Physical Communication 22 (2017) 1–8

Contents lists available at ScienceDirect

Physical Communication

journal homepage: www.elsevier.com/locate/phycom

Full length article

A cost-effective approach for spectrum sensing using beamforming

Kaïs Bouallegue [a], Iyad Dayoub [a,*], Mohamed Gharbi [a], Kaïs Hassan [b]

[a] Department of Opto-Acousto-Electronics of the Institute of Electronics, Microelectronics, and Nanotechnologies, IEMN-DOAE, UMR CNRS 8520, UVHC, F-59313 Valenciennes, France

[b] Université du Maine, LAUM, Le Mans, France

ARTICLE INFO

Article history:
Received 20 April 2016
Received in revised form
6 September 2016
Accepted 2 November 2016
Available online 16 November 2016

Keywords:
Spectrum sensing
Angle of arrival
Cognitive radio
Beamforming

ABSTRACT

Spectrum sensing (SS) is one of the principal challenges on which the mobile communication is based on. Identifying the available frequency bands, also called white spaces, is the main issue. A novel blind approach for SS in the narrowband context is proposed in order to improve the signal detection. Considering a channel with its angle of arrival (AoA), we use beamforming technique to exploit the maximum and minimum angular energy. Both theoretical developments of the threshold and performance analysis are developed. To validate our contribution, the analytical results of the performance developed in this paper are compared with those from simulation. A comparison of state-of-the-art SS method using the eigenvalue decomposition is provided which brings an interesting trade-off between complexity and performance. Finally, simulation results considering the probability of misdetection under very low signal-to-noise ratio (SNR) are presented.

1. Introduction

The mobile communication will operate in a heterogeneous environment and will need to be supported by flexible spectrum management capabilities. Cognitive radio (CR) is a promising technology that can overcome the various problems due to static spectrum allocation [1,2]. Indeed, the high demand for spectral resources and its underutilization lead to define a primary user (PU) and a secondary user (SU) which takes advantage opportunistically of the unoccupied frequency bands [3]. In this context, the detection of a PU becomes the key element since the SU has to be aware of its radio environment and shall not, in any way, interfere with PU. The wireless regional area networks (WRAN) IEEE 802.22 standard is the first to exploit the CR operating on high frequency/ultra-high frequency (HF/UHF) bands allocated to TV broadcasting. The requirement of the detector is to sense the PU at a detection rate of at least 90% and a false alarm one lower than 10% when the SNR is around −21 dB [4].

SS represents the backbone of the CR and many of the detection methods are based on statistical hypothesis tests. Several of these tests, proposed in literature [5], are based on the generalized likelihood ratio test (GLRT). The most basic SS method is matched-filter (MF) [6] which takes a short time to reach a certain probability of false alarm (P_{fa}) or a certain probability of detection (P_d). There are other sensing methods such as the energy detection (ED) [7], [8], and the cyclostationarity detection (CD) [9], each of them has advantages and disadvantages. The major drawback of MF is that it needs accurate synchronization and perfect knowledge of the channel. ED methods are robust but very sensitive to noise uncertainty [7]. CD methods require the knowledge of the cyclic frequency of PU. More advanced methods are based on the behavior of the covariance matrix as the covariance absolute value (CAV) and the covariance Frobenius norm (CFN) [10], or the eigenvalues as energy with minimum eigenvalue (EME), maximum–minimum eigenvalue (MME) [11], arithmetic-to-geometric mean (AGM) [12], simplified predicted eigenvalue threshold (SPET) [13], blindly combined energy detection (BCED) [8], maximum-eigenvalue-geometric-mean (MEGM) [14] and eigenvalue moment ratio (EMR) [15]. These methods have good performance and are robust under a very low SNR, but they require a high number of symbols in order to provide efficient covariance estimation and they are computationally expensive.

Some of SS methods need *a priori* knowledge either on the distributions of the source signal and noise or the channel information like likelihood ratio test (LRT), energy-correlator (EC) [7] and optimally combined energy detection (OCED) [8]. However, several detection techniques do not require information on the transmitted signal and the channel. Some among these methods (e.g. EME, CAV, and CFN) give less detection performance

* Corresponding author.
E-mail address: iyad.dayoub@univ-valenciennes.fr (I. Dayoub).

http://dx.doi.org/10.1016/j.phycom.2016.11.001
1874-4907/

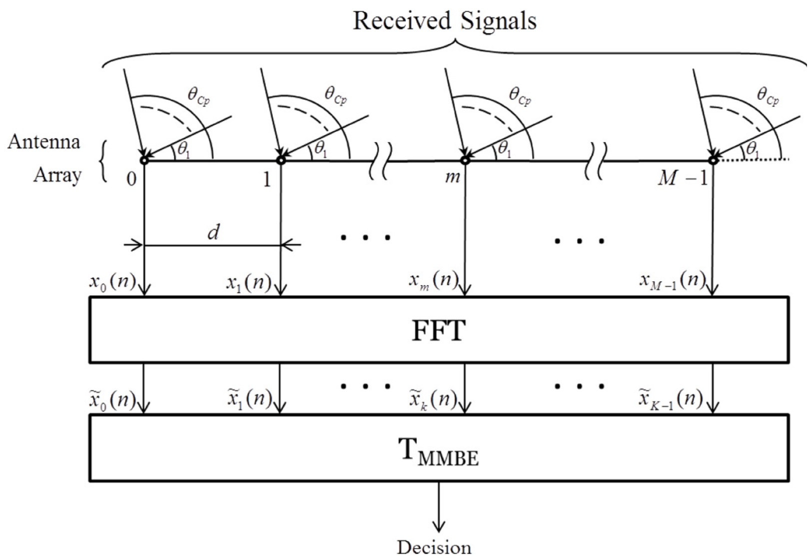

Fig. 1. Diagram of the proposed spectral detection system considering channel order with the same delay for one PU.

when compared to the rest, but all of them are very sensitive to multipath.

The spatial scanning allows to detect powers according to the directions of the AoA from the primary user signal. Hence, we can spatially filter the signal from a given direction. Beamforming has greatly contributed to the improvement of wireless communications [16]. It controls the phase of antenna array in order to separate signal from interfering sources. Many beamforming techniques have been also developed in order to divide a domain into sectors to detect the PU [17]. These techniques of spatial filtering have been specified in many standards, including IEEE 802.15.3c for wireless personal area network (WPAN) [18]. In [19], a cooperative SS method using beamforming has been developed to improve detection performance and perform spatial and temporal opportunity detection as Two-Dimensional Sensing (TDS) [20]. Recent method exploit the central symmetry feature of noise spatial spectrum proposed a blind central method based on the existence of central symmetry feature which depends on the presence/absence of primary user signal as Central Symmetry-based Feature Detection (CSFD) [21]. Other methods based on spatio-temporal diversity exploit the cooperative sensing with an optimal fusion range and scheduling a series of sensing stages with an optimal stopping time [22]. In [23] and [24], the authors consider the primary user signals with a model of AoA having a Laplace distribution. The detection system is based on a switching of the radiation pattern in different angular directions. Power allocation policy is also developed for the secondary transmitter using beamforming [25]. In this paper, we introduce a new blind SS method based on beamforming. In fact, the signals transmitted by the PU arrive at the antennas according to different paths and angle of arrival (AoA). Based on beamforming, SU is able to detect with more accuracy the presence of the PU by comparing, from all directions, the maximum estimated energy of the signal to the minimum using the multiple antennas. The blind proposed algorithm, called maximum-to-minimum beam energy (MMBE), is compared, by analogy, to the well-known and widely used algorithm MME [26] [27]. The rest of this paper is organized as follows, we present the system model in Section 2. Section 3 gives the theoretical approaches of our proposal method with its computational complexity. Section 4 provides the performance analysis through simulations. Finally, some conclusions are drawn in Section 5.

Notation: Boldface lower letters to denote vectors and boldface capital letters to denote matrices. Superscript $(.)^T$, $(.)^*$ and $(.)^H$ stand for transpose, complex conjugate and Hermitian (complex conjugate transpose) respectively. $\mathbf{I}_u$ and $Tr(.)$ denote the identity matrix of order u and the trace of a matrix respectively. $E[.]$ and $V[.]$ stand for expectation and variance operations respectively.

2. System model

In this section, we consider two hypotheses: $\mathcal{H}_0$, when the signal is absent, and $\mathcal{H}_1$, when the signal is present. For each antenna m, the received signal at the instant n is given by

$$\mathcal{H}_0 : x_m(n) = b_m(n) \tag{1}$$

$$\mathcal{H}_1 : x_m(n) = r_m(n) + b_m(n), \quad m = 0, 1, \dots, (M-1), \tag{2}$$

where M is the number of linear receive antennas ($M > 1$) and $b_m(n)$ is a zero-mean additive white Gaussian noise with variance σ_b^2. Under $\mathcal{H}_1$ hypothesis and for the antenna m, the received signal component $r_m(n)$ includes multipath and AoA. Let A_p be the set of paths including all possible AoA from the pth PU. θ_p is the AoA as illustrated in Fig. 1. According to the AoA θ_p, each path has a delay i which depends on θ_p. The nth received symbol at the antenna m is expressed as

$$x_m(n) = \sum_{p=0}^{P-1} \sum_{\theta_p \in A_p} a_{mp}(\theta_p) s_p(n - i(\theta_p)) + b_m(n), \tag{3}$$

where $a_{mp}(\theta_p)$ is the path gain between the mth antenna and the pth PU, P is the number of PUs and $s_p(n)$ represents the source signal of the pth PU.

The first term of Eq. (3) can be rewritten as

$$\sum_{\theta_p \in A_p} a_{mp}(\theta_p) s_p(n - i(\theta_p))$$

$$= \sum_{i=0}^{C_p} \sum_{\theta_p \in \Delta_i} a_{mp}(\theta_p) s_p(n - i), \tag{4}$$

where $\theta_p \in \Delta_i$ means all the AoA of A_p having the same delay i. Thus, we can note

$$x_m(n) = \sum_{p=0}^{P-1} \sum_{i=0}^{C_p} h_{mp}(i) s_p(n - i) + b_m(n), \tag{5}$$

where C_p is the channel order and

$$h_{mp}(i) = \sum_{\theta_p \in \Delta_i} a_{mp}(\theta_p). \tag{6}$$