Cluster based Cognitive Radio Network: A review

Nikhil Dhamne[1], Prof. Madhuri Bhalekar[2] ,Dr. M.U.Kharat[3]
[1]M.E. Student ; [2]Assistant Professor ; [3]Head of the Department
Department of Computer Engineering, MET's Institute of Engineering,
Bhujbal Knowledge City, Adgaon, Nashik.
University of Pune.
nikhil.dhamne@gmail.com, madhuri.chatur@gmail.com, mukharat@rediffmail.com

Abstract – The underutilization of electromagnetic spectrum calls for a need to shift from static allocation policies to dynamic usage of the precious natural resource. The Clustering techniques can be broadly classified into two categories: Cluster first and ClusterHead first. The dynamic nature of the cognitve radio and the radio environment calls for network maintenance issues. The dynamic and unpredictable usage of frequency bands or channels is also a issue because it changes the spectral holes detected by each cognitve node in network. In order to harmoniously coexists with primary lisenced users, the secondary users have to adjust accordingly. Cognitive Radio users observing highly similar spectrum opportunities can be grouped and a common frequency be used for exchange of control messages called as the control channel.

Keywords – *Cognitive Radios, Common control channel, clustering, cluster head, gateway nodes.*

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I. Introduction

The underutilization of electromagnetic spectrum calls for a need to shift from static allocation policies to dynamic usage of the precious natural resource. A common control channel (CCC) is used for transmission of control messages over the network for various functionalities such as broadcasting spectrum availability information, sharing spectrum sensing data, routing information to name a few. The allocation of the spectrum is governed by government agencies mostly on lease basis. This gave rise to fixed spectrum allocation to a particular operator in a specific geographical location for certain period of time. The users of these operators do not always use a particular slice of spectrum in a geographical location and time. This means that some of the spectrum remains vacant and cannot be used by any others because of the fixed allocation to a operator. The part of spectrum that is free in a particular time and space is termed as Spectrum Hole. The spectrum holes prove the underutilization of the electromagnetic spectrum. On one hand the electromagnetic spectrum is not fully or efficiently utilized due to the allocation policy whereas on the other hand, the number of wireless user is increasing exponentially.

To improve spectrum efficiency, many operations such as sharing data in cooperative spectrum sensing, broadcasting spectrum aware routing information, and coordinating spectrum access rely on control message exchange on a common control channel. Thus, a reliable and "alwayson" common control channel is indispensable. Since the common control channel may be subject to primary user activity, the common control channel design in cognitive radio networks encounters unprecedented challenges: cognitive radio users are unable to negotiate a new control channel when the original one is occupied by primary users. Cognitive radio networks are designed by assuming the availability of a dedicated control channel. However a static control channel allocation is contrary to opportunistic/dynamic access paradigm. CR users observing highly similar spectrum opportunities can be grouped and a common frequency be used for exchange of control messages called as the control channel .

II. Related Work

The allocation for such a control channel can be achieved through various schemes. The most common of them are dedicated, sequence-based, clustering (group-based), Ultra-wideband(UWB) [3]. Of these, dedicated is absolutely against the dynamic nature of the Cognitive Radios. Sequence-based scheme is partially dynamic, in the sense that, the seqence of allocation of control channels is predetermined or randomly done. The limitation of UWB is that due to the limit on transmission power to avoid interference to primary users, the transmission range is limited.

In clustering technique, the groups of Cognitive Users are formed based on the similarities they observe mainly in the spectrum holes. In this paper, the terms cluster and groups are used interchangeably throughout.

The Clustering techniques can be broadly classified into two categories: Cluster first and ClusterHead first.

In cluster first approach, the algorithms strive to for the formation of the cluster and then a node that is one-hop away from every other node in the cluster is elected as the Cluster head. On the other hand, in cluster formation the

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cluster head first is constructed with respect to the cluster head. Any node that start the process of cluster is the cluster head. This cluster head then invites other nodes with similar spectrum holes to join in the cluster. The implementation of first approach is seen in [1] as against the implementation of the second can be seen in [2].

III. Clustering Methodology

A. Cluster First Approach

The details working of the cluster first approach [1] is as follows: All the cognitive radio nodes sense the spectrum holes sensed in its vicinity and generate a list of idle channels. It is assumed that each node has the information of its neighbors beforehand, i.e. neighbor discovery is not of importance in this approach. In other words, the nodes neither strive to get information regarding its neighbors nor it takes into account the status of the node (dead/alive). After generating the idle channel list, the nodes that observe similar spectrum opportunities are to be grouped in a single cluster. The cluster formation is considered if and only if there is at least one common for each cluster. Though, it is desirable to have more than one control channel to accommodate the PR activity on the single common control channel. The constraint of number of possible common control channel is inversely proportional to the size of the cluster. The higher number of CCCs in a cluster formation will inevitably reduce the size of the cluster. There is a need for balancing these two complementary contraints. This requires for a fair tradeoff between the number of CCCs per cluster and the cluster size. In cases where the number of CCCs is high, the cluster will be unaffected by the PR activity dynamics, whereas in case of lesser number of CCCs per cluster, the working may get adversely affected.

The algorithms mentioned in [1] namely Spectrum Opportunistic Clustering (SOC) and Constrained-SOC (C-SOC), the problem of cluster formation is mapped to biclique problem and the cluster formation occurs thereby. In SOC, in every iteration, a new node is selected i.e. a node that has not been previously examined. The node has the information about its immediate neighbors (one-hop neighbors) and the spectrum holes i.e. the list of spatio-temporally available idle channels. The next step is to create a bipartite graph such that the two sets/parts consists of the node under consideration and its immediate neighbors on one side and the list of idle channels of the node under consideration on the other. The vertices are nodes on side and the free channels on the other. An edge exists between the vertices if and only if the node has the said idle channel in its channel list. This creates a bipartite graph. Next step is to convert this bipartite graph to biclique. Biclique is a complete bipartite graph such that every vertex on one side is connected to every vertex on the other.

Mathematically, the bipartite graph can be viewed as union of two sets, say A and B. Let A correspond to the node under consideration in the particular iteration and its immediate neighbors. Let B be the list of the idle channels sensed by the node under consideration. Then, in the biclique, the number edges will be $|A| \times |B|$. Starting with the node under consideration, in each sub-iteration of the algorithm, The product of $|A| \times |B|$ is computed. Each sub-iteration corresponds to the addition of one of the remaining immediate neighbor of the node under consideration and compute the product of the nodes and idle channels that are common to those nodes. Finally, out of all the sub-terations, a maximum value is found. The maximum value will have information regarding the set of nodes and the common idle channels of those nodes. This way a cluster is formed. In the next iteration of the algorithm, one of the remaining nodes is taken in to consideration.

The cluster head is elected from a cluster such that it is one-hop away from every other node in the cluster. The cluster head then selects a channel as CCC from the available list of probable CCCs and informs the other nodes of this decision.

B. Cluster Head First Approach

The cluster head first approach is quite different as compared to cluster first approach and is extensively dependent on neighbors. In cluster head first approach, a node imitating the cluster formation process is the cluster head and then other nodes having similar spectrum holes join the cluster one by one. The network is formed by interconnecting the clusters.

The implementation in [2] works as follows: A node forms a cluster on a particular channel. In other words, the cluster head and control channel are known at the first step itself. A node that initiates the clustering process is the clusterhead. The clusterhead invites the immediate nodes to join the cluster who observe similar spectrum holes. The aforementioned invitation is send on one of the idle channels. This channel is the master channel i.e. control channel. The clusters are formed on this control channel, which simply means there is exactly one control channel per cluster. The whole network is constructed using combining such clusters. One interesting phenomenon that cannot go unnoticed inthis technique is that a node may have two different channels which are the control channels of different clusters. Thus, such a node is a member of two clusters. In [2] such a node is termed as a gateway node. This type of gateway nodes facilitate efficient intercluster communication.

IV. Non-overlapping vs. Overlapping clusters

In [1], the clusters formed are always nonoverlapping meaning that one node will be a member of exactly one cluster. The nodes in the clusters formed using SOC and C-SOC can be classified as clusterheads and ordinary nodes. The clusterheads control the clusters in the sense that the functionalities such as network management, cooperative spectrum sensing, packet routing are controlled and coordinated by the clusterheads of each individual cluster. The algorithms do not provide a insight so as to what action is to be initiated if a node fails or the clusterhead itself fails. If the clusterhead fails due to hardware malfuntioning or other unforseeable reason, there is no mechanism in place to inform the cluster members about the event. Hence for quite a significant amount of traffic directed towards the clusterhead would be lost. It will take a while for the members of clusters to anitcipate that there is a need for election a new clusterhead. The nodes in this case have options, namely, participate in the election of new clusterhead amont the member nodes or try to merge itself in another cluster.

In [2], the clusters formed are based on the control channel. A node which senses multiple idle channels such that more than one of these channels act as control channels in different clusters. This implies that such a node has the privilege of being a member of more than one cluster at a time. Such nodes are gateway nodes, in the sense that they provide a link for intercluster communication. This leads classification of nodes into three categories, namely, clusterheads, gateway nodes and ordinary nodes.

V. Classification of nodes

The nodes in the clusters are classified based on the role they perform in the cluster. In cluster first approach, the nodes can either be clusterheads or ordinary nodes. The clusterheads carry out the functionality of controlling and coordinating the cluster. This controlling and coordinating occurs through the use of control channel allocated in that cluster originting from cluster head. In clusterhead first approach, the nodes are classified as clusterhead, gateway nodes and ordinary nodes. The gateway nodes are meant for the ease of intercluster communication.

In [1], the clusterhead can only communicate to another clusterhead if they are immediate neighbors of each other. This has to be realized through the use of a common idle channel other than the control channel of those individual clusters. A message sent on control channel is intended for the cluster members for efficient intracluster coordination and communication. Hence the intercluster coordination should be carried out on a channel that is not allocated as the control channel.

In [2], a special type of node named as gateway node is of special interest. The gateway node is a node that can communicate with another cluster in two ways: communication from gateway node of one cluster to gateway node of another cluster or gateway node of one cluster to clusterhead of another cluster. The former case describes a scenario where the clusterhead of the another cluster (destination cluster) is two hop away. The communication between two clusterheads is realized through the use of two gateway nodes. The communication occurs from clusterhead to gateway node of the corresponding cluster to gateway node of destination cluster to destination clusterhead. Even though it seems to be elaborate process, the intercluster communication can actually take place. In the later scenario, there lies only one gateway node between teo clusterheads. The communication route is from clusterhead to gateway node to cluster head. The only requirement is that the gateway node should must have the control channels of both clusters in its idle channel list.

VI. Topology Management

The topology management is primarily a function of the clusterhead. The dynamic nature of the cognitve radio and the radio environment calls for network maintainance issues. These issue address the dynamic changes that occur in the network and the corresponding actions to be intitaited in the event of such occurences. It is a good practise to appoint a secondary clusterhead when the communication and all the nodes are active in the network so that in case of failure of the clusterhead the secondary clusterhead can assume the role of the clusterhead. Various issues have been identified as a challange for the network maintainance and toplogy management in cognitive radio radio networks. The dynamic and unpredictable usage of frequency bands or channels is also a issue because it changes the spectral holes detected by each cognitve node in network. In order to harmoniously coexists with primary lisenced users, the secondary users have to adjust accordingly. Let us identify and address the major issues in such a network.

1. Nodes leave the network : There are two reasons for a node to leave the network. First, the work to be done is completed and second, the node dies. In the first scenario, when the node leaves the network intentionally, it notifies the clusterhead about his activity. In the later scenario, the node fails beacuse of reasons like hardware failure, power cutoff, software malfunction etc. In this case the node is unable to notify the clusterhead about this event. The absence of the node is detected by the clusterhead when it does not receive any messages from the dead node. The clusterhead, then communicates the other members of the network about the dead node.

If the node is the clusterhead itself, the members of the clusters are notified first and then the cluster is dismissed in case if there is no secondary clusterhead or else the secondary clusterhead takes the charge as the clulsterhead and the cluster remains intact. If there is no secondary clusterhead then the cluster is dismissed with notification in the case where clusterhead leaves intentionally. The cluster is dismissed when the cluster members are unable to communicate with the clusterhead and do not receive any messages from the clusterhead. The cluster is then dismissed.

If the node is a gateway node, the clusterhead hunt for another gateway node so that the intercluster communication is facilitated.

2. Nodes join the network : The nodes can join the network as ordinary nodes at the first stage. They can be then upgraded to gateway nodes depending on the spectral holes

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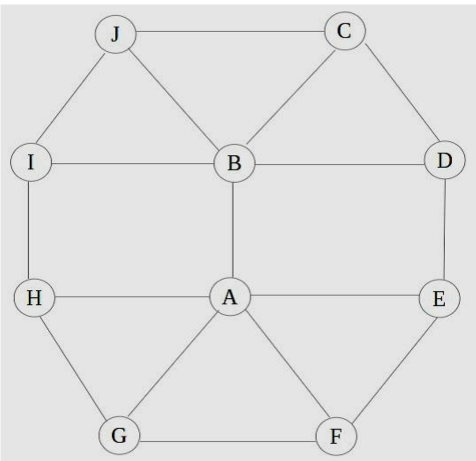
detected by the new node. In the joining process, the nodes detects the spectrum holes and creates a list of idle channels sensed in its vicinity. The node then listens on these channels for messages from other nodes. After several such rounds, the cluster has the knowledge of its immediate neighbors and then finalizes the cluster membership.

3. Change in spectral holes : The cognitive radio network works on the principle of use of the frequency band currently not occupied by the primary users. These unused bands are termed spectral holes. The spectral holes keep on changing according to the primary user activity. The channel that might be idle at some point of time may not be available at another. This dynamicity needs to addressed. The change in spectral hole causes drastic changes in the network. For instance, if the control channel is occupied by the primary user, then intracluster communication is not possible any longer. The solution to this can be switching to another control channel. If there is no other possibel control channel, then the members start to search from spectral holes so that they can become members of other clusters. The change in the spectral holes, is a major factor for reclustering.

VII. Network Model Analysis

The cluster first and clusterhead first approaches are applied to the network shown in Fig.1. The cluster formation process for one node to illustrate the working of both the approaches is elaborated and the formed clusters are indicated in Fig.2 and Fig.3 for cluster first and clusterhead first approach respectively.



Lists of idle channels sensed by each CRs:

A = {1,2,3,7,9}	B = {2,4,6}
C = {1,2,3,5,7,8,9}	D = {2,3,5,6,9,10}
E = {2,4,6,8}	F = {5,7,9}
G = {1,3,4,7,9}	H = {1,3,5,7,8,9,10}
I = {3,4,6,7,8,10}	J = {2,5,7,9}

Fig.1 10-node CRN with lists of idle channels sensed by each CRs.

It is assumed that the list of immediate neighbors is available with all the nodes and the spectrum holes do not change during the process of clustering.

The working of node A for cluster first approach, is explained here. Node A has five nodes as immediate neighbors, namely, B,E,F,G,H. The list of idle channels sensed by A is 1,2,3,7,9. The intersection of each nodes' channel list is obtained as the next step. So, the number of common channels of nodes B,E,F,G,H with A are 1(2),1(2),2(7,9),4(1,3,7,9),4(1,3,7,9) respectively where numbers in brackets indicate the channel numbers. The node node A has sensed 5 idle channels and if A was tto be the only member of the cluster the product of nodes in the cluster and the common idle channels in the cluster would be 5. In the next step, A and G forms a cluster with 4 common idle channels. Since the intersection is highest and sequential (in the event for tie breaking). The common channels are 1,3,7,9. Cluster members are 2 and idle channels for that cluster are 4. The product of which is 8. The node H also joins the cluster in the next step because it also has the same common channels with A. So, the number of node becomes 3 and the common idle channels are 4. The product is 12. The nodes B and E do not have any common channel with this cluster so such nodes would obviously reduced the product and resulting into smaller clusters with very less common idle channels in each cluster. Of the products 5, 8 and 12; 12 is the highest. Hence the cluster is finalized with members A,G,H and common idle channels as 1,3,7,9. These four represents the possible candidates for control channel of that cluster. One of these channels is selected as a "*control channel"* and one the nodes is elected as clusterhead. It must be noted that after the formation of the cluster, the clusterhead is elected. A typical requirement for a node to be clusterhead is that it should be one hop away from every other node of the cluster. So, Let us assume that node is elected as cluster head. On similar lines, the clusters are formed control channel from a list of possibilities is selected and clusterheads for respective clusters are elected. The clusterheads could be A, B, C, E and F for their respective clusters. The clusters formed and the idle channels of those clusters are indicated in Fig.2.

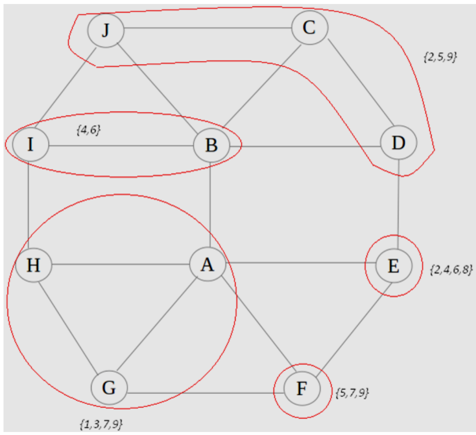


Fig.2. Clusters formed by cluster first approach

The working of node A in clusterhead first approach is as follows: Node A initiates the cluster formation process. So, node is the clusterhead of the cluster that will be formed. Node broadcasts invitation to its immediate neighbors for cluster formation on the lowest frequency channels, which is channel 1 in this case. The immediate neighbors H and G receive the invitation and join the cluster on channel 1. It is worth noting that the channel 1 is the only control channel for the cluster formed and moreover the cluster is formed on this channel. The other idle channels may or may not form clusters on them depending on the invitations received or themselves initiating the cluster formation process. Thus the cluster formed by A has two other members namely G and H and the control channel is 1 while the node A is the clusterhead. The clusters formed with clusterheads and the idle channels of those clusters are indicated in Fig.3. The overlapping clusters are formed due to the reason that a node is a member of one cluster on one channel and member of another cluster on another channel. Such nodes, as mentioned previously are gateway nodes. The clusterheads are B,E,F,G,I for their respective clusters and the gateway nodes are A,H,D. Node A is a member of a cluster on control channel 1 and memebr of other clusters on channels 2 and 5. Similarly H is a member of one cluster on channel 1 and member of another on channel 3. Also D has two memberships i.e. on channels 2 and 6.

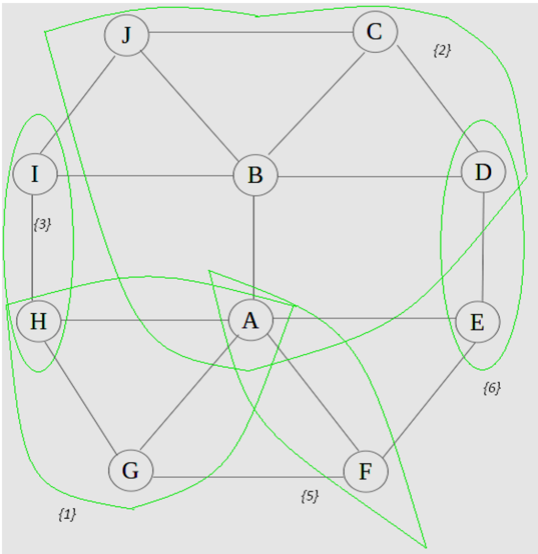


Fig.3. Clusters formed by clusterhead first approach

Conclusion

The common control channel facilitates a variety of network operations through the use of a channel that is common to the nodes observing highly similar spectrum opportunities. In this paper, we have discussed two broad categories of clustering methodologies in cognitive radio networks. The design of overlapping and nonoverlapping clusters leading to various functionalities of nodes. The topology management issues are discussed considering dynamics of primary and secondary users. A sample network with analysis of both the methodologies is also shown. The graphical output of both the strategies are applied to the same network and formed clusters are indicated with the list of control channels allocated in each cluster.

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