Clustering Approach For Distributed Cooperative Detection in Cognitive Radio Networks

Jani Nidhi R, S.K. Hadia, Jani Preetida V.

Abstract*— *There have been significant advancements towards realizations of cognitive radios, as well as towards the development of the various enabling technologies needed for the diverse potential application scenarios of CRs. Nevertheless, we have also seen that a lot of further research and development work is definitely needed before general cognitive wireless networks can be realized. Cognitive radios (CRs) can exploit vacancies in licensed frequency bands to self-organize in opportunistic spectrum networks. Such networks, henceforth referred to as Cognitive Radio Networks (CRNs), operate over a dynamic bandwidth in both time and space. This inherently leads to the partition of the network into clusters depending on the spatial variation of the Primary Radio Network (PRN) activity. Many of the solutions mentioned earlier have been designed only for limited-size CRN, for example due to the presence of centralized controllers. However, we would ideally like to be able to extend such a paradigm to virtually infinite CRNs. In this work, Weighted Clustering Algorithm designed for basic cluster formation for CRNs is proposed, which explicitly can take into account the spatial variations of spectrum opportunities in future.

Index Terms*— *Cognitive Radio, Cooperative sensing, Weighted Clustering Algorithm.

I. INTRODUCTION

Cognitive Radio (CR) is the newer version of Software Defined Radio (SDR), which has been introduced in [1]; CR will provide significant improvements over services offered by current wireless networks. CR is aware of and sensitive to the changes in its surroundings. It learns from its environment and adapts its internal parameters in real-time.

In CR networks, the unauthorized user, called as Secondary User (SU) or Cognitive Radio (CR) node, can use the licensed bands when the authorized user, namely Primary User (PU) is absent. For the SU, in order to utilize the frequency bands that are not occupied by the PU, the SU should accurately identify the spectrum hole (white space). When spectrum hole is found through some kinds of detection technologies, it is reused to communicate. However, in order to protect the PU from interference, the SU has to get awareness and vacate immediately when the PU is active. So the spectrum sensing technology is the premise and the key technology to realize the CR. [2]

The presence of the PU can be identified either by the independent detection or the cooperative detection. In the independent detection, the final decision on the presence of PU is made by itself, such as energy detection, matched filter detection and cyclostationary feature detection [3]. However, the performance of spectrum sensing will be degraded due to fading, shadowing or hidden terminal issues. To mitigate the impact of these issues, cooperative detection has been shown to be an effective method to improve the detection performance.

As per [2], in the cooperative detection, the local observed results come from different users in a CR network are shared each other. In a centralized CR network, the Fusion Center (FC) will collect the local observed results or local decisions come from different cooperative users and make a combined decision about the presence of the PU in the target licensed band. And in a decentralized CR network, i.e. Ad hoc, each cooperative user will make a final decision based on the shared data come from all users, because there doesn't exist the FC. However, conventional cooperative sensing isn't efficient when users suffer different fading environments. So many present works focus on the weighted-cooperative sensing. In [4], a weighted cooperative spectrum sensing scheme based on distance is proposed, but it only takes care of the distance of different SUs. Here Weighted Distributed Clustering Algorithm is proposed which takes into consideration the parameters: connectivity (C), residual battery power (BP), average mobility (M), and distance (D) of the nodes to choose locally optimal Clusterheads. The objective of this work is to implement this algorithm for Cognitive Radio – Distributed Cooperative Networks.

The rest of the paper is organized as follows. In Section II, Clustering Model is proposed. Section III with simulation results; the conclusion & Future work are summarized in Section IV.

II. PROPOSED CLUSTERING MODEL

In[5], Weighted Distributed Clustering Algorithm (CBPMD) is presented for Mobile Ad hoc Networks. The same approach is used for Cognitive Radio Networks (CRN) in this paper. According to [5] the goals of this algorithm are

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maintaining stable clustering structure with a lowest number of clusters formed, to minimize the overhead for the clustering formation and maintenance and to maximize the lifespan of CR nodes in the system. According to the research proposed in [5] an improved clustering algorithm is inspired by the fundamental idea of combined metrics. According to [5], the following points briefly describe metrics considered in the proposed clustering algorithm:

The **clustering algorithm** (formation or maintenance) is not invoked if the nodes don't exist from the transmission range of their master Clusterheads.

The **weighting factor** is a generic parameter used in the decision of selecting a Clusterhead. The node having the greatest weight is elected as Clusterhead.

The **max value** denotes the upper limit of the number of nodes simultaneously capable of support by a cluster-head. In other words, specifying a pre-defined limit on the number of nodes that a Clusterhead can ideally handle, thus ensuring that none of the Clusterheads are overloaded at any given time. A high system throughput can be achieved by limiting or optimizing the degree of each cluster.

The **min value** denotes the lower limit of the number of nodes belonging to a given cluster before invoking to the merging algorithm. The min value therefore, may avoid the inherent complexity of the management of greater numbers of clusters.

The **residual battery power** can be efficiently utilized within certain transmission ranges, i.e., it takes less power for nodes to communicate with others if they share close proximity. A Clusterhead consumes more battery power than an ordinary node since a Clusterhead has extra responsibilities to carry out for its members.

Mobility is a crucial element in deciding the Clusterheads. In order to avoid frequent Clusterhead changes, it is advantageous to elect a slow-moving Clusterhead. When a Clusterhead moves fast, the nodes may detach from it resulting in a reaffiliation, which occurs when an ordinary node moves out of a cluster and joins another existing cluster and as such, the amount of information exchange is limited between the node and the new corresponding Clusterhead as local and comparatively small.

The **communication ability** (connectivity) of a Clusterhead is more efficient and effective with neighbors that have closer proximity to it within the transmission range. As the nodes move away from the Clusterhead, signal attenuation from the increasing distance can be detrimental to the communication. Finally, these parameters play a decisive role in the proposed model.

A. The Metric Components and Combined Weight

Connectivity Metric (C):

The first parameter is the connectivity. Neither nodes with the highest connectivity nor the lowest should be elected as Clusterheads. The former will be congested and their battery power will drop rapidly and the latter will have a low cluster size and the advantages of clustering will be unable to be exploited. In [6] a distributed algorithm (Combo) is presented which aims at creating clusters of a given size (in number of hops) that takes into account the cardinality of the set of commonly available channels among CRs when making decisions. Neighbor discovery phase is able to provide to the CRs the list of their k-hop neighbors, along with their corresponding available channels. After the neighbor discovery phase, all CRs run the clustering algorithm independently, and base their decisions on the information stored in the ternary key $\tau_j = \{c_j, d_j, ID_j\}$, where d_j is the k-degree of connectivity of CRs j, namely the cardinality of its k-hop neighbors set N_j^k, ID_j is the cognitive radio ID, and c_j is the minimum number of common channels that CR_j has with each of its neighbors. Based on this information each CR calculates a weighted priority key that will be used during the cluster formation process to decide whether the CR will be a cluster head or join an existing cluster. A CR_j is elected as cluster head if its weighted priority key is the highest among its neighbors. Here in our case we are considering the same connectivity metric as shown for Combo algorithm in [6].

The Connectivity metric is denoted by C, as

$$\boldsymbol{C = \sum_{j=1, j\neq i}^{N} L_{i,j}(t)} \qquad \textbf{(1)}$$

Let N be the number of CR nodes in the system.

Let $L_{i,j}(t)$ be the indication that whether node i is a neighbor of node j, at time t with available free common channels;

$L_{i,j}(t) = \{0,1\}$

Where,

$L_{i,j}(t) = 0$; If node i is not a neighbor of node j at time t,

$= 1$; If node i is a neighbor of node j at time t.

It is assumed that all links between any two neighbor s are bi-directional. A node with the largest connectivity can perform well as Clusterhead. [5].

Residual Battery Power Metric (RBP):

The second parameter is the residual battery power. CR nodes usually depend on battery power supply; therefore prolonging a network's lifespan by reducing energy consumption is an attractive proposition and as CH as team leader and administrator carries extra responsibilities and performs more tasks compared with ordinary members it is likely to "die" early because of excessive energy consumption. These 'deaths', or 'dies', diminish the effectiveness of the network; a deficiency of CR nodes due to energy depletion may cause network partition and communication interruption. Hence, it is vital to balance the energy consumption among nodes to avoid node failures, especially when the network density is comparatively sparse. Also, the *battery power* (set residual battery power of the node i as RBP_i) can be resourcefully used within an optimum transmission range, i.e., nodes within close proximity will require less power to communicate with other nodes. The objective is to avoid this detriment where the total collapse of the current network topology may result and reduce the number of Clusterhead elections and cluster formations. Finally, a node with high residual battery power RBP_i can perform well as Clusterhead for a longer duration. Therefore, a node with sufficient battery power to survive a predicted term is to be selected as Clusterhead to reduce the amount of overhead incurred during Clusterhead re-election and to avoid the premature demise of nodes [5].

Average Mobility Metric (M)

Each CR node i measures its own average mobility M_i, used to calculate the weighted function value, in formula (4). This is achieved through contrasting the topology information it obtains during successive Hello Messages (HMs). CR nodes maintain a short ‘Neighbor Record Table’ (NRT); NRT rows comprise vectors representing the IDs of neighbor ing nodes, where each NRT row refers to different HM. Calculated M_i value actually represents the values recorded by *i* during the latest *n* HMs (where *n* is a small integer in order to minimize memory requirement):

$$\boldsymbol{M_{i,n} = \frac{1}{n-1} \sum_{i=n}^{1} (i-1) \left| NRT_{t(i+1)} - NRT_{t(i)} \right|} \qquad (2)$$

Where, *t* denotes the current time. The coefficient $(i - 1)$ increases the weight of recent over older node movements on calculated $M_{i,n}$ values since the former are regarded as more reliable indicators of future mobility trends. Nodes with lower mobility are favored for the role of Clusterheads as there will be fewer changes in Clusterheads either by replacement or re-education [5].

Distance Metric (D)

The fourth parameter is the distance between node and others within transmission range. It’s better to elect a Clusterhead with the nearest members. This might minimize node detachments and enhances clusters’ stability. For a node i, D is computed as the cumulative mean square distance to neighbor s divided by the total number of neighbor s as shown in formula (3):

$$\boldsymbol{D = \frac{1}{d_i} \sum_{j \in N(i)} \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2}} \qquad (3)$$

Where, the neighbor s of each node *i* (i.e., nodes within its transmission range) which defines its degree, d_i as:

$$\boldsymbol{d_i = |N(i)| = \sum_{j \in V, i \neq j} \{dist(i,j) \leq T_x\}}$$

Where, X_i, X_j □ □*and* □Y_i, Y_j□ □ are the coordinates of the nodes *i* and *j* respectively. The motivation of D is primarily linked to energy consumption.

It is understood that more power is necessary to communicate to a greater distance. Following this, it could be suggested that to use the sum of the squares (or higher exponent) of the distances would be more expedient because the increased demand on power required to support a link linearly is more severe.

Combined Weight (W)

Based on the above parameters about residual battery power, average mobility, connectivity and distance, it is obvious that a node j is the best candidate for a Clusterhead among all its neighbor s, if its M_j is the lowest, its RBP_j is the highest, its C_j is the highest, and its D_j is the lowest. In other words, a node with the highest weight is the best candidate for a Clusterhead when we combine these four metrics together as the weight, which is calculated in formula (4) [5]. But these metrics have different units, as

The mobility can theoretically vary between zero and infinity, a normalized translation is needed. One way to do it is:

$$\boldsymbol{M \to e^{-M}}$$

The residual battery power can theoretically between 0 and max power, a normalized translation is needed. One way to do it is:

$$\boldsymbol{RBP \to \frac{RBP}{Max\_Power}}$$

The connectivity can theoretically vary between zero and *N – 1*, a normalized translation is needed. One simple way to do it is:

$$\boldsymbol{C \to \frac{C}{N-1}}$$

The distance can theoretically vary between 0 and ($dv*T_x$) a normalized translation is needed.

One way to do it is:

$$\boldsymbol{D \to e^{-\left(\frac{D}{d_v * T_x}\right)}}$$

Using the result from the above, the combined weight W_i for each node *i* is:

$$\boldsymbol{W_i = W_1 * e^{-M_i} + W_2 * \frac{RBP_i}{Max\_Power} + W_3 * \frac{C_i}{N-1} + W_4 * e^{-\left(\frac{D_i}{D_i * T_x}\right)} + \left(\frac{i}{i+1} 0.00000001\right)} \quad (4)$$

Where $W_1 + W_2 + W_3 + W_4 = 1$, and i is the ID number of node. In this formula (4), the weighting factors $W_{1,}$ $W_{2,}$ W_3 *&* W_4 are set according to the different scenarios in the applications.

The last part of the weight definition is used to make each weight unique (i.e. no two nodes will have the same ID number). Therefore, no two nodes will have the same weight even if the value of the left part of the weight definition is the same [5].

B. Election of the Clusterhead (CH)

Step 1: The position of nodes will be located according to the idle channel found by the node using one of the spectrum sensing techniques and a sequence of events to determine this for the ultimate election of the Clusterhead ensues.

Step 2: Each node will then broadcast a Hello message to notify its presence to all of its neighbor s; a Hello message contains its ID and position value and information of idle channels found by spectrum sensing. During this phase each node compiles its neighbor list based on the receipt of Hello messages.

Step 3: Election of the Clusterheads is based on the weight values of the neighbor nodes; each node calculates its weight value based on the metrics discussed in above and after finding its weight value, each node broadcasts the weight value using a *Weight_Info ( )* message to its k-hop neighbors.

Step 4: Following the collection of *Weight_Info ( )* messages from the neighbor s, each node builds a set *S*, which contains the IDs and the weight values of itself and its neighbor s.

Step 5: With *Weight_Info ( )* information the node then broadcasts its weight to its neighbor s in order to compare the better among them.

Step 6: The node that has the largest weight is chosen as a cluster head. If two nodes have same weight then the node with lower ID will be selected as Clusterhead.

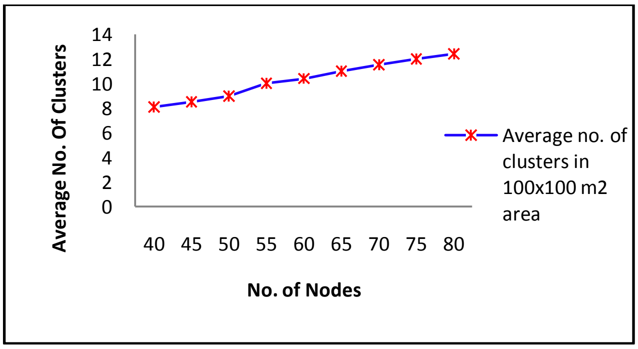
Formation of the Cluster Members' Set

This stage is the final step of the algorithm where the construction of the cluster members' set is presented. Each Clusterhead neighbor is defined at k-hop maximum and these nodes form the members of the cluster. Next, all information about its members is stored by each Clusterhead, and all nodes record the cluster head identifier. This exchange of information allows the routing protocol to function both within and between the clusters.

III. SIMULATION RESULTS

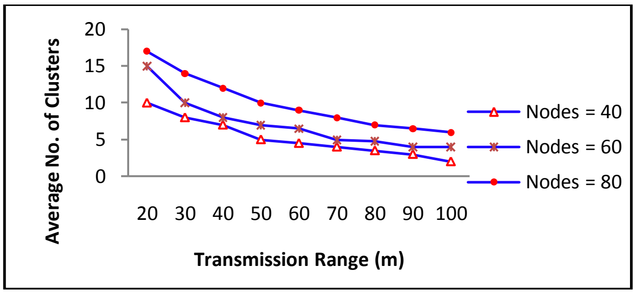
A simulation model is developed using discrete event simulation to evaluate the inherent stability, reliability, and efficiency of the election clusterhead algorithms. This simulation is performed in NS2 environment. Three different network sizes are taken into account, 40, 60 and 80 CR nodes, and the transmission range was varied between 20 and 100 m. Initially, each CR node is assigned a unique node ID with idle channel information, a random x-y position, a random mobility speed, and a random power level greater than 95% of its maximum battery power. At every time unit, the nodes are moved randomly according to the random waypoint model in all possible directions in 100 X 100 m^2 square space with velocity distributed uniformly between 0 and maximum speed along each of the coordinates. This behaviour is repeated for the duration of the simulation and each simulation scenario is run for enough time to reach and collect the desired data at the steady state. Several runs of each simulation scenario are conducted (each run representing random initial parameters) to obtain statistically confident averages. We assumed a predefined threshold for each clusterhead which can handle (i.e. cluster size) at most 10 nodes, and min value is 1.

As shown in the figure 1, proposed scenario is simulated for 100x100 m^2 area with 80 CR nodes, with transmission range = 35 m.

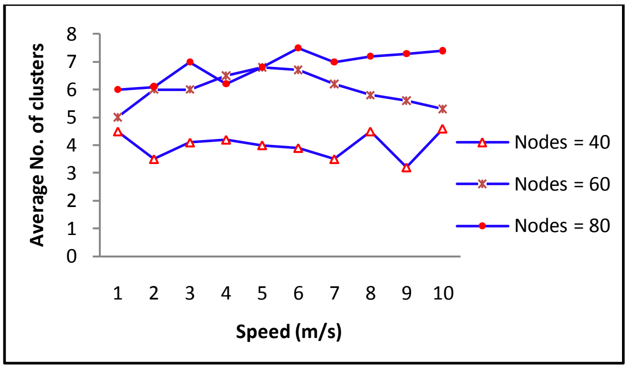


[Figure 1. Average Number of clusters in 100x100 m^2 area]

Then results are analysed with different transmission ranges and speed with nodes = 40,60 and 80 which is shown in figures 2 and 3 respectively for 100 x 100m^2 area.



[Figure 2. Impact of transmission range on the average number of clusters]



[Figure 3. Impact of Speed on the average number of clusters]

As shown from the figure Average numbers of clusters increases with increase in number of CR nodes in both criterias. With increase in transmission range, there is significant decrease in Average number of clusters for all three sereises i.e. Nodes = 40,60 &80. But for the scenario based on the varying speed of the CR nodes seems different than first scenario, here we can see fluctuation in Average no. of clusters for different speeds.

IV. CONCLUSION & FUTUREWORK

A Cognitive radio is the key technology to utilize unused spectrums & Spectrum sensing is a key function of cognitive radio to prevent the harmful interference with licensed users and identify the available spectrum for improving the spectrum's utilization. Cooperative sensing appears to be an effective technique to improve detection performance by exploring spatial diversity at the expense of cooperation overhead. In this work, Weighted Clustering algorithm is proposed as a stepping point for Organized Cluster Based Distributed Cooperative CRN in terms of Cluster formation to have better approach to reduce the overhead and delay of sensing in cooperative CRN. We conducted simulation that shows the performance of the proposed clustering algorithm in terms of the average number of clusters formation. The algorithm uses a set of weighting parameters for the election of a cluster-head hence that node is elected as the cluster-head which is more powerful than the other nodes. The proposed algorithm attempts to minimize the average number of clusters. As a future work analysis of proposed weighted-cluster formation algorithm to enhance the performance of cooperative spectrum sensing scheme when the set of users in each cluster suffer the different channel environment is expected to be carried out. Works still need to be done in security, inter-operation, and interference area also.

References

[1] I. J. Mitola, “Software radios: Survey, critical evaluation and future directions,” *IEEE Aerosp. Electron. Syst. Mag.*, vol. 8, pp. 25–31, Apr. 1993.

[2] Huiheng Liu, Wei Chen, “Cooperative Spectrum Sensing and Weighted-Clustering Algorithm for Cognitive Radio Network,” *I.J. Information Engineering and Electronic Business,* 2011, 2, 20-27

[3] D. Cabric, S. M. Mishra, and R. Brodersen, “Implementation Issues in Spectrum Sensing for Cognitive Radios,” *in Proc. 38th Asilomar Conf. Signals, Systems and Computers, Pacific Grove,CA, pp.* 772-776, November 2004.

[4] Yi-bing Li, Xing Liu, Wei Meng, “Multi-node Spectrum Detection Based on the Credibility in Cognitive Radio System,” *5th International Conference on Wireless Communication, Networking and Mobile Computing,* pp. 1-4, 2009

[5] Ayman Bassam Nassuora, Abdel-Rahman H. Hussein, “CBPMD: A New Weighted Distributed Clustering Algorithm for Mobile Ad hoc Networks (MANETs),” *American Journal of Scientific Research ISSN 1450-223X Issue 22(2011),* pp.43-56

[6] Alfred Asterjadhi, Nicola Baldo, Michele Zorzi, “A Cluster Formation Protocol for Cognitive Radio Adhoc Networks”