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A Survey on Spectrum Sharing Techniques in Cognitive Radio Networks

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***Abstract*:** According to Federal Communication Commission (FCC), more than 70% of the available spectrum is not utilized optimally. Cognitive radio is a better technique to fulfill the utilization of radio frequency spectrum. Both licensed and unlicensed users can use the frequency spectrum using cognitive radio technique. Licensed users are the primary users and unlicensed users are the secondary users. Secondary user requests the primary user for some amount of spectrum. Primary user allocates the spectrum to the secondary users by itself without degrading its own performance using spectrum sharing techniques. This paper deals with different types of spectrum sharing techniques.

Keywords: Cognitive radio, Primary user, Secondary user, Licensed user.

1.INTRODUCTION

With the popularity of various wireless technologies and fixed spectrum allocation strategy, spectrum is becoming a major bottleneck, due to the fact that the most of the available spectrum has been allocated. Moreover, the increasing demand for new wireless services, especially multimedia applications, together with the growing number of wireless users and demand of high quality of services have resulted in overcrowding of the allocated spectrum bands, leading to significantly reduced levels of user satisfaction. Particularly, spectrum congestion is a serious problem in communication-intensive situations such as after a ball-game or in a massive emergency. According to Federal Communication Commission (FCC) [1], some spectrum band remains unused at a given time and location, indicating that a more flexible allocation strategy could solve the spectrum scarcity problem. For example, cellular network bands are overloaded in most parts of the world but television broadcasting, amateur radio and paging have been found to be grossly underutilized.

This motivates a new paradigm of either through opportunistic spectrum sharing or through spectrum sharing for exploiting the spectrum resources in a dynamic way. Cognitive radio (CR) [2-5] allows the secondary users (SUs) (lower priority) to share the licensed spectrum originally allocated to the primary users (PUs) (higher priority). In opportunistic spectrum access, the SUs, also called cognitive radio users (CRUs) needs to sense the radio environment and identify the temporally vacant spectrum, i.e. the secondary and primary users do not operate on the same spectrum simultaneously. Quickly and accurately detection of the presence of PUs is an important and difficult task so that the SUs can search and move to other empty spectrums within a certain time [6]. On one hand, if the PUs do occupy their spectrum too long that the SUs have no chance to access, the spectrum usage of such CR systems would not be efficient. If the PUs and Sus can concurrently share, the regional spectrum efficiency would be increased dramatically. In spectrum sharing scenario, the SUs can coexist with the PUs all the time as long as (1) the interference generated by the SUs to PUs is below certain accepted threshold as well as (2) maximize its own\transmit throughput.

As the first step of exploring of CR technology, IEEE 802.22 Wireless Regional Access Network started in November 2004 provides more service capacity and coverage than the current standards of wireless networks.

Many prior researches on CR technology have focused on spectrum sharing. To trade off two conflict goals, multiple transmit antennas techniques have been exploited [8-9]. Since the number of transmit beams is limited by the number of antennas, the criteria to select CRUs are also crucial to increase the sum-rate of CR system. In [10-11], zero forcing beamforming is used to null the self-interference among CRUs selected by the orthogonal user selection algorithms. However, the resulting transmit weights do not handle the interferences generated by the cognitive radio base station (CRBS) to the PUs and it needs two steps in the proposed multiuser selection algorithm. Power allocation is used to solve the drawback of the zero forcing and the subspace-based secondary user selection scheme is presented. Orthogonal transmit is generated by Gram-Schmidt orthogonalization to enable transmitting data from the CRBS to CRUs without interfering to the PU.

Although no interference to the PU, CRUs still suffer from the self-interferences among CRUs scheduled by the opportunistic beam forming method. The number of secondary users is fixed and two iterative algorithms for joint optimal power control and two different scenarios: with and without cooperation between the primary and secondary networks are considered. The protection of the PU from excessive interference induced by the SUs as well as to satisfy SINR requirement of each SU are done by constrains of the optimization problem. Similarly, minimizing the transmit vectors of CRBS while keeping the SINR of CRUs above certain level and interference introduced by CRUs below specific thresholds simultaneously is regarded as a second order cone programming (SOCP) problem & threshold as well as a low interference to the PU.

2. Cognitive Radio

The idea of Cognitive Radio was officially presented byJoseph Mitola in a seminar at the Royal Institute of Technology in Stockholm in 1998, later published in an article by Mitola and Gerald Q. Maguire, Jr. in 1999 [12]. The term Cognitive Radio is used to describe a system with the ability to sense and recognize its context of use, in order to enable it to adjust its radio operating parameters dynamically and autonomously and learn the results of its actions and its environmental setting operation.

CR is a form of wireless communication in which a transmitter/receiver can detect intelligently communication channels which are in use and those who are not, and can move to unused channels. This optimizes the use of available spectrum radio frequency while minimizing interference with other users.

The principle of CR, included in the IEEE 802.22 and IEEE 802.16h [13], requires an alternative spectrum management that is: a user called secondary (SU) may at any time access to frequency bands that are free, that is i.e., not occupied by primary user (PU) of the licensed band. The SU will assign the service once completed, or once a PU has shown an inclination connection. Cognitive radio system requires four major functions that enable it to opportunistically use the spectrum [14]. These functions consist in the CR terminal’s main steps for spectrum management. They are: spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility.

2.1. Spectrum Sensing

This is the basic functionality; it consists on sensing unused spectrum and sharing it without interference with the other users. One of the goals of the spectrum sensing, especially for the interference sensing, is to obtain the spectrum status (free/busy), so that the spectrum can be accessed by a SU under stress of interference. The challenge is that of measuring the interference at the receiver caused by the primary transmissions of SUs.

2.2. Spectrum Decision

A decision model is required for spectrum access. The complexity of this model depends on the parameters considered in the analysis of the spectrum. The decision model becomes more complex when a SU has multiple objectives. For example, a SU may intend to maximize performance while minimizing disturbance caused to the primary user. Stochastic optimization methods will be an interesting tool to model and solve the problem of spectrum access in a CR. When multiple users (both primary and secondary) are in the system, preference will influence the decision of the spectrum access. These users can be cooperative or uncooperative in access to spectrum.

In a non-cooperative environment, each user has its own purpose, while in a cooperative one, all users can work together to achieve one goal. For example, many SUs may compete with each other to access the radio spectrum (eg,O1, O2, O3, O4 in Figure 1 below) so that their individual throughput is maximized. During the competition between SUs, all ensure that the interference caused to PUs is maintained below the temperature limit corresponding interference.

In a cooperative environment, CRs cooperate with each other to make a decision for accessing the spectrum and maximizing the objective function taking into account the common constraints. In such a scenario, a central controller can coordinate the spectrum management.

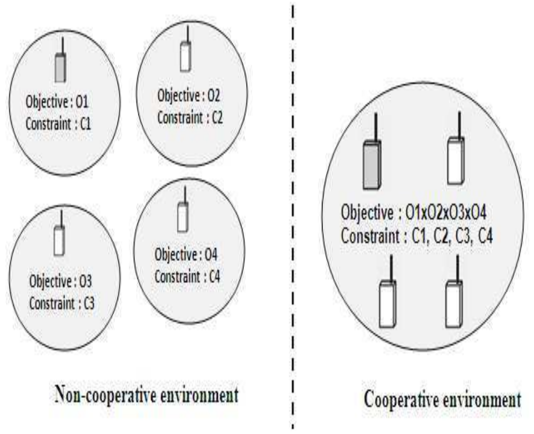

Figure 1. Cooperative and non-cooperative spectrum Access

In a distributed multi-user environment, access to non-cooperative spectrum, each user can achieve an optimal decision independently by observing the behaviour of other users (historical/action). Therefore, a distributed algorithm is required for the SU to make the decision to access to spectrum independently.

2.3. Spectrum Analysis or Sharing

The sensing spectrum results are analyzed to estimate the spectrum quality. One issue here is how to measure the spectrum quality which can be accessed by a SU. This quality can be characterized by the Signal/Noise Ratio (SNR), the average correlation and the availability of white spaces.

Information on the available spectrum quality for a CR user can be imprecise and noisy. Learning algorithms of Artificial Intelligence techniques can be used by CR users for spectrum analysis.

2.4. Spectrum Mobility or Handoff

Spectrum mobility is the process that allows the CR user to change its operating frequency. CR networks are trying to use the spectrum dynamically allowing radio terminals to operate in the best available frequency band, to maintain transparent communication requirement during the transition to a better frequency. Figure 2 illustrates the four main spectrum management functions of the cognitive radio cycle as well as the possible transitions between them[15].

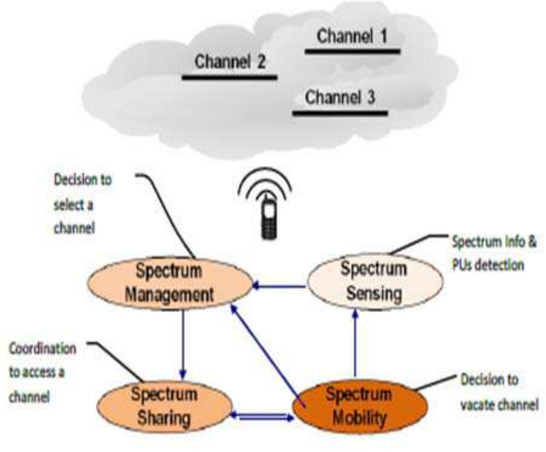

Figure 2. Spectrum management functionality' s

3. Features of Cognitive Radio

1. Cognitive capability: Using this feature the cognitive radio dynamically scans the whole spectrum and finds portion for its transmission. Spectrum sensing, spectrum management and spectrum sharing are the components of the cognitive capability [11,12].

2. Reconfigurability: It is the parameter adjustment capability without any modification in the hardware components. The parameters are Operating frequency,

4. Spectrum Sharing Aspects & Techniques

The main challenge after detecting the available spectrum is to access or share the spectrum among the secondary users of the cognitive radio. The solutions for spectrum sharing in cognitive radio networks can be mainly classified in three aspects[15]

a) Architecture Assumption
b) Spectrum Allocation Behavior
c) Spectrum Access Technique

The first spectrum sharing technique in the cognitive radio is based on the architecture, which is of two types; more specifically spectrum access can be centralized and distributed as explained below

1. *Centralized spectrum sharing:* In this solution, a centralized entity controls the spectrum allocation and access procedures. Each entity in the cognitive radio network forwards the measurements of the spectrum allocation to the centralized entity. Using these measurements, the centralized entity constructs the spectrum allocation map

2. *Distributed spectrum sharing:* the distributed spectrum sharing is used where the construction of an infrastructure is not necessary. In this case there is no presence of the centralized entity, each and every node is responsible for the spectrum allocation and access is based on local policies.

The second classification for spectrum sharing techniques in cognitive radio networks is based on the access behavior, which is of two types:

1. *Cooperative spectrum sharing:* cooperative spectrum sharing is also called as the collaborative spectrum sharing. it considers the effect of the node's communication on other nodes, in this case the interference measurements of each and every node shared among the other nodes. All the centralized spectrum sharing solutions are considered as the cooperative spectrum sharing[9,15].

2. *Non-cooperative spectrum sharing:* this is also called as the non collaborative spectrum sharing (selfish) solution; it considers only the node at hand. The nodes will not share the measurements tothe other nodes, so it is referred as the selfish solution. By using this method, spectrum utilizationcan be reduced.

Both cooperative and non-cooperative solutions are compared through their fairness, spectrum utilization and throughput, both the approaches are considered such the cooperative approaches also consider the effect of the channel allocation on the potential neighbors. The results show that cooperative spectrum sharing outperforms the non cooperative spectrum sharing.

Coming to the comparison of the centralized and distributed spectrum sharing, the distributed spectrum sharing closely follows the centralized spectrum sharing. But, this is not always valid in the cognitive radio networks.

To exploit the performance of the cognitive radio spectrum access solutions game theory was proposed, game theory is exploited to analyze the behavior of the cognitive radio for distributed adaptive channel allocation. The comparison between the cooperative and non cooperative spectrum sharing techniques has been presented using the game theory

The evaluations reveal that Nash equilibrium point for cooperative users is reached quickly and results in a certain degree of fairness as well as improved throughput, more over fairness and spectrum utilization are degraded by using the non cooperative spectrum sharing. The communication and information exchange required by selfish users is very low.

The third classification in the spectrum sharing of the cognitive radio is based on the access technique; these are two types as explained below

1. *Overlay spectrum sharing:* overlay spectrum sharing is one of the spectrum access techniques. In this method, the node accesses the network using a spectrum hole which is not used by the primary user (licensed user), so that the interference to the primary user is reduced.

2. *Underlay spectrum sharing*: in the underlay spectrum sharing the node accesses the networks by observing the spread spectrum techniques developed for the cellular networks. When the spectrum allocation map is ready, the cognitive radio begins transmission. Due to this, at certain position, it will interfere with the primary user and causes interference. This solution needs increased bandwidth compared to the overlay technique.

Two types namely inter network and intra network spectrum sharing, these are the combination of the above three classifications.

1. *Centralized-intra-network spectrum sharing:* In the centralized-intra-network spectrum sharing there exist a spectrum server and the spectrum server coordinates all the cognitive radio users. All users in this case exhibit the cooperative nature.

2. *Centralized-inter-network spectrum sharing:* The dynamics of the centralized-inter-network is similar to the intra network but in this case spectrum broker shares the spectrum among the cognitive radio users.

3. *Distributed-intra-network spectrum sharing:* In the distributed spectrum sharing technique no single entity makes the own sharing decision. Each cognitive radio user in the intra-networks plays their role in spectrum sharing process.

4. *Distributed-inter-network spectrum sharing:* In this case also each entity involves in the spectrum sharing decision. Each cognitive radio network plays their role in the spectrum sharing process.

CONCLUSION

The cognitive radio networks are developed to solve the current existing problems in the wireless communications. Efficient spectrum sharing is very important in the cognitive radio networks. To enhance the utilization of the frequency spectrum the cognitive radio should follow optimal spectrum sharing policies. Currently, dynamic spectrum sharing is being used in the CR networks. Spectrum sharing is the critical issue among all the functional blocks of the cognitive radio, so it is necessary to know about the spectrum sharing techniques for efficient use of the frequency spectrum.

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