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Improved local spectrum sensing in cluttered environment using a simple recursive estimator☆

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ABSTRACT

Recently, the issue of spectrum sensing (SS) in cognitive radio networks (CRNs) has been widely reported in the literature. This paper presents a new strategy to improve the reliability of SS. One of the challenges in CRNs is to sense all information about a secondary user (SU) that is moving, especially in a cluttered environment, because the mobility of that user has a considerable impact on the sensing performance of the primary user. Thereby, an algorithm that ensures a high sensing level, in the case of a SU moving with a low velocity in a cluttered environment, is proposed. Besides, the shadowing element becomes important in cluttered environments. Therefore, it is important to provide a weighted averaging mechanism to obtain a stable measure of the signal strength at the SU. To do this, a simple recursive estimator is used. In the end, the algorithm proposed is evaluated through simulations and results.

1. Introduction

During the last decade, information and communications technology (ICT) as well as industrial, scientific and medical (ISM) applications have undergone rapid development. As a result, the wireless spectrum has become more congested. Moreover, the spectrum in certain bands of the cellular network has been increasingly utilized; this is the case of the second generation standard (global system for mobile or GSM), third generation standard (universal mobile telecommunications system or UMTS) and fourth generation standard (long term evolution or LTE). On the other hand, the other portions of the spectrum turned out to be largely under-utilized; this is the case of broadcast bands for television, industrial, scientific and medical (ISM) applications, etc. Naturally, these technologies (ICT and ISM) encounter various impediments related to quality settings such as data rate, mobility, quality of service, etc. Currently, the theory of cognitive radio (CR) is a useful and attractive solution to solve the shortage of spectrum resource [1,2]. The concept of CR was coined by Joseph Mitola (1999–2000) as a smart radio which can automatically detect available channels in a wireless electromagnetic spectrum [3]. In addition, the CR technology is a robust solution to optimize licensed spectrum utilization. The most important aspect in CR is spectrum sensing (SS).

Intensive research is currently being conducted on the SS approach in cognitive radio networks (CRNs). The SS technique may be either collaborative or non-collaborative. Several algorithms, such as energy detection, adaptive filtering, cyclosta-

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tionary feature detection and wavelet based detection [1,3–7], have been proposed for non-collaborative spectrum sensing (NCSS). However, it has been widely reported that the process of energy detection has often been used in various works, due to its simplicity and ease of implementation; in addition, this type of detection does not need any prior knowledge of the licensed users [4–7]. For this reason, the authors in [7] suggested the energy detection method for SS in CRNs. Using this method, they showed that the proposed scheme increases the performance of CR systems and improves the SS ability greatly in low signal-to-noise ratio (SNR) situations.

The detection of a primary signal, in presence of interference, noise, multipath fading, shadowing and hidden node, causes a major problem in CRNs. In fact, cooperative spectrum sensing (CSS) was found to be a promising solution for mitigating those effects [8], in order to overcome the co-channel interference problem. In [9], the authors discussed the issue of jamming management, using a secondary base station for LTE and UMTS. The authors in [10] have recently designed a consensus-based decentralized clustering algorithm for CSS in CRNs. After obtaining the numerical results, these authors found that the proposed can provide a sensing performance that is incomparable with that of the optimal soft combination scheme [11], with a significantly reduced detection load. Furthermore, the authors in [12] gave a brief introduction to CSS, and also discussed the different techniques related to CSS in CRNs. The scheme proposed in [12] examined two phases. The first phase concerns CSS with a single partner and the second one is related to CSS with multiple partners. According to the results obtained through simulation, the authors succeeded in improving the detection probability and the agility gain in the first phase. However, in the second phase, they could reduce the detection time and interference but increased the agility gain of CRNs through collaboration.

Two problems in SS, i.e. detection time and energy consumption, are to be overcome. In [13], the authors reported a valuable contribution, which examines the energy efficiency of CSS schemes for CRNs. In that same article [13], it is well noted that the proposed scheme, namely the two time-saving and energy efficient one-bit CSS (TSEEOB-CSS), is intended to optimize the energy efficiency of a system with the same sensing performance in the traditional CSS schemes. Moreover, another approach was proposed in [13], which allows diminishing the energy consumption and detection time of the TSEEOB-CSS scheme, with a highly reliable sensing performance. This approach was compared with the conventional CSS schemes. On the other hand, when noise uncertainty is severe, the conventional detectors become inoperative in addressing such problem. It has also been established that the entropy of a GWN (Gaussian white noise) is constant within the frequency domain. To solve the noise uncertainty problem [14], the authors proposed a novel sensing technique using the PSD-based entropy (power spectral density). They showed that the PSD-based entropy offers a better performance than the entropy of spectrum amplitude, with low computational complexity. Furthermore, they succeeded in improving the reliability of sensing performance with the two-stage entropy-based CSS (TSEB-CSS) scheme, using the two-bit decision. Based on the obtained results, the authors showed that the TSEB-CSS scheme can achieve a better performance compared to others, namely AND-CSS, OR-CSS [1,3], and VOTING-CSS [15].

The localization and mobility of wireless networks have been investigated in various applications [16]. In this context, it was found that the mobility of CRNs [17–19] affected seriously the SS performance. The authors in [17] reported a serious problem associated with the impact of mobility on SS in CRNs. In the latter paper, the proposed scheme was designed to monitor the CR node according to distance, in each sensing interval, with a constant velocity. Unlike the authors in [17], those in [18] investigated the impact of acceleration on the performance of mobile CRs. In their paper, they indicated that change in the acceleration can considerably affect the sensing performance in CRNs. In [19], the authors proposed a scheme that focused on the estimation of SS in real-time for CRNs, using the Kalman Filter. They found that the mobility of the secondary user (SU) has a negative impact on the SS performance, and this has been verified by studying the behavior of the probability of detection as a function of the link distance between the primary user (PU) and SU nodes. Moreover, the proposed scheme provided excellent results with minimum error. Our contribution is motivated by the facts mentioned above, and this justifies the importance of this work.

SS has become the key mechanism in enabling the sensing awareness of a PU in CRNs. However, the local sensing performance of the primary signal in a cluttered environment is limited by the channel conditions, which depend on noise uncertainty, path loss, multipath, shadowing and local interference. The combination of all these limitations may lead to a regime where the strength of the signal received at the SU is below the sensing threshold of the PU; this can lead to missed sensing.

Therefore, the primary purpose of this work is to overcome all phenomena that may prevent the sensing of a primary signal by a SU in a well-defined geographic area. To do that, a hybrid algorithm is proposed; it is intended to improve the reliability of sensing in a cluttered environment (see Fig. 1). This algorithm has two phases; a simple recursive estimator is used in the first phase, and two sensing approaches are used in the second.

This paper contributes to the study and assessment of the sensing performance of a PU by a SU in real-time, with the impact of the mobility of a SU in cluttered environments. The contribution is twofold:

The first phase focuses on the following points (as shown in Fig. 1):

- First stage - As stated in the previous paragraphs, the mobility of a SU has a significant impact on the sensing performance of a PU. To provide a more realistic contribution, it was considered that the SU was in motion. During that phase, the position and velocity of the SU were first estimated, using the random Gauss–markov mobility model (GMMM). It is worth noting that this model (GMMM) presents a minimum estimation error for the random movement pattern of mobile nodes.

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