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Optimal power allocation and allowable interference shaping in cognitive radio networks

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ABSTRACT

We investigate an interference management problem in multi-carrier cognitive radio systems. To this end, we propose a new framework for protecting primary users such that the primary user can shape the envelope of interference on each subcarrier. Furthermore, we introduce the concept of minimum individual interference budget that the primary user should allow on each subcarrier so that the secondary user can receive a certain quality of service. We develop a joint optimal transmit power and interference budget allocation algorithm for the primary user, which maximizes the throughput of the primary user. Through simulations, we show that our approach can provide better protection for primary users than the existing approach.

1. Introduction

1.1. Background

With the explosive growth of wireless devices, the demand for wireless broadband has been rapidly increasing. To address this issue, a number of communications technologies such as MIMO and OFDM have been developed and adopted in real wireless communication systems. The idea behind those technologies is that higher capacity can be achieved by increasing the dimension of spectrum resources. Recently, an alternative approach, referred to as *cognitive radio*, has emerged as a promising solution for enabling efficient utilization of spectrum resources [1–4]. In cognitive radio systems, unlicensed (or secondary) users are allowed to share the spectrum exclusively allocated to licensed (or primary) users, provided that the secondary user generates limited or zero interference to primary users. In this paper, we focus on the underlay mode where secondary users are allowed to transmit their data simultaneously with primary users [5–10].

1.2. Related work

In this section, we introduce related studies with the problem we will consider in this paper.

1.2.1. Primary protection techniques based on interference power

Clearly, in the underlay mode, a primary receiver can experience interference from secondary senders, and hence, it is necessary to provide a mechanism that can protect primary users (who were to use the spectrum exclusively). One of the well-known spectrum

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underlay methods is to allow the secondary users only if aggregate interference over all subcarriers at the primary receiver is maintained below a certain threshold [11]. While this aggregate interference budget approach enable the secondary user to maximize its system throughput by optimally determining individual interference level on each subcarrier, the primary user is usually excluded in such a determination process, and hence its system throughput is arbitrarily deteriorated.

1.2.2. Primary protection techniques based on achievable rate

More recently, other approaches for primary user protection were proposed by employing more explicit constraints on the performance of primary user (while experiencing interference from secondary user). In [12], the transmit power of secondary user in the single-carrier system is optimized subject to the decodability of primary user's signal, which in turn translates to the minimum rate constraint. On the other hand, [13] considers a multi-carrier system, and imposes the constraint that the total rate loss of primary user due to interference over all subcarriers should be no greater than a certain threshold. Even though these rate-based protection outperforms the conventional ones with interference temperature in terms of the achievable rate of the secondary user, there exist several technical challenges for applying the technique in practical cognitive networks. First, both [12,13] assume global channel state information (CSI), which ultimately requires the information exchange between the primary transmitter and the secondary transmitter. Second, both [12,13] cannot perfectly guarantee the achievable rate of the primary network in *practical* cognitive networks utilizing adaptive modulation and coding scheme (MCS) since unexpected interference for certain sub-carriers may result in packet decoding error. Furthermore, the formulation in [13] is non-convex, making it hard to find an optimal power allocation for secondary user.

1.3. Contributions

To address the aforementioned problem that primary users can be often subject to unpredictable interference, we propose a new framework for protecting primary users. In particular, our framework allows the primary user to determine individual interference budget on each subcarrier. The individual interference budget is defined as the maximum amount of interference on each subcarrier that the primary user can withstand, and hence the secondary user should not generate interference greater than this budget on each subcarrier. This clearly enables the primary user to achieve guaranteed throughput since interference on each subcarrier can be easily predicted. Furthermore, we introduce the concept of *minimum interference budget* on each subcarrier. Namely, the individual interference budget determined by the primary user should be no smaller than the minimum interference budget, so that the secondary user uses all subcarriers if it wants. We present a mathematical formulation of joint transmit power and individual interference budget allocation for throughput maximization. The formulation is a non-convex optimization problem, which is hard to solve in general. Despite this difficulty, exploiting the structure of the problem, we develop a joint optimal transmit power and individual interference budget allocation algorithm that maximizes the throughput of the primary user subject to minimum interference budget requirements. Note that the proposed algorithm is not optimal in terms of sum-rate of primary and secondary users.

1.4. Organization

The remainder of this paper is organized as follows. Section 2 describes the system model. Section 3 explains the proposed optimization technique. In Section 4, numerical results are shown. Section 5 summarizes the paper with some concluding remarks.

2. System model

We consider the multicarrier cognitive radio system in Fig. 1 where there are one primary user and one secondary user. The set of channel coefficients between primary transmitter (PT) and primary receiver (PR) is $\{h_i, 1 \le i \le n\}$, where n is the number of subcarriers. Similarly, over the same set of subcarriers, $\{h_i', 1 \le i \le n\}$ denotes the set of channel coefficients between secondary transmitter (ST) and secondary receiver (SR). The channel gain a_i between PT and PR over each subcarrier i is given as $a_i = |h_i|^2$. Similarly, $a_i' = |h_i'|^2$ denotes the channel gain between ST and SR over each subcarrier i. Let $p = [p_i, i = 1, \ldots, n]$ and $p' = [p_i', i = 1, \ldots, n]$ be the transmit power vectors of primary and secondary users, respectively. Also let $g = [g_i, \forall i]$ and $g' = [g_i', \forall i]$

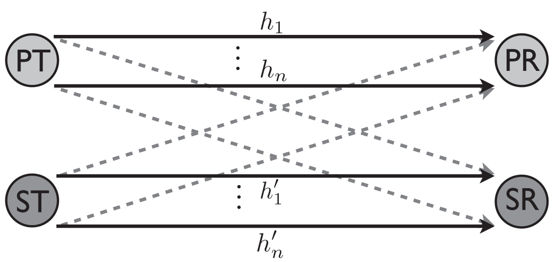

Fig. 1. The system model of a multicarrier cognitive radio network: solid lines are intended signals and dotted lines are interference. The primary transmitter (PT) transmits to the primary receiver (PR) over n subchannels $\mathbf{h} = \{h_1, \ldots, h_n\}$. The secondary transmitter (ST) transmits to the secondary receiver (SR).