An Efficient Spectrum Allocation Mechanism for Cognitive Radio Networks

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Abstract: - Cognitive Radio (CR) is viewed as a novel approach for improving the utilization of a precious natural resource: the radio electromagnetic spectrum. CRs can efficiently share the available spectrum both in licensed and unlicensed bands with the neighboring devices. The efficient use of available spectrum is becoming more and more critical with increasing demand and usage of the radio spectrum. To this extend, in this paper we propose an approach to solve the spectrum allocation/sharing problem using cooperation spectrum management method based on coalition that enables CR devices to share the unutilized spectrum efficiently. The key aspect of our design is the deployment of Multi-Agent System (MAS) where agents are deployed on each device and are grouped into coalitions. The powerful node in each coalition is selected to be a leader which handles allocation requests received from CRs of the same coalition. All these coalitions cooperate in order to have a better use of the spectrum. Our simulation results show that the proposed solution provide an intelligent management and achieves good performance in terms of spectrum access/sharing, within the span of few message.

Key-Words: - Cognitive Radio; Multi-Agent Systems; Cooperation; Spectrum allocation/sharing; Coalition; Artificial intelligence.

1 Introduction

An increasingly important engineering challenge in today's wireless communications domain is the proper management of the electromagnetic radio spectrum, a valuable yet limited natural resource. The current static assignment of the radio spectrum in combination with the often criticized governments' overregulation, leads to underutilization situations [1] [2]. Thus, there is need for the development of a robust spectrum management scheme, capable of exploiting available frequency bands as efficiently as possible.

Cognitive Radio [3] [4] is seen as the solution to the current low usage of the radio spectrum. The CR was presented officially by Joseph Mitola in 1999, and since, this concept has been very popular with researchers in several fields such as telecommunications, artificial intelligence, and even philosophy. Joseph Mitola has defined the CR as "A radio that employs model-based reasoning to achieve a specified level of competence in radio-related domains". CR has the potential to utilize the large amount of unused spectrum (so-called white space) in an intelligent way. Then, it needs to adopt the best strategy for selecting channels for sensing and access. The existing solutions for spectrum sharing in cognitive radio networks can be mainly classified in three aspects: i.e., according to their architecture assumption, spectrum allocation

behavior, and spectrum access technique as shown in Figure 1. However, one of the key issues in CR networks is to avoid device level collisions and interferences while maintaining efficient spectrum usage. We argue that a non-cooperative node can cause harmful interference to its neighbors and hence can reduce the overall spectrum usage.
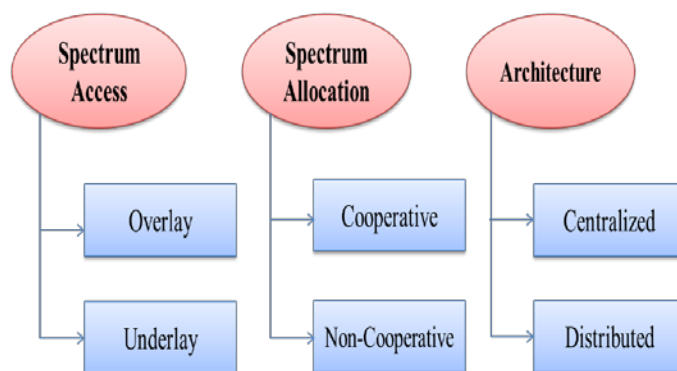

Fig.1 Classification of spectrum sharing in xG networks based on architecture, spectrum allocation behavior, and spectrum access technique [5]

Research is therefore in progress on understanding the cooperative sharing techniques in cognitive radio networks. Similar to CR network, a multi-agent system [6] [7] is a system composed of multiple autonomous agents, working individually or in groups (through interaction) to solve particular

tasks. Like CR nodes, agents work dynamically to fulfill their user needs and no single agent has a global view of the network. Each agent maintains its local view and shares its knowledge (when needed) with other agents to solve the assigned tasks (Table 1). These adherent features make them really suitable for dynamic spectrum allocations in CR networks.

Table 1. Comparison between an agent and a CR.

Agent	Cognitive Radio
Environment awareness via past observations	Sensing empty spectrum portions and primary user signals
Acting through actuators	Deciding the bands/channels to be selected
Interaction via cooperation	Interaction via beaconing
Autonomy	Autonomy
Working together to achieve shared goals	Working together for efficient spectrum sharing
Contains a knowledge base with local and neighboring agents information	Maintains certain models of neighboring primary user spectrum usage

Motivated by the above discussion and observation, in this paper, we study the problem of resource allocation; therefore we propose a cooperative multi-agent approach based on coalition that focused mainly on the spectrum allocation/sharing process, it is capable of exploiting available frequency bands as efficiently as possible. In this system, the agents are deployed on each user devices which are grouped into coalitions. The coalition members select the powerful node to be a leader which is in charge of handling their allocation requests. These coalitions cooperate in order to have a better use of the spectrum.

The rest of the paper is organized as follows. The related work is discussed in section 2. Our problem statement is shown in section 3. Section 4 describes our scheme in which spectrum allocation/sharing is a vital issue. The experimental setup and some results are given in section 5. Section 6 concludes our work with the future perspectives.

2 Related Works

In literature, several dynamic spectrum sharing approaches have been proposed using different techniques such as game theory, auctions and medium access control protocols. In fact, some researchers have also drawn their focus towards multi-agent based cooperative approaches for spectrum sharing [8] [9]; but in these works, several limitations exist. For example, in [10], Multi Agent System is used for information sharing and spectrum assignments. All the participating agents deployed over Access Points (APs), form an interacting Multi-Agent System, which is responsible for managing radio resources across collocated WLANs. The authors have not provided any of the algorithms and results for their approach.

Generally, game-theory has been exploited for spectrum allocations in CR networks [11] [12]. In game-theoretical approaches, each SU has one individual goal i.e., to maximize its spectrum usage and the Nash equilibrium is considered to be the optimal solution for the whole network (or game). Furthermore, it incorporates two basic assumptions: first, the rationality assumption, that is, the participating primary and secondary users are rational so that they always choose strategies that maximize their individual gain. And, second, the users' common knowledge assumption, which includes the definitions of their preference relationship. These assumptions may behave well by allowing each user (or player) to rationally decide on its best action, although in most of the competitive games, sometimes users can provide false information in order to maximize their profits and thus can affect the whole network performance.

The works proposed in [13] [14] consider market-based auctions for dynamic spectrum sharing. The SUs working as consumer agents submit their bids to PUs (or auctioneer agents) which show their willingness for spectrum sharing. The auctioneer agents then share the spectrum based on the received bids. The ultimate aim of using auctions is to provide an incentive for SUs to maximize their spectrum usage (and hence the utility), while allowing network to achieve Nash Equilibrium. However, considering the competitive nature of market-based approaches, it is hard to develop agents with cooperative behaviors.

In MAC-based spectrum sharing [15] [16] [17] [18], when an SU is using a specific channel, both the transmitter and the receiver synchronize themselves by sending a busy tone signal through the associated control channel, such that the signal

interferences should be avoided. Nevertheless, sending frequent busy tones can interrupt the neighboring devices, because each time they have to stop their normal working flow in order to listen to the busy tone on the control channel.

A local bargaining approach is presented in [19], where the CR users self-organize into small bargaining groups.

The group formation process starts by the initiator CR node, sending a group formation request to its neighbors for a subset of spectrum portions. The interested neighbors acknowledge the request, and the bargaining group is formed ensuring minimum spectrum allocation to each group member. The experimental results prove that local bargaining performs similar to greedy approach [20] incurring less communication overhead.

A different cooperative approach named DSAP (Dynamic Spectrum Access Protocol) is presented in [21] [22]. This approach is based on the concept of centralized server which is responsible for leasing spectrum to the requesting users in a small geographical region. The server also maintains a global view of the network's channel conditions through a series of frequent information exchanges with its clients. However, centralized server can become a huge bottleneck in diverse network conditions.

The solutions based on Multi-Agent System learning are also presented in [23] [24] [25]. Basically, the SUs periodically share the relative traffic information on the sensed channels (they are likely to be used in near future), with the neighboring devices. Based on this information exchange, multi-agent learning (i.e., delay sensitive and Q-learning) algorithms are proposed which allow the CR users to dynamically and autonomously optimize their transmission power on a selected channel and to avoid the inter-device interferences. Conversely, sometimes these learning algorithms can create a situation, where the agents have weak assumptions about other agents' spectrum usage making the task of getting accurate information more difficult.

Our solutions are different from the above in a sense; they provide the way in which the spectrum sharing is performed efficiently in cooperative manner; firstly, they avoid competitive access and collision problem between the SUs. Secondly, they allow PUs to satisfy the SUs' spectrum demands by working cooperatively.

3 Problem Statement

3.1 Context and assumptions

The runtime model is described as follows: we address the spectrum allocation challenges in cognitive network where WLAN [26] has been adopted as a common technology deployed in the area with sets of primary users PU = {PU_1, PU_2,… , PU_n} that have a high priority in a given frequency band (e.g. TV station, cell phone provider, emergency services, etc) and secondary users SU = {SU_1, SU_2,… , SU_m} that are capable of accessing both licensed and unlicensed channels[1] (figure 2).
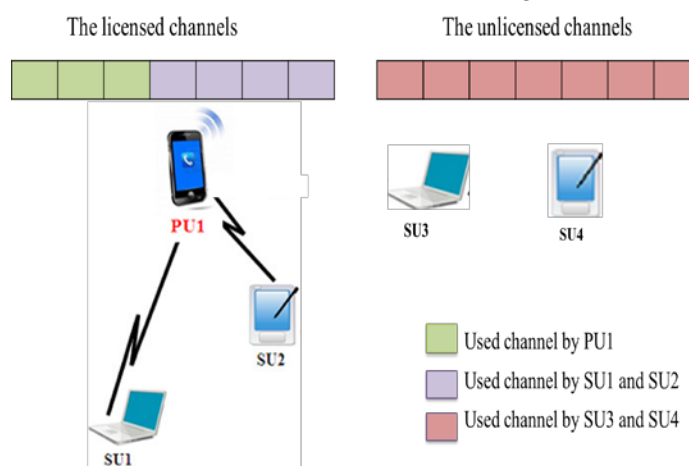

Fig.2 Spectrum allocation/sharing.

The following assumptions are placed throughout this paper:

- The secondary users are sufficiently close to each other such that they form some coalitions and they share the available spectrum of primary users.

- Similarly to CRs, PUs which are permanent in their own spectrum form some coalitions to organize sharing process.

- To allow nodes to communicate, the agents are deployed at each of secondary and primary devices.

- In each coalition, there is a SU-Leader agent which is in charge of handling allocation requests of several SUs. Similarly, PUs select

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[1] When there are more channels, there is less competition; thus making the problem easier. When there are few channels, collision must happen if no negotiation mechanism is applied.

PU-leader in each coalition to handle sharing proposals.

- We assume that the detection process is restricted to SU-Leader agent, and it is performed on a periodic and adaptive manner, this period changes depending on the number of demands. In our approach, we detect only the unlicensed channels because the unused licensed channels are sending to SUs as proposals of sharing by PUs.

- Detection process and PU proposals sending are proactive and not reactive to the SU-allocation demand. The proactive behavior can reduce the response time of SU requests (to avoid wasting time).

- We assume that the activity of primary users over each channel is a Markov chain[2] with states (busy: the channel is occupied by primary users and cannot be used by secondary users) and (idle: there is no primary user over this channel) and PUs are ready to share their free channels.

- Each SU-leader agent has an allocation table. This table contains the information about allocated and available spectrum. So there is no negotiation between SU and PU about price or time of sharing because all this conditions are known in advance.

- SU-Leader agents exchange their allocation table information.

- We promote the use of licensed bands in accordance with the cooperative aspect between primary and secondary agents, when an SU does not have the required price to pay PU, it will use the unlicensed band to accomplish its task.

3.2 Problem Formulation

We can address the problem statement of the above model as follows.

A. Spectrum allocation access: The main goal is to satisfy SUs demands and focus on maximizing their

spectrum utilization (S_{su}) taking into account the overall system utility.

B. Response time: the time is one important factor in spectrum allocation/sharing process. Then, we formulate Response time of SU as follow:

$$TR_{SUi} = TD_{SUi} + TH_{SUi} \qquad \forall i \in M \qquad (1)$$

M is the number of SU in the network. Delay time of SU (TD_{su}), which is the time it takes for accessing the available spectrum. It includes time of submission request, queuing time and processing time. Holding time of SU (TH_{su}) is the time required to utilize the available spectrum. Then, we aim to minimize TD_{su} and maximize TH_{su}.

C. Communication Cost: In cooperative systems, communication should be targeted towards improving overall system utility. The number of messages exchanged by SUs in the network for successful spectrum usage determines their communication cost (C_{su}).

Then, for each secondary user we formulate our problem as follow.

$$\text{Maximase} \sum_{i=1}^{m} S_{SUi} TH_{SUi} \qquad \forall i \in M \qquad (2)$$

Subject to

$$\text{Minimase} \sum_{i=1}^{m} TD_{SUi} \qquad \forall i \in M \qquad (3)$$

$$\text{Minimase} \sum_{i=1}^{m} C_{SUi} \qquad \forall i \in M \qquad (4)$$

4 Cooperative spectrum management based on coalition

In this section, we propose the deployment of cooperative spectrum management method based on coalition where its system structure is illustrated in Figure 3.

We start our proposition by assuming a CR network framework, with a number of primary and secondary user devices in the same geographical area, where an agent is deployed over each of them for the purpose of cooperation and decision making, these agents are grouped into coalitions according to their geographical locations. So, the main functionality's of a CR network (Message exchange, channel allocation, spectrum access and unused spectrum detection) can be addressed more efficiently. The coalition can overcome the problem of allocation spectrum as competitive access and collision.

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[2] A more reasonable model for the activity of primary users is semi-Markov chain. The corresponding analysis is more tedious but similar to that in this paper. Therefore, for simplicity of analysis, we consider only Markov chain in this paper.
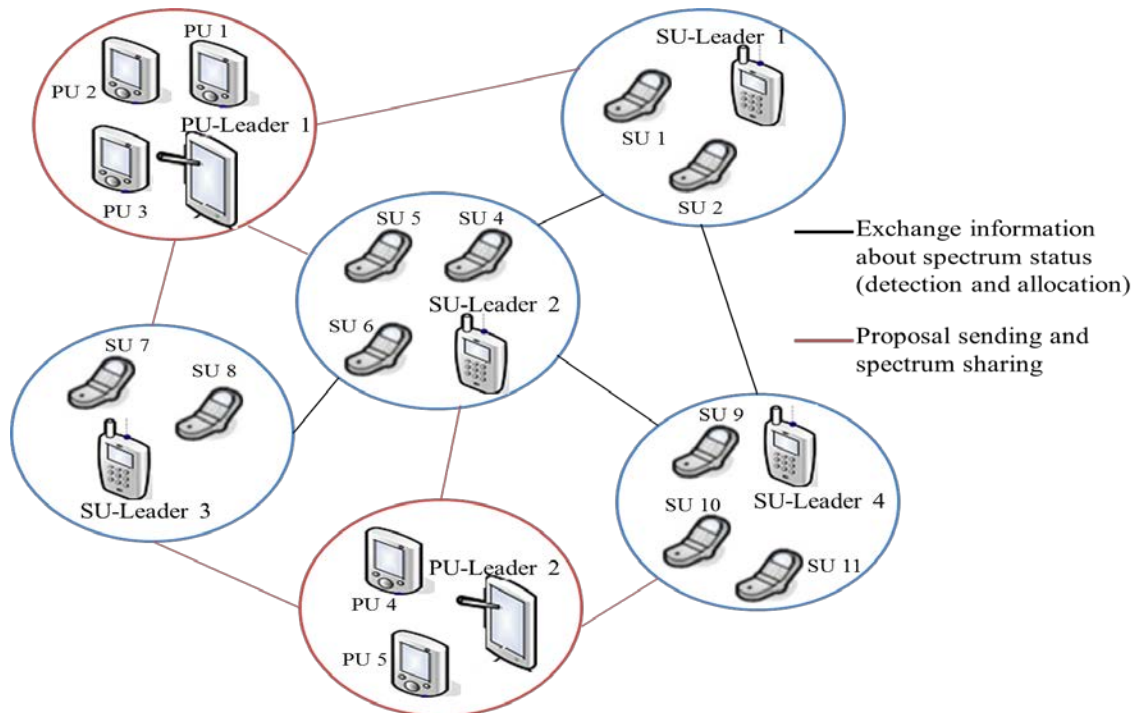
Fig.3 Cooperative spectrum allocation based on coalition.

One CR agent is selected (based on one or more criteria such the powerful node in term of energy and has a long lifetime) to be a leader in each coalition to handle allocation requests received from other CRs and to make decisions based on their own cognition.

4.1 Cooperative Framework

As is mentioned above for the purpose of cooperation between the devices, agents are deployed at each of them (both SU and PU).

These agents cooperate with each other to make a decision to the spectrum access and to maximize a common objective function, taking into account the constraints. In the following, we will explain the role of each agent in the network.

The CR coalition consists of the following different interlinked agents as shown in figure 4.
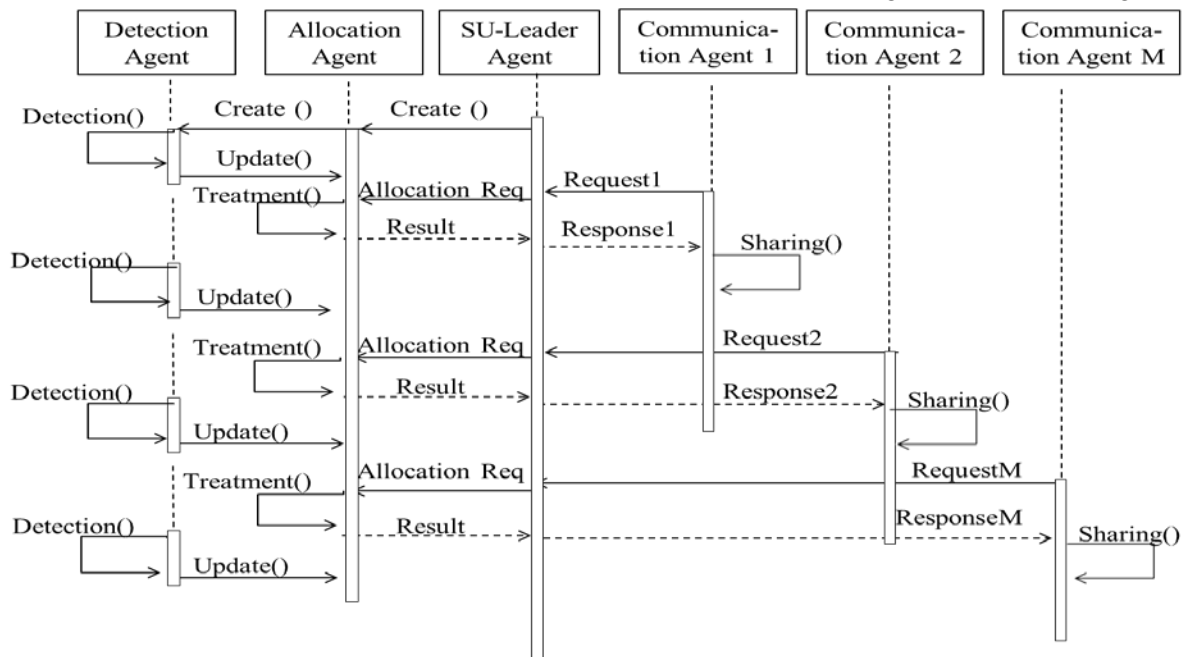

Fig.4 CR agents working.

SU-Leader agent: it is responsible for the launch of two other agents in its coalition; an agent for detection and another for allocation as shown in Figure 5. SU-leader agent has an allocation table that contains the information about status of spectrum; this table is updated by the internal agents: the detection agent (the idle unlicensed spectrum) and the allocation agent (the spectrum used by the SUs), it is updated also by the external agents: PU-leader agent (PU's proposals of licensed spectrum sharing) and the other SU-leader agents (the information of the other coalition).
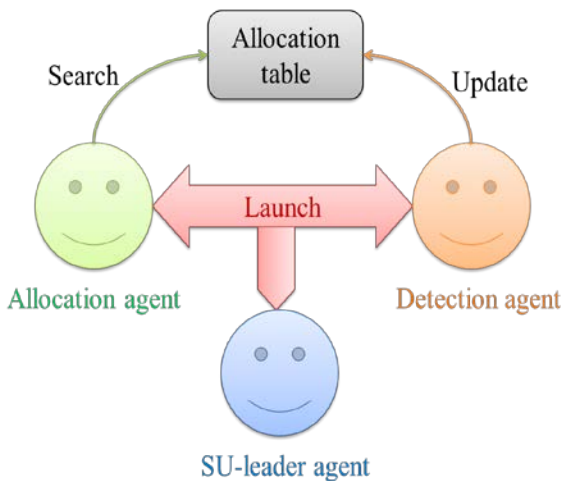

Fig.5. SU-Leader agent's behavior.

Fig.6 Description of leader agent scenario.

SU-leader agent receives the allocation requests from all SUs of the same coalition and it is able to reply to any of these (Figure 6), when it comes to sharing the licensed bands, it is responsible for sending the sharing request of the unused spectrum

to PU-leader agents. Periodically, SU-leader agents exchange their local information on the spectrum status and this period of update changes according to the environment. If this information is important, SUs of the updated coalitions are capable to move (because the CR nodes are mobiles) to accomplish their applications.

Detection agent: once the detection agent is launched, it starts the detection of unlicensed spectrum holes and it will update the allocation table of its coalition in periodic and adaptive manner (Figure 7), this period changes depending on the number of demands, if the number of demands is large in coalition then the period is short, else the period becomes longer.
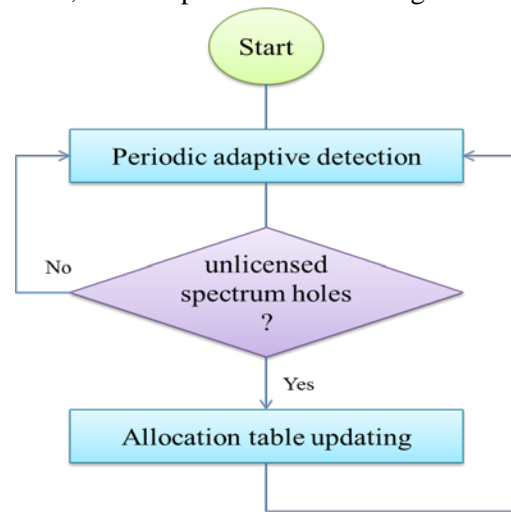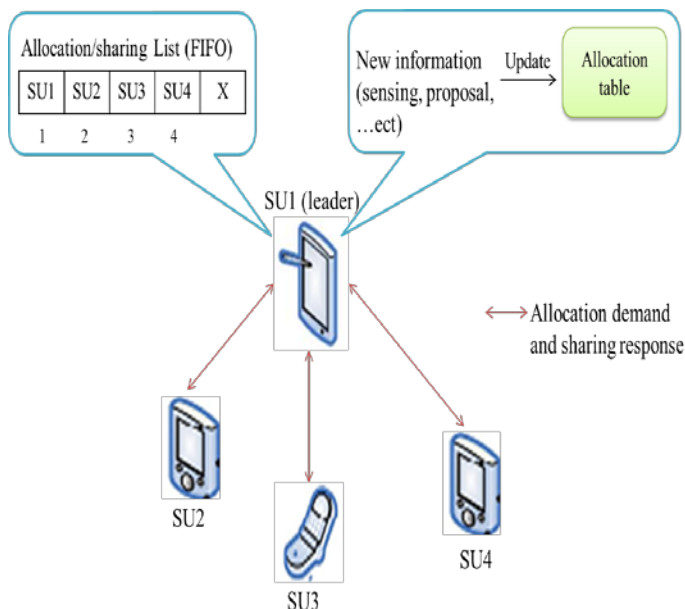

Fig.7 Sensing agent's behavior.

Allocation agent: it is responsible for the decision making; it will insert each new request (CR allocation demand) in a list named "allocation list", it will treat all requests of the same coalition in order of arrival FIFO (First Input First Out).

Furthermore, allocation agent may access to the allocation table to find the appropriate channel to the request in question, then it will delete the request from the allocation list and will update the allocation table, if no appropriate channel is found, the request will be processed later (as shown in Algorithm 1).

As mentioned above in section 3 there is no negotiation between SUs and PUs because the price is fixed in proposal, if SU in request is willing to pay PU then the sharing request is established by SU-leader agent to confirm if the PU proposal is still valid or not. Otherwise, SU uses the unlicensed channels to accomplish its task.

```
Each new allocation request Req_i will be insert in the allocation List L ;
Each new sensing information will be updated in the allocation Table
Tab ;
forall Req_i of L do
    Get information from Req_i;        /* information about spectrum
    needed, time and price desired */;
    Search_Tab (LicensedBand);  /* check the allocation table to
    find appropriate channels for Req_i */;
    if ∃ LicensedBand then
        Send_SharingReq_i (LeaderPU);    /* LeaderPU checks if the
        channels are still available or not */;
        Wait(confirmation);
        if confirmation then
            Sharing_LicensedBand;
            Delete_L (Req_i); /* delete the request Req_i from the
            allocation list                                    */
        endif
    endif
    if not LicensedBand Or not confirmation then          /* request
    processing failed in LicensedBand */
        Search_Tab (UnlicensedBand);
        if ∃ UnLicensedBand then
            Using_UnlicensedBand;
            Delete_L (Req_i);
        endif
    endif
end
```

Algorithm 1: Allocation process

SU-Communication agent: at the arrival of SU in the coalition its communication agent sends a message for allocation spectrum. Obviously, it will inform SU-leader agent by its characteristics. We assume that a request is in the form such that.

$$RequestSU\ (SUID, s, t, p)\quad (6)$$

Where *SUID* is the secondary user ID (or the secondary user's communication agent identification) and it is used to help SU-leader agent to reply back to the corresponding SU, *s* is the amount of spectrum needed (or number of channels needed) by the SU, *t* is the desired time limit (or holding time) for the spectrum utilization, and *p* is the price it is willing to pay to PU ($p >= 0$).

There are two types of agents which are deployed in primary user coalition: PU-Leader agent and PU-Communication agent.

PU-Leader agent: it collects the PU proposals for spectrum sharing in its sharing table that contains all PU which is present with their proposals (the amount of spectrum it is willing to share with SU, the respected time limit and the expected price to get after sharing its spectrum) and information about spectrum portions already shared with SUs. Accordingly, PU-leader agents broadcasts these proposals to all SU-leader agents and when it receives a sharing request from them it must check in the sharing table if the proposal is still valid or not.

PU-Communication agent: This agent is used for communication between the PU and its leader; to inform it by its connection or disconnection and proposal sending. PU's proposal is still valid as the PU is present in the spectrum until it decides to cancel its proposal. The proposal is in the form such that.

$$RequestPU\ (PUID, s, t, p)\quad (7)$$

Where PUID is the primary user's communication agent identification, *s* is the amount of spectrum that PU is willing to give to SU, *t* is the proposed spectrum holding time and *p* is the expected price to get after sharing its spectrum.

4.2 An illustrative example

To better understand the proposed allocation method, we present an example of two coalitions of CRs and one coalition of PUs that coexist in a

given area. PU offers to share their unused licensed channels with SUs specifying the price per channel and the proposed spectrum holding time (is sufficient for all SUs) as shown in table 2. We also assume that there are 10 unlicensed channels in the same band of PUs. With the arrival of SUs in the coalition, each SU sends an allocation request to its SU-leader agent (as shown in Table 3) which will handle all this requests to find appropriate channels as needed.

Table 2. Primary user's proposals.

PUID	Number of willing channels	Expected price
PU1	6	2
PU2	7	3
PU3	8	2

We assume that SU1 and SU5 are leaders of C1 and C2, respectively. These coalitions work simultaneously in a cooperative manner to avoid the problem of collision between SUs.

Table 3. Secondary user's requests.

Coalition ID	SUID	Number of needed channels	Willing price
C1	SU1	6	3
	SU2	3	4
	SU3	5	2
	SU4	4	1
C2	SU5	5	2
	SU6	4	3
	SU7	3	2

In the beginning, the detection agents associated to each SU-leader agent detect the available channels and exchange this information about spectrum which will be stored in the allocation table. The allocation agents use these allocation tables to handle spectrum assignments. Starting with SU-leaders where SU1 and SU5 need 6 and 5 channels respectively, the allocation agent of each of them find appropriate channels of PU1 and PU3 for SU1 and SU5 respectively where the licensed channels are more suitable for the application since the SU is ready to pay their price. As mentioned above, PU can share its spectrum with several SUs as long as there has unused spectrum. Then, SU2 and SU6 have sharing agreement with PU2. In C1, the allocation agent affects SU3 and SU4 to the unlicensed bands because the required number of channels by SU3 > remaining number of licensed channels and the price that SU4 is willing to pay < the price of licensed channel. But in C2, the remaining numbers of licensed channels of PU3 are sufficient to satisfy SU7 application (Table 4).

Table 4. Spectrum assignment.

Spectrum holes	Occupied by
Licensed channel of PU1	SU1
Licensed channel of PU2	SU2, SU6
Licensed channel of PU3	SU5, SU7
Unlicensed channel	SU3, SU4

5 Experiments and results

5.1 Simulation setup
In this section, we present various numerical results to evaluate the working of the proposed cooperative approach, based on the following simulation setup. We perform our simulations under the assumption of cognitive radio network. Multiple sets of primary and secondary users are placed according to Poisson distribution [27]. Considering the capacity

of a single machine, the maximum number of primary and secondary users is 80 in total. Moreover, the rates λp and λs denote the Poisson distributions of primary and secondary users respectively. Then in our approach, each SU's coalition contains λs SU nodes and each PU's coalition contains λp PU nodes. We assume that each device contains an agent deployed over it for cooperation purposes to make spectrum sharing deals.

In our simulation we consider for each next round of λp there is an addition of one spectrum bands and we set the bandwidth of each spectrum portion to 3.75MHz [28]. The basic and extended bands can support 40 channels and 3 PUs activity regions, each PU has 10 channels and the remaining channels are the unlicensed channels. According to [29], we set the mean spectrum usage of PUs to 40% and we assume that each PU has random unused spectrum portions. Also, we follow the assumption that once agreed, PUs would not be able to withdraw their commitments and they should share their spectrum with the corresponding SUs for the agreed time period. The network parameters chosen for evaluating the algorithm and the methodology of the simulation are shown in Table 5. All the simulations are conducted in Java Application Development Environment (JADE) [30], overall PC with 2.4 GHZ dual processor and 3 GB memory.

Table 5. Simulation parameters

Parameter	Value
Maximum number of SUs (N_S max)	50
Maximum number of PUs (N_p max)	30
Maximum Spectrum bands	10
Number of unlicensed channel per Band	10
Size of a Spectrum portion (B)	3.75 MHz
PUs' mean spectrum usage	40%
Type of interface per node	802.11 g
Total simulation runs	10

Additionally, during a simulation run we compare our solution to cooperative local bargaining [19], greedy algorithm [20] and cooperative multi-agents approach [8]. In greedy algorithm, most of the PUs are self-interested, and they are hesitant to share the available spectrum, until they get the highest offer maximizing their individual utility. Local bargaining is cooperative, where the users exchange messages and they self-

organize into bargaining groups for spectrum sharing. In cooperative multi-agents approach, the primary and secondary user devices that cooperate in order to make spectrum sharing but both SUs and PUs are self-interested where SUs negotiate with PUs and choose PU who has required spectrum with minimum price value and PU select the SU who has maximum price value with minimum spectrum portion required . Thus, we compare our approach to three different solutions showing cooperative multi agent, bargaining and greedy behaviors, respectively. All the solutions are implemented under our network framework, and the users are deployed according to Poisson processes with λp = 3 and λs = 5.

5.2 Obtained results

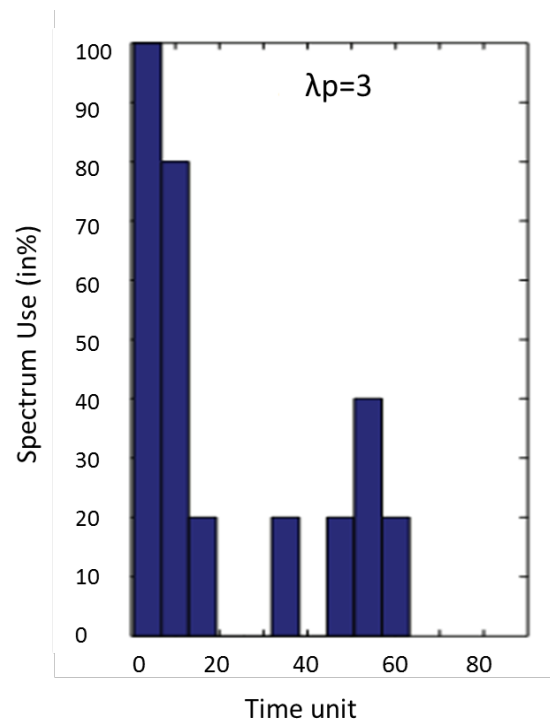Fig.8 Primary user's spectrum utilization.

Firstly, we show the histograms of PUs' spectrum usage at λp= 3 in Figure 8. The histogram depicts the spectrum usage percentage of PUs at different instances of time. At early stages, this percentage is high, but, later, the spectrum is mostly unutilized, and, thus, the SUs can have a successful spectrum sharing agreements during these periods.
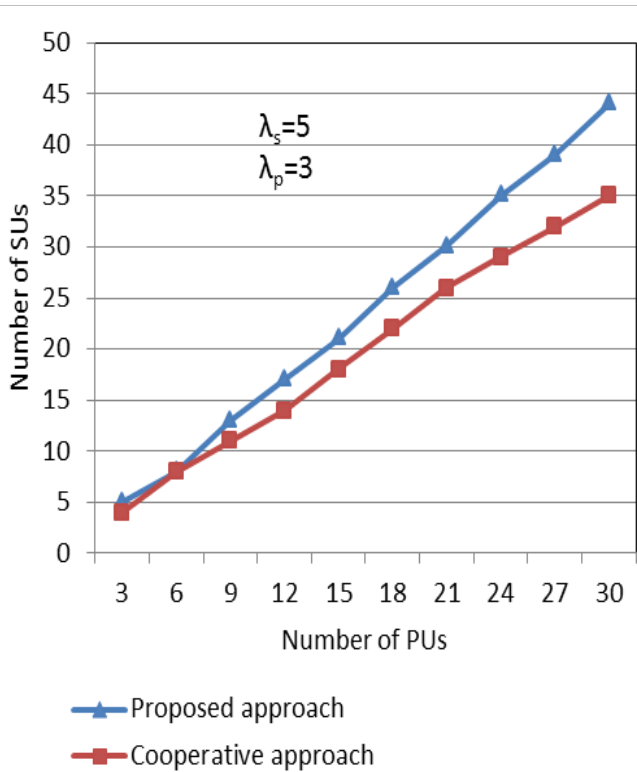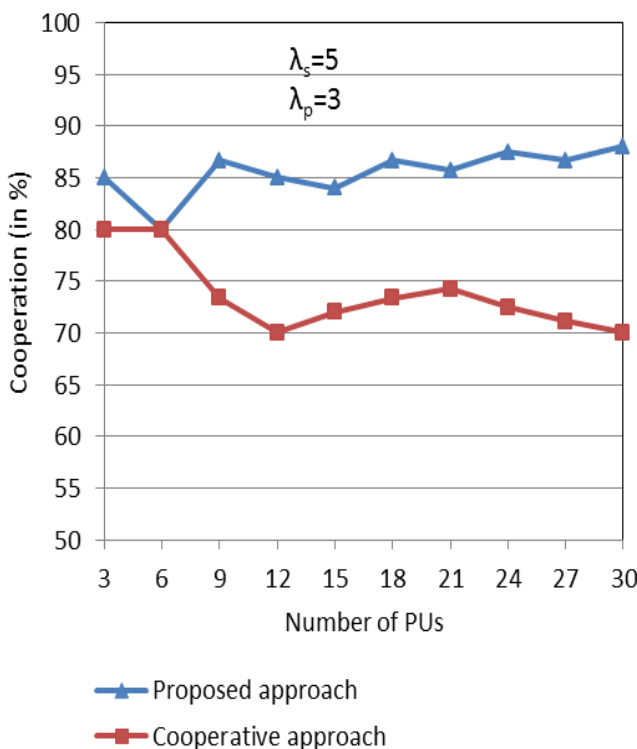
Fig.9 Number of SUs served by different value of PUs.

Fig.10 Percentage of cooperation between SU and PU agents.

Agent's cooperation. Figure 9 compare our proposed solution with cooperative multi-agent approach in term of cooperation between PU and

SU agents where $\lambda s = 5$ and $\lambda p = 3$. Figure show the curves of the maximum number of SU supported by PUs. Supported SUs are those which have completely gained the required spectrum. We observe that for small value of PUs (3, 6, 9), the number of supported SU are marginally same for both the proposed approach and cooperative approach but with increasing the value of PUs, the difference between the two curves becomes more observable and the number of supported SUs by PUs in our approach is greater than number of cooperative approach because in our approach there is cooperation between SU's coalitions where all coalitions exchange information about available spectrum detected by their detection agents. Returning to our example in section 4 where PU2 support 2 SUs from C1 and C2, if we assume that C1 who has detect the available spectrum of PU2 then C1 has exchange with C2 this information and instead PU1 share its spectrum only with SU2 it will also share it with SU6 . However, there is an improvement in terms of cooperation between the agents in our approach which is illustrated in figure 10. This depiction illustrate the percentage of cooperation between PU and SU agents, we observe that the results of the proposed solution are between 80 to 88%, for 3 to 30 PUs agents, while cooperative approach have somewhat lesser values around 70 and 75% . The results are coherent with those of figure 9 which displays that in the proposed approach, the cooperation between the agents remains high even with the larger number of SUs (allocation demand).
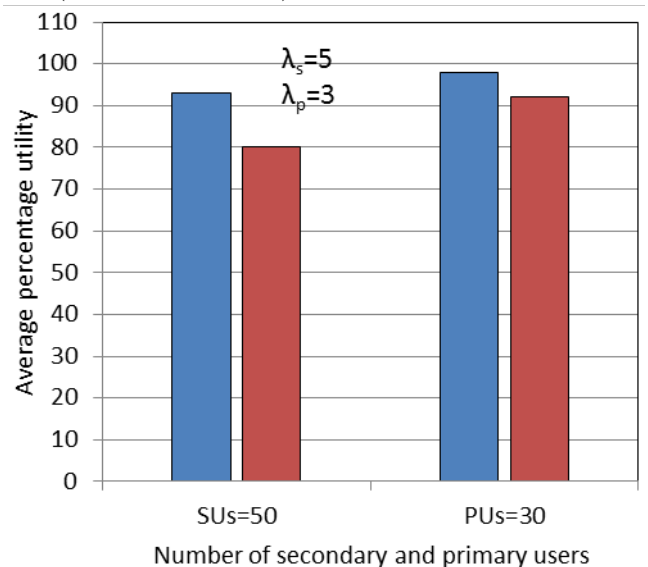

Fig.11 Percentage utility.

Percentage utility. We now compare the average percentage utility values of primary and secondary users achieved through proposed solution simulations to the result of cooperative multi-agent approach. We calculate a primary user's utility as the number of shared channels by SUs divided by the number of unused channels by PUs. Likewise, a secondary user's utility is represented as the number of used channels by SUs divided by the number of needed channels by SUs.

The optimal value can be achieved when the average percentage utilities of primary and secondary users are fully satisfied (i.e., 100%). Figure 11 summarizes the results; we observe that the average percentage utility of SUs is 93% in our approach and 80% in cooperative multi-agent approach; the average percentage utility of PUs is almost 90% and 98% for cooperative multi-agent approach and our approach respectively, since the PUs are always less in number compared to SUs and there is relatively a higher chance that they can easily share their unutilized spectrum with SUs. The results show that the values achieved through experiments of the proposed approach are close to the optimal value than the cooperative multi-agent approach showing good utility-based performance of our approach.
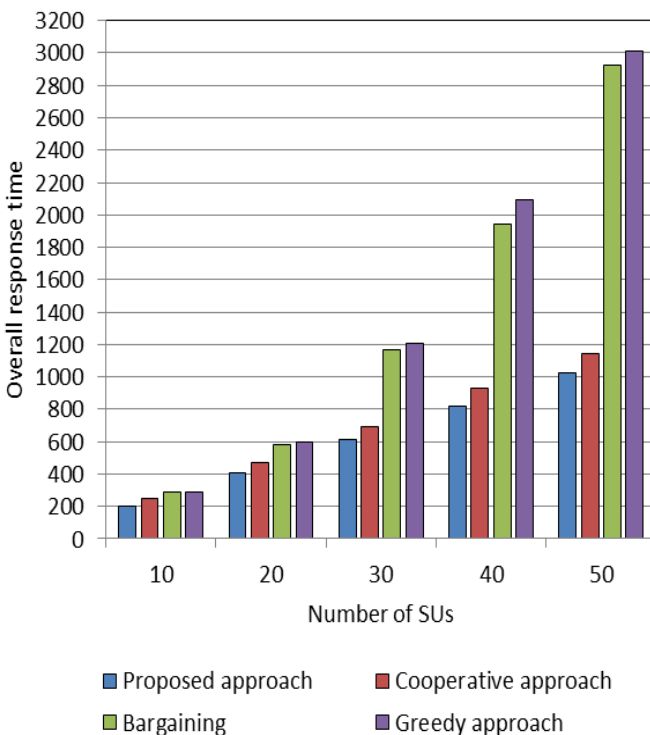

Fig.12 Response time of secondary users.

Response time. The time is one of the most important factors to be considered in CR network,

for that we run the simulation with several values of SU agents. Figure 12 plot the overall response times (explained in section 3) of SUs for a total of 10 to 50 SU agents. We compare our solution to cooperative multi-agents approach, greedy algorithm and cooperative local bargaining, we observe that for greedy algorithm and cooperative local bargaining have highest value of overall response time which increases quickly with increasing the number of SUs this means that the SUs have difficult to find available spectrum for sharing (high delay time) compared with our approach and cooperative approach which have small value of overall response time. We notice that our approach has the optimal value of response time which means that SUs can easily find the unused spectrum showing the performance of our approach in term of allocation process.

Successful spectrum allocation. Figure 13 depicts the number of successful spectrum allocation. Thus, we run the simulation of the proposed solution and the other approach with several sets of CRs as showing in the figure.
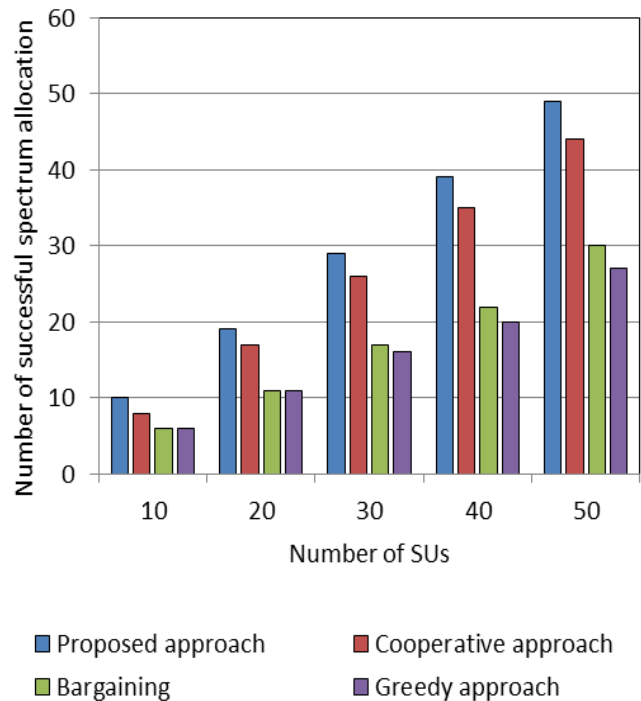

Fig.13 Successful spectrum allocation with number of SUs.

The successful spectrum allocation is the served SUs which have completely obtained the required spectrum. We observe that the greedy approach, local bargaining and cooperative multi-agent approach have fewer successful spectrum allocations than our approach where almost SUs are

fully satisfied because in our approach we promote the unlicensed spectrum utilization to avoid wasting time to find the appropriate PU's proposal if it is not available, in other hand each allocation demand not satisfied in the time it be stored in the cache until the required spectrum will be available which shows the performance of the proposed approach.

Communication cost. Figure 14 plot the histogram of communication cost (explained in section 3). The increasing pattern in communication cost is directly relational to the number of SUs. When SUs are less in number, the message exchange between the users is not high. Similarly, when number of SUs increases, there is whole information to share causing communication cost to increase.

We notice that communication cost for greedy approach is very high considering the non-cooperative nature of PUs. Consequently, most of the time SUs receive unsatisfactory proposals, and several messages are wasted. The local bargaining approach is limited to one-to-one bargaining, where an SU can bargain with only one PU at a time.
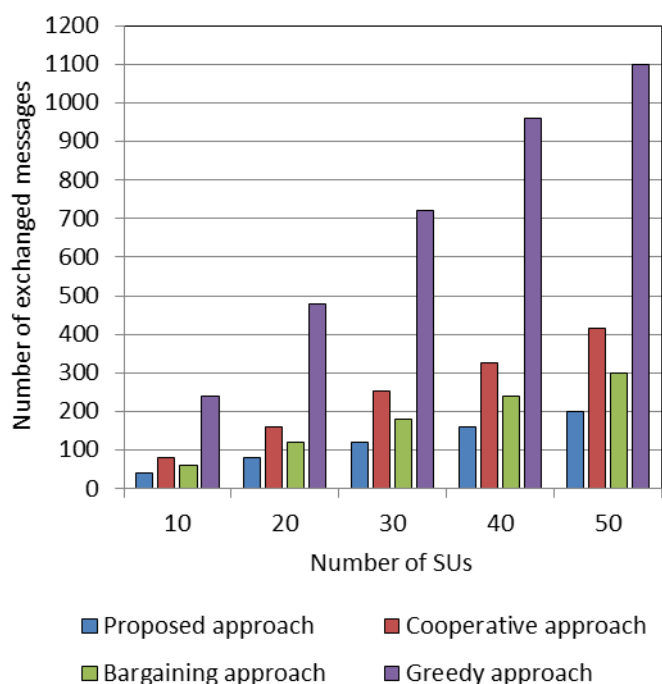

Fig.14 Communication cost.

Thus, local bargaining has a reduced communication cost. Considering Cooperative multi-agent approach, SUs exchange several kinds of messages with different PUs and some users may be dissatisfied making its communication cost higher. On the other hand, we notice that the communication cost for the proposed approach is

much lower than other approach where the results are very spaced. However, the number of exchanged messages is very small in our approach because the users are grouped into coalitions, which is known to be effective in reducing communication overhead in variable network environment showing the communication efficiency.

6 Conclusion

In this paper, a novel cooperative approach based on coalition to enable spectrum allocation in cognitive radio network is presented. The solution is based on multi-agent system cooperation and implemented by deploying agents on both SUs and PUs where these agents are grouped into coalitions. These coalitions cooperate in order to have a better use of the spectrum.

Experimental results show that compared to greedy, bargaining, and cooperative multi-agent solutions, our solution works very effectively and can absorb spectrum allocation demands by introducing leader agents (allocation agents and sensing agents) in each coalition in the network where the successful spectrum allocation and utility of both SUs and PUs are higher even with large number of agents and the cooperation with primary agent for spectrum sharing can reach 88%. Furthermore, our solution works very effectively without having higher communication cost and the scalability is guaranteed by organizing the users into coalition.

As an extension to this contribution, in the future we will focus on the energy consumption and lifetime of the cognitive network during the spectrum management process. Furthermore, we will interest to integrate a routing protocol in our framework to improve the overall performance efficiency of the cognitive network.

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