Spectrum Access during Cognitive Radio Mobiles' Handoff

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Abstract **— Cognitive radio is an emergent technology in wireless networks that aims to improve spectrum's use by allowing opportunist access. Recent research activities related to cognitive radio consider static terminals, neglecting the impact of user's mobility. In this paper, we are interested in the concept of mobility in cognitive radio networks. Thus, we propose an algorithm of spectrum handoff for mobile cognitive radio users. Our algorithm presents a decentralized approach using multi-agent systems. Each terminal is managed by an agent that enables it to negotiate and cooperate with neighboring users. During the handoff, agents recover sensing information then choose appropriate band to switch if spectrum handoff is necessary. Finally, agents use negotiation and cooperation methods to insure a more efficient spectrum sharing.**

Keywords- Cognitive radio, Dynamic spectrum access, Mobility, Spectrum sharing, Spectrum handoff.

I. INTRODUCTION

Recent evolution of wireless technologies is creating greater demand in terms of spectrum resources. To overcome this problem, researchers have used a new paradigm known as cognitive radio (CR) [1] that senses the nearby spectrum and tries to utilize it opportunistically. Indeed, there are unused spectrum portions (spectrum holes), which can be utilized in order to increase the number of users and to better distribute the available resources [2].

In CR networks [3], there are two types of users: licensed or primary users (PUs), and unlicensed or secondary users (SUs). PUs can access the wireless network resources according to their license. SUs are equipped with CR capabilities to opportunistically access the spectrum.

Researches on CR networks are mainly focused on detection and allocation of available spectrum resources, leaving terminal mobility issues mostly unexplored. In fact, mobility makes spectrum management problem more complex notably because of handoff management.

Due to the above facts, our work focuses on mobility management and spectrum sharing for mobile CR terminals during the handover. This latter occurs when mobile terminal switches from one network point of attachment to another one [4]. In CR context, it can come with spectrum handoff, which is the change of the used spectrum frequency. The goal of managing handoff is mainly to keep alive ongoing sessions with the requested quality of service (QoS). In the rest of the paper "spectrum handoff" [5] and "spectrum mobility" [6] will be used interchangeably.

The remainder of this paper is organized as follows. Section II presents related works on spectrum and mobility management in CR networks. Next, Section III describes the considered scenario. Section IV details our proposed solution, depicts the suggested handoff algorithm for mobile CR terminals and gives an illustration of the resulting dynamic spectrum distribution. Finally, Section V concludes the paper.

II. RELATED WORKS

Since the last decade, a large amount of literature already exists on CR. Consequently, several dynamic spectrum access approaches have been proposed [6], [7], [8], mostly addressing the issues of spectrum sensing and spectrum allocation while there is no much research effort to address the problems of spectrum handoff.

The spectrum sensing [7], [9] is a fundamental step to detect the presence of PU in CR networks. There are different ways in, which CR users are able to perform spectrum sensing. Theses ways are classified into two categories: Non cooperative and cooperative spectrum sensing. *Non-cooperative spectrum sensing* occurs when a CR acts on its own and self-configures according to the signals it can detect. *Cooperative spectrum sensing* uses a central station to receive reports of signals from a variety of radio users. CR cooperation reduces problems of interference where a CR user cannot hear a primary user because of issues such as shading from the PU. Besides, channel miss detection phase a problem that may occur during sensing phase and it depends necessarily on the selected sensing algorithm. In our work, we do not address spectrum sensing issues as our research is focused on spectrum sharing and mobility.

Dynamic spectrum allocation and sharing [10] exploit temporal and spatial traffic statistics to share more efficiently the underutilized spectrum. Game-theory approach [11] is the mostly used for spectrum sharing. Bargaining, auctions and multi-agent systems are also increasingly used.

Broadly, research works on CR have been concentrated on the case of static networks without taking into account mobility and handover aspects. Although the mobility-based handoff mechanisms have been extensively investigated in wireless, cellular and heterogeneous networks [4], [12], [13], it is still an open research issue for CR networks.

Nevertheless, some works like [14], [15] have used CR concept to improve mobility management in traditional cellular networks. For example in [15], the proposed approach enables changes in the base station's parameters to meet the new services requirements in modern wireless cellular systems. These changes are performed using agents that manage cells via negotiation, learning, reasoning, and identification strategies. The principal aim of this solution is to reduce interference, HO delay and blocking probability. However, it is only suitable for traditional cellular networks with a centralized management system.

Our objective in this paper is to achieve an optimal dynamic spectrum sharing and an efficient spectrum mobility management by considering the handover in the CR networks. Therefore, next, we propose a typical scenario and a spectrum handoff algorithm for mobile CR users.

III. SCENARIO

Most scenarios previously discussed in the literature in CR context are restricted to the spectrum management between fixed nodes (absence of HO). In this work, we consider the scenario of a mobile node, as shown in Fig. 1.

Mobile cognitive radio terminal (MCT) moves from location A towards location B through a set of areas, where the space is supposed to be distributed in zones each having its own characteristics (frequencies, number of users, etc.).

The MCT uses initially a spectrum portion already assigned to it in the departure zone. This allocation was made after detection and decision phases according to the MCT resources requirements. Assigned spectrum portion can be shared with PU or SUs.

When moving from one zone to another one, the MCT can meet the following scenarios:

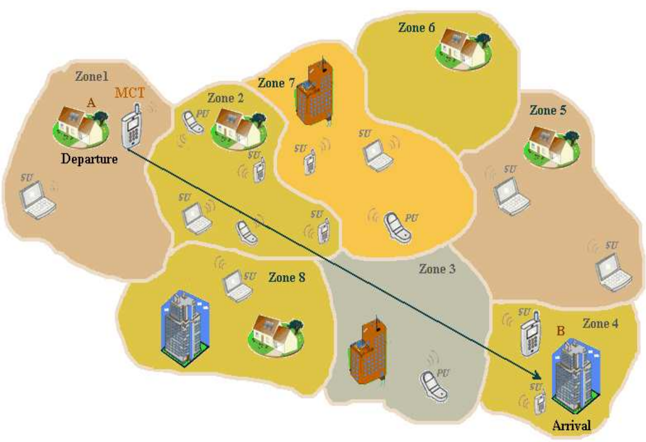

Figure 1. Scenario of mobile cognitive radio node

- The spectrum portion used by the MCT no longer guarantees the QoS required in the new zone.
- The spectrum portion is partially occupied and negotiation/ cooperation are possible. This happens in the following cases:
    - The band is occupied by a PU.
    - The band is occupied by one or several SUs.
    - PU and a set of SUs coexist in this band.
- Other spectrum portions ensuring a better QoS are available in the new zone.

IV. PROPOSED SOLUTION

In this section, we first present the basic behavior of the MCT. Then we propose an algorithm for dynamic spectrum sharing and handoff for the MCT when switching zones. Finally, we give an example of the spectrum distribution to illustrate our solution.

A. *The basic behavior of mobile cognitive radio terminal*

The state diagram in Fig. 2 details the MCT behavior within the same zone.

During the detection phase, the CR node senses its surrounding radio environment to find spectrum holes. This detection process continues till discovering available spectrum portion (at least one). Then, the CR node starts the decision phase to choose the appropriate band based on the requested QoS by the running applications on MCT. During this phase, the CR node observes and characterizes bands and chooses on FIFO bases the first one that satisfies its applications' needs. By using FIFO strategy when selecting spectrum portion, we aim to minimize the decision process duration. If none of free channels is suitable (for instance, insufficient bandwidth or QoS not guaranteed), the CR node starts again the spectrum sensing.

Once the appropriate channel is selected, the CR node may share it with other users. Two possible scenarios can

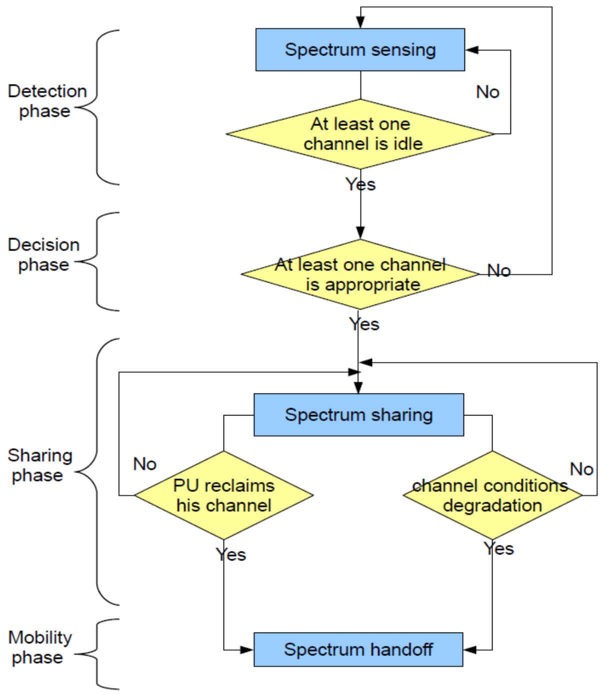

Figure 2. State diagram of cognitive radio node behavior

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lead to spectrum handoff: (1) a coexisting PU would reclaim its radio spectrum resources and thus, the MCT has to move immediately to another available portion since a PU has always the priority; (2) QoS degradation due to interference can also lead to spectrum mobility.

B. *Spectrum handoff algorithm for MCT*

The node mobility imposes new challenges, which include the topology change and breaking the continuity of services during HO. Hence, the MCT requires a specific behavior when switching to new zones (section 3 details eventual scenarios). It should know in prior new spectrum conditions and should react towards new circumstances. Different mechanisms to ensure continuity of service and efficient spectrum management are needed. For these reasons, we propose an algorithm of spectrum access that is executed by the MCT when Handoff occurs (algorithm 1).

In the rest of the paper, we use the following notations:

- *QoS(MCT) : Quality of service required by MCT.*
- *spectrum* $_{i(zone\ j)}$ *: Current spectrum portion i used by the MCT in zone j.*
- *spectrum* $_{i(zone\ j+1)}$ *: Spectrum portion i that should be occupied by the MCT in the new zone j+1.*

We assume that the MCT activates its handoff decision algorithm as soon as it comes close to a new zone in order to anticipate a possible handover. According to the information recorded about its new environment, the MCT updates its knowledge base with, among others, spectrum conditions.

Our proposed solution uses multi-agent systems where each CR node is equipped with an agent. Every Agent is autonomous and manages its spectrum resources needs in a decentralized way. It interacts with other users to insure an effective spectrum management. The MCT will then negotiate with the PU and cooperate with SUs.

Negotiation with PU means a discussion indented to produce a contract between the MCT and the PU. The PU can accept or refuse to share its licensed spectrum portion with the requesting SU.

Cooperation means that MCT and SUs collaborate together to share the spectrum. SUs will check whether the new distribution of spectrum including new arriving MCT still satisfies their network access needs.

If in the new zone, the current used spectrum is totally occupied or if it does not guarantee required QoS then the MCT has to execute a spectrum handoff. Otherwise, if the spectrum is totally idle, it keeps using it.

On the other hand, if the current used spectrum is partially occupied in the new zone, it is necessary to check, which kind of existing users (PU or SU) are there. The MCT can distinguish between a PU and an SU either by using a particular sensing algorithm [16] or by exchanging (or broadcasting) messages with new zone s' users.

If a PU is present then the MCT must request its approval for spectrum sharing. In case of disagreement, MCT has to look for another portion. When the spectrum is partially used only by SUs then they should verify the sharing feasibility with the MCT.

Algorithm 1: Spectrum Mobility management for MCT during Handoff

```
If (spectrum i(zone j+1) = fully occupied)
  Or (spectrum i(zone j+1) does not guarantee QoS(MCT))
  Then spectrum i(zone j+1) ← Choose_new_portion()  // Spectrum Handoff
   Else
     If (spectrum i(zone j+1) is totally idle)  // Band is totally free
       Then
         spectrum i(zone j+1) ← spectrum i(zone j)
         // Continue to use the same spectrum
       Else
         If (PU Є spectre i(zone j+1))
           // If a PU is using a portion of the spectrum
           Then
             If negotiation (PU, MCT)= acceptance
               Then spectrum_sharing(PU, MCT)
               Else spectrum i(zone j+1) ← Choose_new_portion()
             End If
           Else  // If there are one or several SUs in the spectrum
             If cooperation (SUs, MCT)= acceptable
               // free spectrum portion is sufficient
               Then spectrum_sharing (MCT, SUs)
               Else spectrum i(zone j+1) ← Choose_new_portion()
             End If
         End If
     End If
End If
```

Choose_new_portion() function makes the same tests for another spectrum hole detected by the sensing algorithm in order to choose a new portion to be utilized by the MCT in the new zone. Returns a portion that meets MCT access needs without disrupting other available users (PU or SU) in the same zone.

Through sensing, the MCT can find more than one appropriate spectrum portions in the new zone. However, our algorithm avoids MCT unnecessary spectrum handoff assuming that the current used spectrum is still available in the new visited zone and provides QoS requirements.

In addition, our algorithm insures maintaining PU QoS. Indeed, TCM cannot use spectrum unless it receives PU acceptance. PU agreement depends on many factors like PU QoS, disposal of unutilized appropriate spectrum resources, price, etc. In other words, PU would not accept to share its spectrum with a TCM if this will degrade PU QoS.

C. *Example of spectrum disribution*

To better understand our proposed algorithm (algorithm 1) an example of spectrum distribution is depicted in Fig. 3.

Initially, the MCT is located in zone1 and uses spectrum portion 1. When starting the handover from zone 1 to zone 2, the MCT discovers that the spectrum portion 1 in use is unavailable in zone 2. The spectrum portion 1 is either fully used by PUs and/ or SUs or no longer guarantees the required QoS. Thus, the MCT switches to an idle spectrum

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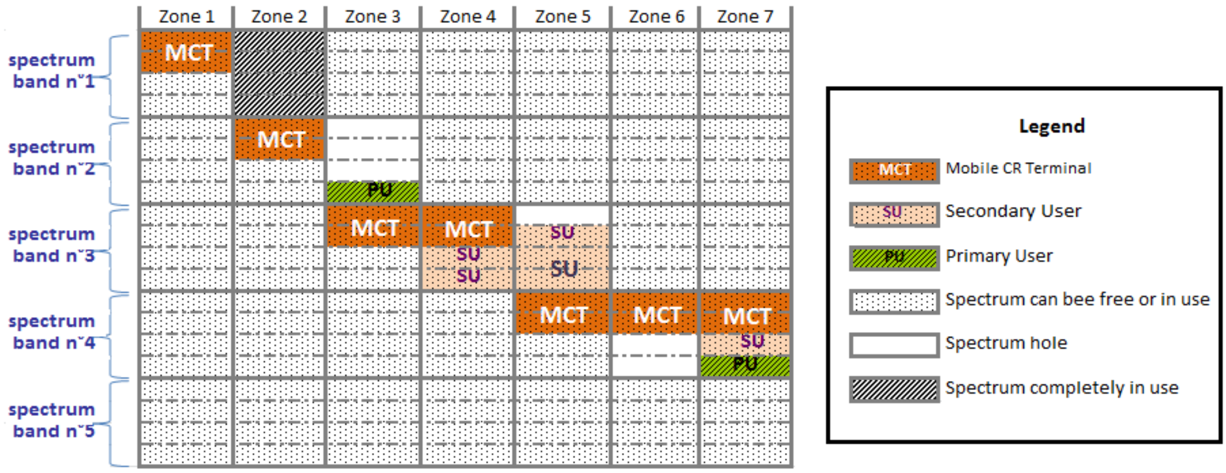

Figure 3. Exemple of dynamic spectrum distribution

band, the portion 2. When moving from zone 2 to zone 3, the MCT meets a PU, which is partially using the spectrum portion 2 in zone 3. The MCT starts a negotiation with the PU for spectrum sharing. In our selected scenario, the PU disagrees sharing and the MCT runs another spectrum handoff to acquire portion 3 (idle in zone 3).

During the handover from zone 3 to zone 4, the MCT detects the presence of SUs. The MCT cooperates with them for spectrum sharing. As the available amount of band meets the MCT request without affecting the other SUs, the MCT continues to use spectrum portion 3 in zone 4. When arriving to zone 5, remaining band is not sufficient bringing the MCT to a spectrum handoff by switching to portion 4. MCT continues to operate in the same band within zone 6 as it is totally idle and in zone 7 since the PU accepts here to share its spectrum portion.

V. CONCLUSION

In this paper, we have addressed the spectrum management issues in CR networks and showed the limitations considering the mobility. We proposed then a spectrum management algorithm that combines terminals mobility with negotiations for dynamic spectrum sharing in CR networks. We have then illustrated our proposal through an example of spectrum distribution. Our solution relies on decentralized and multi-agent approach and uses negotiation and cooperation mechanisms in order to ensure dynamic and efficient spectrum access.

As future works, we will choose well-defined negotiation algorithms and define channels selection parameters more precisely. We will also study (in more details) agent's interactions to refine our decision process. We will subsequently evaluate the performances of our solution through simulations and mathematical modeling.

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