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Frequency agility in cognitive radios: A new measurement algorithm for optimal operative frequency selection

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A B S T R A C T

The wide diffusion of multimedia services delivered also on mobile terminals (smartphone, tablets and so on), is causing a fast and continuous increasing of spectrum usage demand. Nevertheless, several studies have demonstrated that portions of radio spectrum are not in use for significant periods of time. This waste of spectrum shows the necessity to design a more flexible way to manage this resource with respect to the traditional frequency allocation policy.

In this context, cognitive radios play a crucial role, because they are thought to enable such flexible spectrum allocation by suitably changing their operating frequency without interfering with other transmitters. As a consequence, they have to implement a method to dynamically select the appropriate operating frequency based on the sensing of signals from other transmitters. This capability is usually called frequency agility.

Several spectrum sensing methods have been proposed in literature, whereas few studies have been focused on the development of methods for satisfying the frequency agility capability.

In this framework, the paper proposes a novel measurement algorithm able to meet those requirements. It is based on two sequential steps: the former performs a preliminary spectrum sensing aimed at excluding the frequency ranges surely occupied by primary users, while the latter performs a more refined analysis, restricted to frequency intervals not excluded by the previous stage, with the aim of selecting an operating frequency for the cognitive radio terminal that minimizes potential interferences with primary users. It has been designed for operating in scenarios involving signals based on OFDM or which present spectrum shapes and slopes similar to ones shown by OFDM.

A key feature of the proposal is the ability to operate even in scenarios characterized by low signal-to-noise ratios as confirmed also by the experimental campaign.

1. Introduction

Thanks to the continuous advances in information and communication technology, nowadays, multimedia services are available also for mobile users (smartphone, tablet, intelligent car, and so on). This scenario is addressed to quickly evolve as new multimedia services are introduced and new users require to avail these contents. As a

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consequence, the spectrum usage demand is quickly increasing.

Currently, the radio spectrum used for telecommunication applications is statically managed by assigning the operating frequency and bandwidth allocations to each company. This policy, because of the increase of users and the increasing demand of services would bring to a saturation of the radio spectrum resource.

Starting from these considerations, several national commissions and companies have started to study the spectral efficiency of the traditional frequency allocation policy in main cities of different countries. Results of such analyses show that portions of the radio spectrum are not in use for significant periods of time [1]. As a consequence, it would be very important to design a more flexible way to manage the radio spectrum resource.

To this aim, several solutions for improving the efficiency in the spectrum utilization have been introduced in literature, further ones are still subject of research work [2,3].

Among them, *Cognitive Radio* (CR) plays a very important role [4]. CRs have been conceived to enable such flexible spectrum allocation, making a more intensive and efficient spectrum use by licensees within their own networks, and by spectrum users sharing spectrum access on a negotiated or an opportunistic basis [5]. They have the ability to determine their location, sense spectrum use by neighboring devices, change dynamically their transmission parameters, such as carrier frequency, bandwidth, output power, and modulation scheme characteristics, in order to exploit various not busy spectrum sections.

The capabilities, that a CR system should have, are defined in [5]. Among them the frequency agility is surely one of the most important. It is the ability of a radio to change its operating frequency, combined with a method to dynamically select the appropriate operating frequency based on the sensing of signals coming from other transmitters.

As an example, Fig. 1 depicts a typical scenario in which CRs have to operate. It involves the presence of traditional

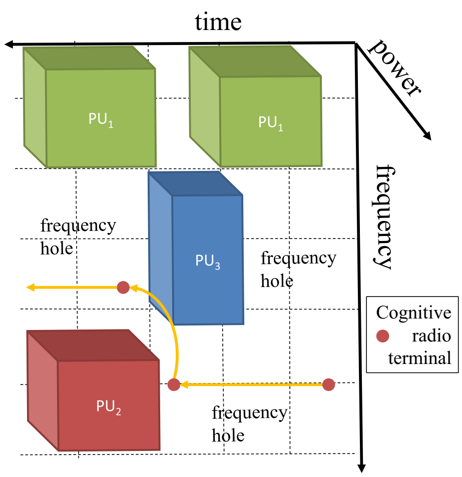

Fig. 1. Frequency agility capability of a cognitive radio terminal.

telecommunication transmitters, typically called *Primary Users* (PUs), which cannot sense the presence of signals emitted by other transmitters.

As CR terminals concern, they should implement at least the capabilities of spectrum sensing and frequency agility. In particular, the spectrum sensing identifies the portions of radio spectrum that are not currently in use, named *frequency holes*, whereas the frequency agility selects the most suitable portion of spectrum which minimizes the risk to employ a band already occupied by a PU. These smart users are generally called *Secondary Users* (SUs).

As a consequence, given also the large variety (in terms of modulation scheme, occupied bandwidth, spectrum shape, method of access to the channel) of PUs, the correct selection of the operating frequency to be adopted by a CR transmitter is not a trivial task, especially when blind scenarios are involved.

The careful spectrum sensing is the first main operation to be performed since it allows the reliable frequency agility stage of the transmitter. Several methods for spectrum sensing in CRs have been proposed in the literature [6–20]. Some of them propose to sense the presence of a PU, assuming that the pattern of its signal is known [8], or exploiting the cyclostationarity features of the received signal [9,19]. Other techniques are completely blind, i.e. do not have any *a priori* knowledge about the PU signal or spectrum shape. Among them, it is possible to cite the *energy detection-based sensing* [10,19], the *spectrum segmentation-based sensing* [11,12] and the *eigenvalue-based sensing* [13,14]. Solutions that combine two or more of the above-mentioned methods have also been proposed [15,16]. Recently, the interest of the research community is focused on the development of detection techniques that are effective even in scenarios characterized by very low signal-to-noise ratios (SNR) [18]. Generally, the selection of the most appropriate spectrum sensing technique should take into account the trade-off between the performance and the computational burden. As an example the energy detection-based methods, are characterized by the lowest computational complexity, but, generally, they show very poor performance when they have to detect signals in environments characterized by $SNR < 0$ dB.

Stemming from the past experience in developing original methods for spectrum interference monitoring [21,22] and power measurements in modern RF telecommunication transmitters [23–25], the authors have proposed a new measurement algorithm for frequency agility capability in CRs [26].

The following guidelines have been taken into account for the development of this algorithm: easiness of implementation (to keep low the computational burden for running on cost-effective platforms), operating without a full knowledge of the PU signal features, ability of effectively operating also in environments characterized by $SNR < 0$ dB.

The methods present in literature previously cited do not satisfy contemporaneously all these requirements (a good performance at $SNR < 0$ dB is generally counterbalanced by heavier computational burden or can be reached if the PU signal features are well *a priori* known), therefore