A Genetic Algorithm Based Spectrum Sharing Strategy Using Energy Efficient Clustering for Cooperative CR Networks

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Abstract — This paper considers the problem of spectrum sharing among primary (or “licensed”) and secondary (or “unlicensed”) users. Specifically, multi-phase cooperation architecture is proposed including cooperation partner selection (Intermediate users IUs) and spectrum sharing among secondary users (SUs). In this paper, we use an intelligent cluster-based cooperative spectrum sensing scheme, based on centralised energy and distance criteria, for the appropriate selection of IUs so that IUs communicate efficiently with the PU. Also, an energy efficient cluster based TDMA protocol is proposed for the communication between IUs and SUs. The cluster head (CH), selected from IUs, forwards the data of primary users (PUs) to fusion centre, and then CH acquires the spectrum access opportunities for its own transmission. The problem based on bandwidth allocation is solved in total frame size in which the IUs selection and cluster formation is done on the same time slot and remaining time slot of the frame is distributed between spectrum sharing amongst PU-IUs and IUs-SUs. Simulation results show that the proposed scheme reduces the end to end delay and hence prolongs the network’s lifetime and throughput.

Keywords — Cognitive radio; Spectrum sharing; cooperative spectrum sensing; clustering technique; energy efficiency, Genetic Algorithm.

1 INTRODUCTION

Wireless communication systems have been widely and successfully deployed all over the world. Day by day, upper layer protocols demand high speed wireless access with very low delay requirements for applications in data, voice, video and other high bandwidth multimedia applications. However, the radio spectrum band available to serve the wide variety of all these emerging applications is strictly limited. The regulatory bodies licensed the radio spectrum, implementing strict limitations on operators and manufacturers protecting the radio resource and licensed users. This commandant-control nature of regulations limits the access of radio resource which is a graver problem than the physical scarcity of spectrum. Further, it has been discovered that some frequency bands are largely underutilized or partially occupied most of the time, even in revenue rich urban areas. The Cognitive radio was proposed as a mechanism to efficiently utilize such free bands (spectrum holes) by exploiting its availability by cognitive users (CUs).

In order to complete these cognitive tasks in cognitive radio network, the CU must perform additional tasks than a normal wireless user. The detection of spectrum holes (spectrum sensing) with sufficient reliability is one such major task to be performed by CUs.

1.2 Cognitive Radio
Cognitive radios are wireless radios that opportunistically share the spectrum while avoiding any interference to the primary licensed users. Depending on the ways, that cognitive radios use to tackle the problem of interference to the primary user, three categories of cognitive radios are defined. These categories are underlay, overlay,
and spectrum-sensing (or interweave) cognitive radios. In underlay and overlay systems, the cognitive radios transmit, within the same band, at the same time with primary users while keeping their interference below a certain level. The difference between the underlay and overlay cognitive radios is that in the underlay systems the cognitive radios need to access the channel side information whereas in the overlay systems they need to have knowledge about the codebook side information and messages that the primary users send.

Interweave cognitive radios; on the other hand, employ spectrum sensing to detect the empty portions of the radio spectrum (also known as spectrum holes) at a certain time and geographical location. Upon detection of such a spectrum hole, cognitive radios dynamically share this hole by adapting their transmission power and modulation according to the available resources and the surrounding environment [10]. However, as soon as a primary user appears in the corresponding band, the cognitive radios have to vacate the band. This way, transmission is limited to the bands that are deemed to be empty in order to avoid interference to the primary users. In order to accomplish these tasks, a harmonious cooperation among cognitive users is required which is coordinated through a dedicated control channel [9]. In this work, the focus is on this category of cognitive radios and whenever we talk about a cognitive radio, we mean an interweave cognitive radio.

In order for the unlicensed or secondary users to use the licensed spectrum there are many issues that should be taken care of in advance, like

- scanning the frequency spectrum for the discovery of different empty bands.
- selecting the best available band. The selection can be done on the basis of the secondary user’s application frequency requirement.
- before transmitting on the selected band the power level should be maintained such that it provides minimal interference to other users and to have maximum number of secondary users in the frequency band of interest.
- spectrum sharing should be allowed so that other secondary users can also access the empty bands.

1.3 Related Work

Generally, the energy efficiency includes several aspects such as: energy consumption of transmission, energy consumption of channel switching, energy consumption of spectrum sensing. In addition, there are more other energy consumptions in the cognitive network. In this paper, we only focus on the energy efficiency problem considering these aspects [3].

There are three constraints needed to be considered in the energy consumption problem: reliability of sensing, the throughput, the delay of SU. Reliability of sensing can be measured by two probabilities: probability of detection and probability of false alarm. The probability of detection is the probability of the channel being sensed busy when it is busy. The higher probability of detection means, SU can catch a PU communication more accurately. The probability of false alarm is the probability under the situation: the channel is idle, it is sensed busy [4, 5 and 6].

As mentioned before, the energy problem is considered to be more serious these days, a plenty of research is done to study it. In [2], theoretical analysis is given about the energy efficiency in cognitive radio network. It mainly analyses the physical layer of the OSI model.

More recently authors in [1] have proposed a multiphase cooperation scheme in order to improve the network utility as well as the spectrum access opportunity. The salient features of the work in [1] are as follows:

1. Authors assign the selected relaying SUs as the group of intermediate users (IUs), which cooperate with PUs in traffic relay and share the spectrum access opportunities with the remaining SUs. With the help of IUs, the PUs can improve their own performance as well as not be involved in such a complicated cooperation scheme with multiple SUs. Meanwhile, the SUs starving for the spectrum access opportunities attain what they want as well.
2. An IU selection scheme is implemented by the maximum weighted bipartite matching algorithm, and the utility of the cooperating pairs is enhanced by exploiting the ratio of cooperation pairs’ utility to the total energy consumption with the consideration of the IUs’ energy efficiency.
3. Through the cooperation among the IUs and the surrounding SUs, the starving SUs who form a cluster can obtain the transmission opportunities without consuming too much energy to relay the
PUs’ traffic by using cooperative network coding. Conversely, the IUs’ utility and communication reliability can be enhanced.

In this paper, the multi-phase cooperation scheme proposed in [1] is used as the backbone of the proposed spectrum sharing strategy. In this work, the selection of IUs from SUs is done based on certain energy and distance based criteria and through some artificial intelligence like genetic algorithm, which can intelligently decide the selection of IUs from the SUs.

Other important issue considered in the scheme proposed in [1] is that the frame structure changes as IU selection and cluster formation is done in different time slots. We propose the scheme in which the cluster formation and IU selection is done in the same time slot of a frame and the remaining frame can be utilized for spectrum sharing strategy. Finally, a clustering based energy efficient spectrum sharing strategy can improve the communication between selected cluster heads from IUs and SUs which in turn improves the lifetime and throughput of network as compared to using network coding in such spectrum sharing environment.

2. SYSTEM MODEL
A cognitive radio network with one primary user (PU), N secondary users (SUs) is considered. Out of N SUs, M intermediate users (IUs), acting as local sensing device, are assumed to be organised into clusters, where each cluster has a cluster head (CH) that makes a cluster decision based on the local decisions received from its cluster members and report the result to the cognitive base station that acts as a fusion centre (FC).

The system model has been considered with the following assumptions:
(a). We assume that a CRN topology is stable and consists of one fusion centre FC, one primary transmitter and M of Intermediate users IUs chosen from N Secondary users SUs.
(b). The FC has the location information of all the CRs, possibly determined using Global Positioning System (GPS).
(c). The instantaneous channel state information of the reporting channel is available at the CRs.
(d). The channel between any two IUs in the same cluster is perfect since they are close to each other.

As the primary user’s signal type is not initially known, therefore, an energy detector is employed to conduct the local sensing, which is suitable for any signal type. In this energy detection algorithm, it is assumed that the transmitted power of the primary system is known. Therefore, this power is detected first, and then compared with a predefined threshold \( \lambda \). Based on this comparison, it is decided whether the spectrum band can be used for secondary transmission or not.

The system structure of a cognitive radio network, according to the clustering approach, is illustrated in Figure 1. First, all IUs are grouped into clusters using proposed intelligent genetic algorithm and energy distribution based protocol. This protocol provides an efficient clustering configuration algorithm, in which the cluster heads (CHs) are selected by the proposed scheme in a centralised way, which minimizes the data transmission energy between a CH and other members in a cluster, according to the best reporting channel gain and the energy level of the IUs.

This energy efficient spectrum sensing protocol maintains such clustering hierarchy. In the proposed scheme, the clusters are re-established in each round. New cluster heads are elected in each round and as a result the load is well distributed and balanced among the nodes of the network. Moreover each node transmits to the closest cluster head so as to split the communication cost to the sink (which is tens of times greater than the processing and operation cost.)
2.1 PROPOSED CLUSTER BASED APPROACH

We propose cluster-based cooperative spectrum sensing algorithm using our new energy distribution check mechanism based protocol for cognitive radio networks. We demonstrate that our clustering approach extends the lifetime of cognitive networks and try to maintain a balance energy consumption of CR users. Furthermore, we present a reporting strategy that reduces the average number of reporting decisions, by allowing only the CR with detection information to send its binary decision (0 or 1) to CH.

As shown in figure 2, the cooperation between SUs and PU takes place in a two-phase cooperation scheme in each timeslot $T$. The first phase selected cluster head IU and clustering within the network, while the second phase cooperation is between the PU and with the selected IU and cooperation is between the cluster head and other SUs in the cluster. The partner IU selection scheme is first performed, and then the cluster head IU cooperates with the PU using TDMA where the PU transmits its package to the cooperating IU and the IU relays PU’s last package to the BS simultaneously. After the cooperation between PU and IU, the IU finds the cooperative SUs who form a cluster from the surrounding starving SUs.
3. PROCEDURE OF PROPOSED SELECTION MODEL

The method is applied in a wireless field of area 100x100 m². However the field area can be changed as per the result variations. Also, the base station is assumed to be placed at the centre of CR (PU, IUs, SUs) field initially, however, the position of the base station can be changed. Initially, the dissipated energy is zero and residual energy is the amount of initial energy in a node, hence, initially the total energy $E_t$ also equals the amount of residual energy because it is the sum of dissipated and residual energy.

To reduce the transmission energy consumption, a cluster-based cooperation scheme is proposed. All SU are separated into a few clusters and one cluster head is set for each cluster to collect the sensing results, make cluster decisions and forward results to the common receiver. Thus the transmission energy consumption of SU will be reduced greatly because most of them are closer to cluster heads than to the common receiver and much less power is needed to transmit local decisions.

Also we can calculate the average energy $E_a$ of a node after the particular round with the knowledge of total energy and a particular number of round numbers.

$$E_a = E_t \times \left(1 - \frac{(r/R_{max})}{n}\right)$$

(1)

Here $r$ stands for current round, $R_{max}$ is total number of round which we consider 10,000 and $n$ is total no secondary users which we consider to be 100.

We calculate the Dead Statistics before assigning a CH, and its value renewed every new round. The selection probability mentioned in equation 2 for the selection of cluster head is taken as .1 (user defined).

$$p(i^{th}) = \frac{P_{opt} \times n \times 5(i) \times E(i)}{E_t \times E_a}$$

(2)

where, $S(i)$ is the current amount of energy within the radio, and $E(i)$ initially supplied energy to the $i^{th}$ radio. $E_t$ and $E_a$ are total and initially supplied values of energy and $P_{opt}$ is the optimum probability for the selection of intermediate user and decided through genetic algorithm.

Here, a Node will becomes CH, if a Temporary number (between 0 to 1) assigned to it is less than the global threshold structure given below,

$$T(s_i) = \begin{cases} \frac{P_i}{1-P_i(r \mod \frac{1}{P_i})} & \text{if } r \in G \\ 0 & \text{otherwise} \end{cases}$$

(3)

Where $r$ is current round and $G$ is collection of nods in a cluster.

Here, $P_i$ is obtained from new expression for optimum probability $p(i)$. Hence only the nodes with higher energy amongst the other nodes can fulfill the criteria above and hence a node can transmit data as a cluster head for a longer period which results in increment of network lifetime and throughput.

After a higher energy node becomes CH, energy models are applied to calculate the amount of energy spent by it on that particular round and complete the round of steady state phase. This dissipation energy is calculated by standard wireless radio energy model given below:

$$E_{TX}(l, d) = \begin{cases} lE_{dec} + l\varepsilon_{rx}d^2, & d < d_0 \\ lE_{dec} + l\varepsilon_{tx}d^4, & d \geq d_0 \end{cases}$$

(4)

If a node is not a higher energy node and discarded from the criteria above, then it goes to a set of normal node, and follows the behaviour of normal node and completes the round of steady state phase.

3.1 GENETIC ALGORITHM

Genetic algorithm is a part of evolutionary computing, which is a rapidly growing area of artificial intelligence. In a genetic algorithm, a population of strings (called chromosomes or the genotype of the genome), which encode candidate solutions (called individuals, creatures, or phenotypes) to an optimization problem, is evolved toward better solutions. During each successive generation, a proportion of the existing population is selected to breed a new generation. Individual solutions are selected through a fitness-based process, where fitter solutions (as measured by a fitness function) are typically more likely to be selected. Certain selection methods rate the fitness of each solution and preferentially select the best solutions. The fitness function or the selection of IU problem within CRN is defined over the genetic representation and measures the quality of the
represented solution. The fitness function is always problem dependent. The next step is to generate a second generation population of solutions from those selected through a combination of genetic operators: crossover (also called recombination), and mutation. For each new solution to be produced, a pair of "parent" solutions is selected for breeding from the pool selected previously. By producing a "child" solution using the above methods of crossover and mutation, a new solution is created which typically shares many of the characteristics of its "parents". New parents are selected for each new child, and the process continues until a new population of solutions of appropriate size is generated. Although reproduction methods that are based on the use of two parents are more "biology inspired", some research suggests that more than two "parents" generate higher quality chromosomes. These processes ultimately result in the next generation population of chromosomes that is different from the initial generation. Generally the average fitness will have increased by this procedure for the population, since only the best organisms from the first generation are selected for breeding, along with a small proportion of less fit solutions. These less fit solutions ensure genetic diversity within the genetic pool of the parents and therefore ensure the genetic diversity of the subsequent generation of children. It is worth tuning parameters such as the mutation probability, crossover probability and population size to find reasonable settings for the problem class being worked on. A very small mutation rate may lead to genetic drift (which is non-ergodic in nature). A recombination rate that is too high may lead to premature convergence of the genetic algorithm. A mutation rate that is too high may lead to loss of good solutions, unless elitist selection is employed.

4. SIMULATION RESULTS

In this section, the performances of two different schemes, the proposed one and the one given in traditional clustering approach, are investigated. The case of one PU and 100 SUs are considered. The simulation is carried out for 10,000 independent rounds and network throughput in bits, lifetime of secondary users and end to end delay are compared.

Figure 3 shows that the proposed scheme results in better network throughput as compared to the scheme traditional clustering approach for 100 cognitive radios. Optimal frame duration and energy efficient clustering approach used in proposed work decrease the transmission energy between PU-IU and SUs and FC. The node in the cluster have higher energy can transmit data to cluster head for a longer period which increase the network life time and throughput.

Throughput of receiving bits: It is the ratio of the total number of successful packets in bits received at destination in a specified amount of time.

\[ \text{TH} = \sum \text{Transmission of Routing Packets} \]
Figure 4 shows that all sensing nodes are dead in 1900 rounds for traditional protocol based sensing scheme and in proposed scheme it is increased and all nodes are dead after 2700 rounds. Figure 5 shows that end to end delay of proposed protocol and traditional protocol based scheme. Proposed scheme reduce the end to end delay of secondary users as compared to traditional based scheme.

<table>
<thead>
<tr>
<th>Nodes</th>
<th>Method</th>
<th>Network Throughput (in bits)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>Traditional</td>
<td>210000 bits</td>
</tr>
<tr>
<td></td>
<td>Proposed</td>
<td>379000 bits</td>
</tr>
</tbody>
</table>

TABLE 1: COMPARISONS OF NETWORK THROUGHPUT (BITS) IN DEFINITE ENVIRONMENTAL CONDITIONS

Figure 4: Comparison of the lifetime of secondary users attained by two different schemes

Figure 5: Comparison in end to end delay attained by two different schemes
5. CONCLUSION

In this paper, we have proposed a cooperative spectrum sharing strategy based on energy constrains including an IU selection scheme in CCRN. This is an energy efficient and a cost effective co-operation spectrum sensing technique which performs well in fading and shadowing environment. By using an energy efficient cluster-based cooperative spectrum sensing scheme using centralised energy and genetic algorithm for the appropriate selection of IUs so that IUs communicate efficiently with the PU, also an energy efficient cluster based TDMA protocol is proposed for the communication between IUs and SUs, which reduce the end to end delay between IUs-PU, maximizes the total throughput and extent the life time of secondary users. Moreover, a reporting strategy that reduces the average number of reporting decisions, by allowing only the CR with detection information to send its binary decision (1) to CH. This proposed scheme consumes the transmission energy. Simulation results show that the throughput and lifetime of secondary users obtained by performing the proposed partner IU selection scheme is always higher than that attained by traditional protocol based sensing.

REFERENCES