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Limited reporting-based cooperative spectrum sensing for multiband cognitive radio networks[☆]

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ABSTRACT

The performance of cooperative spectrum sensing depends on the sensing time, the reporting time of transmitting sensing results, and the fusion scheme. While longer sensing and reporting time will improve the sensing performance, this shortens the allowable data transmission time, which in turn degrades the throughput of secondary users. In a cognitive radio network with multi-primary bands, the reporting time increases with the number of reporting nodes and primary bands to be reported. This paper proposes a limited reporting scheme for multiband cooperative spectrum sensing with a soft combination rule in order to reduce the reporting time while satisfying the detection probability constraint. In the proposed reporting scheme, the upper bound of the number of reporting nodes and the reported primary bands are dynamically controlled according to the number of cooperative secondary users. We formulate a trade-off between the throughput of secondary users and the overheads of cooperative spectrum sensing. Simulation results show that the sensing time and reporting time should be jointly optimized in order to maximize the throughput of secondary users. Moreover, in comparison with the conventional sensing-throughput optimization schemes, the proposed reporting scheme significantly increases the throughput of secondary users by reducing the reporting time.

1. Introduction

In cognitive radio (CR) networks with multi-primary bands, spectrum sensing is a key technology to realize spectrum sharing over a confined spectrum (e.g. DTV-bands). Generally, the signal detection techniques can be classified into energy detection, matched filtering detection, and cyclostationary feature detection [1]. However, in response to the transitional detectors being inefficient when noisy uncertainty is severe, an entropy-based detector that is robust to the noise uncertainty has been proposed [2,3]. In practice, many factors, such as multipath fading, shadowing, and the hidden primary user (PU) problem, may significantly affect detection performance. To solve this challenging problem, cooperative spectrum sensing (CSS) has been extensively studied in efforts to increase the sensing performance [4–6]. The CSS has three successive phases, *sensing*, *reporting*, and *decision*. In the sensing phase, each sensing node locally senses the signal of PUs. Then, in the next reporting phase, sensing nodes report their observed sensing results to a fusion center (FC). In the decision phase, the FC determines the presence of a PU by combining multiple independent sensing results reported by sensing nodes, where it can use hard combination methods (e.g., OR-rule, AND-rule, and k-out-of-K rule) or a soft combination method [7–9]. It becomes obvious that the performance of the CSS is dependent on the sensing time, reporting time, and the fusion scheme [10]. As the sensing and reporting time increase, the sensing performance increases; however, with a fixed frame size, the allowable data transmission time of secondary users (SUs) is shortened and therefore the throughput of SUs decreases.

One of the important issues in the design of CSS is determining the sensing time, reporting time, and parameters for the fusion scheme. Many researchers have endeavored to find the optimal parameters that maximize the throughput of SUs. Some researchers have focused on finding the optimal sensing time by formulating a sensing-throughput trade-off problem when a hard combination method is adopted at

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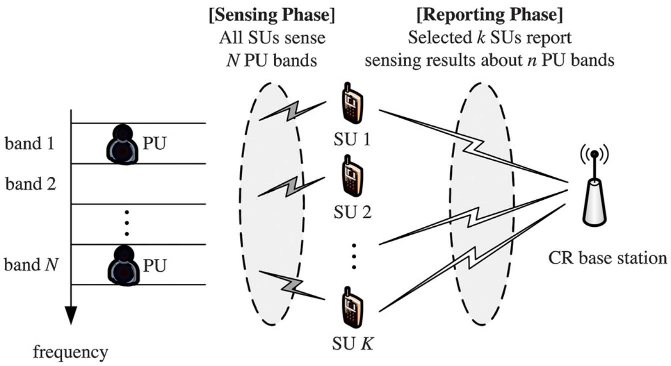

Fig. 1. Proposed system model.

the FC [11–14]. Other researchers have focused on finding the optimal fusion parameters (e.g., the reporting threshold for the OR-rule and a voting threshold for the k-out-of-K rule) that maximize the sensing performance or the throughput of SUs [9,15,16]. The authors of [17] formulated a sensing-reporting optimization problem to find the optimal division of time between the sensing time and the reporting time when the k-out-of-K rule is adopted at an FC, where they assumed the sum of the sensing time and the reporting time is fixed. The author of [2] proposed two-stage entropy-based CSS in order to counteract the effect of noise uncertainty, where the proposed entropy-based CSS scheme required less computational complexity but still outperformed the previous hard combination-based CSS schemes. However, the above studies of [9,11–17,2] did not take into consideration the effect of the reporting time on the throughput of SUs, and moreover they considered single band CSS. Moreover, they adopted a hard combination method, an OR-rule or a k-out-of-K rule, at an FC. A soft combination method shows better sensing performance than hard combination methods at the cost of increased bandwidth of reporting channels [8,18].

In contrast with the above work for single band CSS, some studies have considered CSS with multiple primary bands [19–22]. The authors of [19] proposed a sensor allocation and quantization scheme for multiband CSS. The authors of [20] formulated a sensing-throughput trade-off problem to find a pair of the sensing time and the number of SUs that report their sensing results when an OR-rule is adopted at an FC in multiband CR networks. The authors of [21] formulated a sensing-throughput optimization problem to find the optimal time setting to sense multiple primary bands and they proposed a slotted-time sensing mode and a continuous-time sensing mode. The authors of [22] investigated the relationship between cooperation mechanisms and spatial-spectral diversity over multiple primary channels. However, the above studies of [19–22] failed to propose a reporting scheme that reduces the reporting overhead in order to increase the throughput of SUs.

Some researchers have endeavored to reduce the sensing time or reporting overhead. In conventional hard combination-based CSS, each SU reports only one-bit decision to the FC. Its reporting overhead is thereby minimized but it suffers degradation of the sensing performance because of information loss caused by local hard decisions. To achieve a balanced trade-off between the sensing performance and the reporting overhead, some researchers have proposed a two-bit or three-bit combination rule [8,23,24]. The authors of [25,26] proposed a two-stage spectrum sensing scheme in order to reduce the sensing time and maximize the sensing performance, where coarse sensing based on energy detection is performed in the first stage and, if required, fine sensing is performed in the second stage. While [25,26] did not consider CSS, the authors of [2,27] proposed a two-stage spectrum sensing scheme in the CSS. The author of [2] improved the sensing performance via a two-stage two-bit CSS and the authors of [27] reduced energy consumption via two-stage energy-efficient one-bit CSS.

This paper discusses multiband CSS in CR networks with a soft combination method. The contribution of this paper is twofold. First, this paper proposes a new reporting scheme that reduces the reporting overhead in multiband CR networks. The proposed scheme dynamically controls the upper bound of the number of reporting nodes and reported bands in multiband CSS according to the number of cooperative SUs. The proposed limited reporting scheme significantly increases the throughput of SUs by reducing the reporting overhead of multiband cooperative sensing while satisfying the detection probability constraint. Second, this paper formulates a trade-off problem between the throughput of SUs and the overheads of CSS including both the sensing time and the reporting time. Whereas most previous studies of [11,12,14] formulated a sensing-throughput trade-off problem without taking the reporting time into consideration. Although a few works investigated the effect of the reporting overhead on the sensing performance, they assumed that the FC uses a hard combination method and moreover they failed to propose an idea that reduces the reporting overhead [20,17].

The remainder of this paper is organized as follows: Section 2 describes the system model, where the processes of four phases, sensing, reporting, decision, and transmission of SUs, are described and a limited reporting scheme is proposed in the reporting phase. Section 3 analyzes the false alarm probability of the multiband CSS with the proposed reporting scheme. Section 4 formulates a sensing-reporting-bands optimization problem and presents an iterative algorithm to solve the optimization problem. Section 5 presents the numerical results and finally, Section 6 concludes the paper.

2. System model

2.1. System description

As shown in Fig. 1, we consider a centralized CR network with N primary frequency bands (termed *bands* hereafter) and K SUs, where a CR base station functions as an FC and each SU functions as a cooperative sensing node. In the proposed system model, some of K SUs are selected to report their sensing results to the FC, where the sensing result reported by a selected SU includes the observed sensing