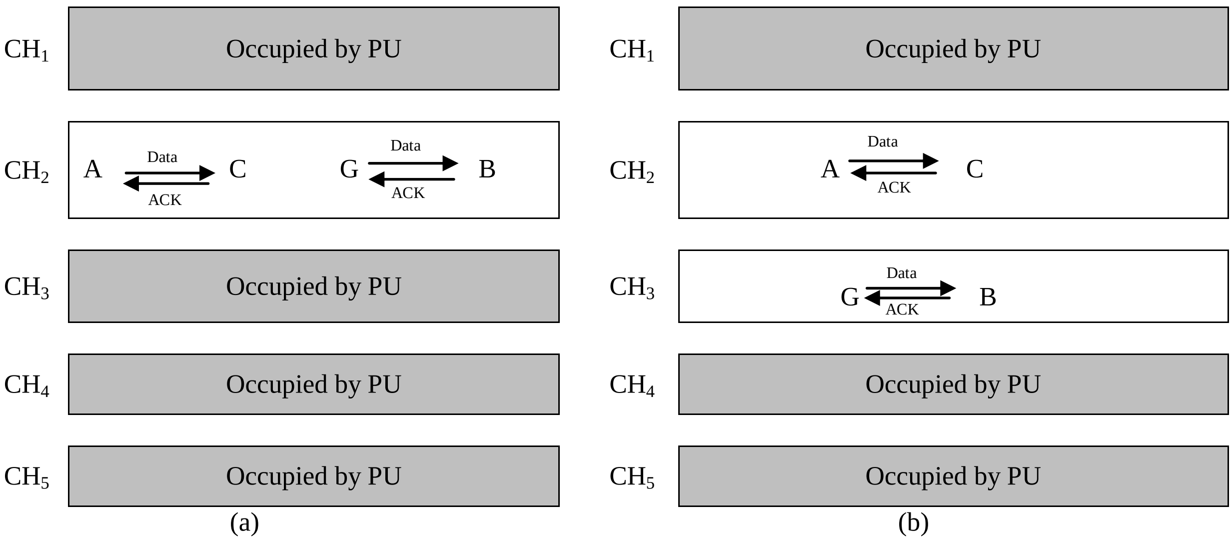


Figure 9: Intra-cluster communication scenario

3.2.6.2 Inter-intra Cluster Communication

Gateway node is responsible for inter-intra communication. If any two-hop neighbor wants to transmit data one cluster member to another cluster member then it sends a control message to their own CH. CH checks the control message and send to the CG. CG will send this to specific CH. Then the CH of receiver cluster checks how many available channels between two nodes. The CH again send control message between nodes through CG. Then the two nodes switch their common channels and complete their data transmission on that channel. If any available channel is busy or occupied by PU then CH check other gateway node in cluster and suggest to the sender and receiver nodes for switching other channel. If the main cluster channel is occupied by PU, then cluster is reformed or re-clustered again matrix calculation. Let, node *D* in Cluster_2 wants to transmit data to node *B* in Cluster_1 via node CG node J (i.e., CG of Cluster_1) then CG node *J* sends a request to CH of

Cluster_1. And then CH checks the available channel list between nodes *D* and *B* then suggests them to go to their available channel 4 for transmitting data. Similarly the nodes *A* and *C* complete data transmission using channel 5 also. The inter-intra cluster communication is illustrated in Fig. 10.

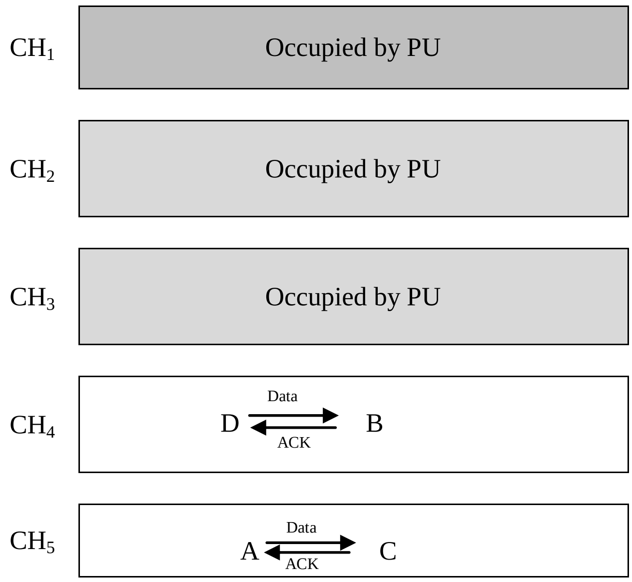


Figure 10: Inter-intra cluster communication scenario

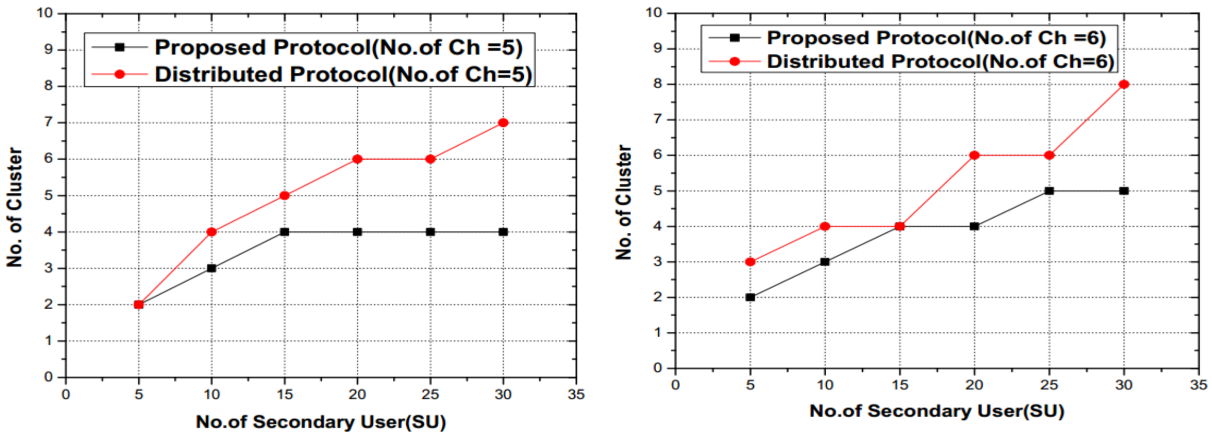
3.2.7 Joining New Node in a Cluster and Re-clustering

If any new node comes in network and wants to join into the cluster, firstly, it senses the available channels and sense the cluster head (CH). If the available channel of new node matches with any cluster common channel then it can join with the cluster. If there is no any common channel with cluster then it makes a new cluster by own available channel(s) or re-clustered. It can communicate other cluster node by available cluster gateway.

IV. Performance Evaluation

In this section, we have described the simulation procedure to evaluate the performance of the proposed clustering algorithm in the simulation environment. We have used our own simulation model developed in C++ programming language platform. We have implemented our proposed DCCP approach for CRAHNs. We have compared our DCCP approach with Distributed Clustering approach. In this simulation environment maximum 6 channels are used for modeling licensed channels for PUs and randomly some of the channels made free and set available to the SUs. Maximum 30 nodes are deployed in 250X250 m^2 are to make variation in number of PU and SU. We have compared our proposed approach with the Distributed Clustering approach in terms of performance metric such as *Number of cluster formation* with respect to number of secondary users based on their available channels.

In Fig. 11(a) is demonstrated the number of cluster formation with respect to secondary users based on their available channels. Here the X-axis represent the number of SUs and Y-axis represents the number of clusters. In Fig. 11(a), it is seen that as the number of SUs nodes increases, the Distributed Clustering approach generates a large number of clusters. According to our clustering formation algorithm our proposed DCCP approach has the minimum number of cluster than the Distributed Clustering approach. When the number of SUs is 20 then in our proposed approach the number of cluster is 4, whereas in Distributed Clustering approach formed 6 clusters at the same time when number of available channels are 5. When SUs is 30 then in our proposed approach the number of cluster is 4, whereas in Distributed Clustering approach formed 7 clusters at the same time when number of available channels are 5.



(a) (b)

Figure 11: Number of Cluster formation with respect to SUs

In Fig. 11(b) it is seen that in our proposed approach only 5 clusters are formed when number of SUs is 25, and on the other hand in Distributed Clustering approach formed 6 cluster at the same time when number of available channels are 6. Furthermore, if the secondary users are increased then in our proposed approach only 5 clusters are formed when number of SUs is 30, and on the other hand in Distributed Clustering approach formed 7 cluster at the same time when number of available channels are 6. So it is concluded that our proposed DCCP approach is better than Distributed Clustering approach in terms of number of cluster formation.

V. Conclusion

In this paper, we have presented a dynamic cluster configuration protocol for CRAHNs using adjacency matrix concept. The goal of this protocol is to reduce channel rendezvous problem and efficient use of spectrum as well as reduce number of cluster formation. Our clustering formation algorithm generates small number of clusters in the network and cluster formation delay is decreased compared to others. There have some problem in our proposed protocol if the channel(s) are occupied by primary users frequently or if the available channel of secondary users will change rapidly then cluster formation will be rapidly changed also. In future, we eliminate the complexity of our proposed approach more efficiently and try to implement it practically as well as implement the rendezvous success rate, overall throughput and rendezvous delay.

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