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Spectrum sensing algorithms based on correlation statistics of polarization vector

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ABSTRACT

In this paper, we consider the problem of spectrum sensing in cognitive radios (CRs) by exploiting inherent polarization characteristics of signal. Since polarization vector can completely describe the radiation's polarization characteristics, we first derive the probability density function (PDF) of received polarization vector and its moments. Then we find the fact that both component and serial correlations of received polarization vector (i.e., the mixed polarization vector of primary signal and noise) are different from those of noise with high probability. This distinctive difference can be used to decide whether the primary signal exists or not. Therefore, component correlation sensing (CCS) algorithm and serial correlation sensing (SCS) algorithm are proposed respectively. Furthermore the closed-form expressions of probabilities of false alarm and detection are available for CCS and SCS algorithms. Simulations show that both CCS and SCS detectors achieve better performance with higher cross-polar discrimination (XPD) and polarization channel correlation coefficients. We also show that, if channel is highly depolarized, CCS performs better than SCS. Otherwise, the latter shows better performance. Compared with existing polarization based detectors, both CCS and SCS detectors perform better in the presence of noise power uncertainty.

1. Introduction

Cognitive radio (CR) is a spectrum sharing technology which enables secondary users (SUs) to access licensed spectrum without causing interference to primary users (PUs) [1]. Spectrum sensing plays a fundamental role in cognitive radio networks and a variety of spectrum sensing methods have been proposed recently in [2–9], such as energy detection (ED) [2], matched filtering detection [3], cyclostationary detection [4], eigenvalue-based detectors including maximum minimum eigenvalue (MME) [5], arithmetic-to-geometric mean (AGM) [6], and generalized likelihood ratio test (GLRT) [7], and covariance-based detectors including covariance absolute value (CAV) [8] and CorrSum [9]. Most of the existing methods make use of the amplitude (power), frequency, or phase characteristics of signal to differentiate received primary signal from background noise. However, the polarization characteristics, which actually represent signals' essential characteristics, are unexploited in previous works. The polarization characteristics are embodied in a vector which received by two branches of the dual-polarized antennas. Polarization contains not only the amplitude, frequency, and phase information of signals, but also the information of the relative relationship between the two components of the vector. Unfortunately all of the previously mentioned

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sensing methods convert the vector signals into scalar quantities at the SUs prior to processing. In other words, the polarization characteristics is thereby ignored.

Furthermore, all radio transmit and receive antennas are intrinsically polarized. Hence, exploring polarization in wireless communications, such as diversity and multiplexing, has been a potential research direction [10–12]. Meanwhile dual-polarized antennas have become a promising cost-effective and space-effective configuration and have been widely used in existing commercial wireless communication systems, such as 2G/3G [10], or future commercial wireless communication systems, such as LTE/LTE-A [10,13]. Moreover, it is natural that cognitive radio would be incorporated into these commercial wireless communication systems to effectively resolve the dilemma between the increasing spectrum requirements and scarce spectrum resources [14]. Hence leveraging cognitive radio in dual-polarized commercial wireless communication systems may logically be the next step. However, to the best of the authors' knowledge, the use of polarization for spectrum sensing has not yet been investigated extensively, and few related research works have been reported in the literature. Recently, a dual-polarized architecture [15] was designed for spectrum sensing under the assumption of known reference polarization just like that in the traditional radar systems [16]. In fact, the dual-polarized antennas enable the SUs to obtain primary signal's polarization information which can be derived from the amplitude ratio and relative phase between the two orthogonally polarized signal branches. Therefore our recent works focused on spectrum sensing based on the obtained polarization information. We first proposed a virtual polarization detection (VPD) method [17], which was regarded as energy based polarization detection since this method optimally combined signals received from two branches of dual-polarized antennas at the energy level. Sharma et al. [18] analyzed the performance of energy based polarization detection with different combining techniques, such as selection combining (SC) and equal gain combining (EGC) in AWGN channel. Sharma et al. and Xu and Lim [19,20] further extended the work in [18] to dual-polarized fading channel. As mentioned above, similar to conventional ED, all the energy based polarization detection methods suffer from the problem of noise uncertainty. To overcome this problem, we then proposed a blind polarization spectrum sensing method, generalized likelihood ratio test-polarization vector (GLRT-PV) [21], based on the resultant vector length of the sample polarization vectors. Since the length of resultant vector is independent of noise covariance and the parameters of PU, the GLRT-PV method has constant false alarm rate (CFAR) property.

In this paper, we further focus on fully exploiting the inherent polarization characteristics of signal. Since polarization vector fully represents the polarization information of received signal, we first derive the probability density function (PDF) of the received polarization vector and its moments. Based on the results obtained, we find that both the component correlation and serial correlation of mixed polarization vector of signal and noise are different from those of noise only with high probability. Therefore, we propose two blind spectrum sensing algorithms based on polarization vector correlation statistics, i.e., component correlation sensing (CCS) algorithm and the serial correlation sensing (SCS) algorithm, in which the above distinguished property is used to decide whether primary signal exists or not. We should point out another reference related to our work. Recently in [21], we have found that the orientation of received polarization vectors containing noise only follows a spherical uniform distribution, while the orientation of received polarization vectors containing both primary signal and noise follows a Fisher distribution. Therefore, we proposed a sensing algorithm by exploiting the difference between the two statistics. Using the GLRT paradigm, the final test statistic, namely, GLRT-PV detector is solely based on the resultant vector length of the sample polarization vectors. Different from [21], this paper uses two kinds of correlation statistic of polarization vector to discriminate signal from background noise. The only significance correlation with [21] is that one of the proposed detector which uses serial correlation statistic, i.e., SCS detector, is equivalent to using resultant vector length of the sample polarization vectors just as GLRT-PV detector does. So, just as this paper pointed out, directional statistic based detector is only a special case of correlation statistic based detector. For practical applications, direction statistic based detector or serial correlation statistic based detector goes for different scenarios with component correlation statistic based detector. Suitable applications are associated with the propagation conditions, which may induce low or high depolarization effects of channel between CR receiver and primary transmitter. In the case of high depolarization behavior of channel, such as rich multipath propagation caused by scattering along propagation path, component-correlation-based detector is preferred than direction-based detector. However, when there exists relatively good propagation conditions, for example, the received signals propagate through a line of sight (LOS) path or a near LOS path, direction-based detector is more applicable for its better performance, and more important point is that direction-based detector has lower implementation complexity, thus more attractive for fast spectrum sensing.

The rest of this paper is organized as follows. In Section 2, the polarization vector and statistical signal model are introduced. The statistical analysis of received polarization vector including PDFs and moments is developed in Section 3. The CCS and SCS algorithms as well as their theoretical performance are presented in Sections 4 and 5, respectively. Section 6 further summarizes the proposed two algorithms and makes comparison with other detectors. Extensive simulations are illustrated in Section 7. Finally, Section 8 concludes the paper.

Notations: $\boldsymbol{E}[\cdot]$ denotes the expectation operation and $*$ represents complex conjugation. Superscripts $(\cdot)^T$ and $(\cdot)^H$ denote transpose and conjugate transpose, respectively. $\det(\boldsymbol{A})$ is the determinant of matrix $\boldsymbol{A}$ and $|x|$ is the absolute value (or modulus) of x. $\otimes$ is the Kronecker product. $\boldsymbol{I}_n$ stands for the $n \times n$ identity matrix.

2. Polarization vector and statistical signal model

We consider a scenario where orthogonally dual-polarized antennas are employed by a SU to detect PUs. The primary transmitter is assumed to be equipped with either uni-polarized antenna or orthogonally dual-polarized antennas, which is determined by its own system design.