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Peak to average power ratio based spatial spectrum sensing for cognitive radio systems☆

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ABSTRACT

The recent convergence of wireless standards for incorporation of spatial dimension in wireless systems has made spatial spectrum sensing based on Peak to Average Power Ratio (PAPR) of the received signal, a promising approach. This added dimension is principally exploited for stream multiplexing, user multiplexing and spatial diversity. Considering such a wireless environment for primary users, we propose an algorithm for spectrum sensing by secondary users which are also equipped with multiple antennas. The proposed spatial spectrum sensing algorithm is based on the PAPR of the spatially received signals. Simulation results show the improved performance once the information regarding spatial diversity of the primary users is incorporated in the proposed algorithm. Moreover, through simulations a better performance is achieved by using different diversity schemes and different parameters like sensing time and scanning interval.

1. Introduction

Ever increasing demand of higher data rates and the emergence of new wireless technologies combined with the static allocation of spectrum are leading to the scarcity of spectrum resources. However, empirical studies have shown 5.2% utilization of the spectrum (30–300 MHz) on different locations [1], which has lead to the concept of “spectrum holes”. To overcome the spectrum scarcity, an adaptive assignment of spectrum is desirable. Cognitive Radio (CR) [2] is a promising technology proposed to overcome this scarcity. CR is an intelligent system which is aware of its surroundings and can change its operating parameters according to the conditions of its environment. It enables the cognitive users (secondary users) to opportunistically access the already licensed bands.

It has the capability of environmental adaptation at a large scale. Further they have to vacate the channel as early as possible when primary user needs it. Because of these characteristics, CRs are also called ‘spectrum-agile radios’. Probability of false alarm (P_{fa} if the licensed user is absent and the cognitive receiver declares it on) and probability of missed detection (licensed user is on and cognitive receiver declares it off) are the two important performance metrics in CR. Lower probability of false alarm for spectral efficiency and lower probability of missed detection for primary protection is desired.

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The demand of ubiquitous communication and the requirement of exploding data rates has forced the convergence of almost all the wireless standards to the incorporation of spatial dimension which has fundamentally transformed the communication paradigm. This appended spatial dimension in the form of Multiple-Input Multiple-Output (MIMO) [3] has been included in almost all the ongoing standardization activities in the wireless industry as Long Term Evolution (LTE) [4], LTE-Advanced [5], WiMAX, Wi-Fi etc. This added spatial dimension has evolved new communication scenarios as stream multiplexing (single-user MIMO), user multiplexing (multi-user MIMO) and transmit diversity (space-time codes) [6]. Also, with antenna array, the transmit and receive beam orientation in order to achieve improved transmit and receive gains has lead to beamforming concept. This paradigm shift in the wireless environment demands transformed and efficient spectrum sensing techniques for the secondary users.

Many spectrum sensing schemes like matched filter detection [7], energy detection (ED) [8], cyclostationary based detection [9], Random Matrix Theory (RMT) based detection [10], eigenvalue value based detection [11] and Peak to Average Power Ratio (PAPR) based spectrum sensing [12] have been proposed. Spectrum sensing based on matched filtering is only valid for pre-known signals as it requires the complete information of the signal for detection [13]. Due to low computational cost, simplicity and general applicability to a wide variety of signals, ED has attained a wide acceptance. However, the determination of an optimal threshold is a dilemma of ED [14]. Moreover, the degraded performance for deep faded signals also limits its use under weak channel conditions. On the other hand, cyclostationary detection, RMT and eigenvalue based detection have improved performance but are computationally very complex [15]. Collaborative spectrum sensing is proposed in [16]. Where as multi-antenna based spectrum sensing by using generalized likelihood ratio test was explored in [17]. Spectrum sensing by using multiple antennas for Orthogonal Frequency Division Multiplexing (OFDM) signals are proposed in [18] and [19]. PAPR based spatial spectrum sensing has very good results even under low signal to noise ratio (SNR) [12]. In [12], the authors have proposed spectrum sensing model for Single Input Multi-Output (SIMO) systems. But in our view, there is a need of low complexity, reliable spectrum sensing algorithms which not only perform well under all SNR conditions but also incorporate the advanced features of modern wireless systems like beamforming and MIMO.

We have already proposed a channel state dependent adaptive spatial spectrum sensing algorithm in [20]. But we only used multiple antennas at the receiver and an adaptive scheme was proposed which selects an appropriate spectrum sensing technique at the receiver depending on the channel conditions. Recently, in [21], the authors describe a system for spectrum sensing using PAPR as signal feature. But this patent only considers multiple antennas at receiver. Also, no analysis regarding beam-forming is provided. Whereas, We propose to use beamforming by estimating angle of arrival and making the peak power function of angle of arrival. MIMO system for correlated noise environment has been explored in [22]. Received covariance matrix and estimate of noise is obtained by exploiting low rank matrix decomposition algorithms. In our case the noise is uncorrelated. The authors have proposed a wideband spectrum sensing technique for cooperative cognitive radio systems in [23]. A multiband spectrum scanning technique is proposed to exploit scheduling diversity in an efficient way for spatial diversity based spectrum sensing. When the number of sensors and the scanning channels is large, a scheduling scheme is proposed to outperform the conventional non scheduled sensing process. The interference effect on primary network is studied due to cognitive radio communications when k-user MIMO interference model is considered [24]. The effect of secondary antenna is used to mitigate the interference at primary receivers. The authors in [25] have analyzed the effect of PAPR reduction in primary signal for the performance of multiband joint detection based wideband spectrum sensing. The multi-band joint detection method is also optimized for both cooperative and non-cooperative spectrum sensing schemes. The signal detection is also improved, when the primary users PAPR is reduced in the cooperative spectrum sensing scenario. In our work, we are taking the PAPR of the received primary signal as measure to perform spectrum sensing.

Thus, we have extended the work in [20] and we have proposed a MIMO based spectrum sensing algorithm for advanced wireless communication systems and specially transmission mode 3, transmission mode 4, transmission mode 5, transmission mode 8 and transmission mode 9 of LTE and LTE-Advanced are addressed in the context of cognitive radios. A scheme for opportunistic use of spectrum is suggested when a system is using the above said transmission modes.

In this work, we focus on such a CR system where the primary users are equipped with multiple antennas and resort to one of the above stated transmission modes. We propose a spectrum sensing algorithm for the secondary users equipped with multiple antennas. The proposed algorithm is based on the PAPR of the spatially received signal and the primary users are using multiple antennas for transmission. Simulation results show that the incorporation of this information in the algorithm of spatial spectrum sensing significantly improves the probability of detection and lowers the probability of false alarm. Furthermore, using beamforming, the effect of angular resolution and orientation is examined and shown that as we increase the angular resolution we achieve a better performance. The effect of number of received samples is also examined.

The paper is organized into five sections. Section 2 considers the system models for the proposed schemes. Section 3 discusses the PAPR based spatial spectrum sensing for the MIMO systems. Whereas, Simulation results are presented in Section 4 while Section 5 concludes the paper.

2. System model

In this section we shall present system model for both SIMO and MIMO systems.