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Power allocation for multiuser precoded OFDM cognitive radio

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ABSTRACT

The high sidelobe leakage from the transmitted signals in orthogonal frequency division multiplexing (OFDM)-based cognitive radio (CR) has always been a subject of concern, particularly when the OFDM-based CR users and the licensed primary users (PUs) coexist in adjacent frequency bands. Orthogonal precoding in OFDM-based CR systems is an effective spectral shaping technique that can significantly reduce this sidelobe leakage in adjacent PU band(s). In this paper, we propose an optimal power allocation scheme which is augmented with orthogonal precoding-based spectral shaping for multiuser OFDM CR systems. The precoding is realized on a user basis such that the transmitted multiuser OFDM signal and its first few derivatives become time-continuous. The objective of the proposed (precoded OFDM) optimal power allocation scheme is to maximize the downlink sum data rate of all users in the OFDM-based CR system, while the interference introduced to PUs is maintained below predefined thresholds and the transmit power of CR base station transmitter is kept within its power budget. Through simulation results, we demonstrate that the proposed precoded OFDM optimal power allocation scheme can deliver much higher sum data rate of CR users in comparison to the conventional (uncoded OFDM) optimal power allocation scheme and the precoded OFDM uniform power allocation scheme. Further, whereas the computational complexity of the precoded OFDM uniform power allocation scheme is the least, the proposed precoded OFDM optimal power allocation scheme has computational advantage over the conventional uncoded OFDM optimal power allocation scheme.

1. Introduction

With the rapid development of new wireless communication technologies and their applications, and the drastic increase in the number of users, there is a huge demand for more spectral resources. Whereas, most of the available radio spectrum has already been licensed as per the traditional static spectrum allocation policy, investigations show that large portions of this licensed radio spectrum remain highly underutilized or unused at a given time in a given region [1]. In this context, cognitive radio (CR) arises as a promising paradigm that has a great potential to improve the utilization efficiency of the radio spectrum [2]. CR users have the capability to sense the radio environment and opportunistically access the spectrum that is originally licensed to primary users (PUs), provided the interference caused to licensed PUs is kept below a specified threshold.

Orthogonal frequency division multiplexing (OFDM) has been recognized as an appropriate modulation scheme for CR systems because it meets most of the physical layer requirements of a CR system [3]. However, despite its numerous advantages, conventional OFDM suffers from high out-of-band radiated interference (OBRI) due to the sidelobes of sinc-shaped spectra on each subcarrier of the transmitted OFDM signal [4,5]. Consequently, in an overlay scenario, where the OFDM-based CR users and the PUs coexist side-by-side (in adjacent bands), the OBRI generated by the transmissions from OFDM-based CR system may significantly affect the performance of the PU system. Therefore, it becomes necessary to keep this OBRI below some tolerable interference thresholds of the PUs. Fortunately, there are techniques available in literature to shape the spectrum of the CR transmitted OFDM signal. These spectral shaping techniques, when employed at the OFDM CR transmitter, may help in reducing the OBRI inflicted on the PUs operating in adjacent bands.

We note that many spectral shaping techniques have been proposed in literature to protect PUs against OBRI. An overview of some of the existing OBRI reduction techniques is given in [6]. Time domain windowing is one of the traditional spectral shaping techniques, but has the drawback of increased OFDM symbol duration resulting in a reduced throughput of the CR system [5,7]. Adaptive symbol transition is another time domain spectral shaping technique wherein the OFDM symbols are extended (in time) adaptively to reduce the effect of symbol transitions, but has the limitation of decreased useful symbol energy [8]. Other approaches to OBRI reduction via spectral shaping include techniques like active interference cancellation (AIC) [9–13] and precoding

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techniques [14–18]. In AIC technique, a subset of reserved cancellation subcarriers is modulated appropriately to suppress the OBRI in adjacent bands. Although the AIC technique exhibits much better performance in terms of OBRI reduction, its computational complexity, the bit error rate (BER) performance and the peak-to-average-power ratio (PAPR) performance are of concerns.

Recently, because of their superior performances, the precoding techniques have attracted a great deal of attention. In precoding techniques, the vector of information symbols is mapped (using a data-independent precoding matrix) to a new vector of precoded symbols under some constraints. The projection precoder proposed in [14], results in a significant reduction of OBRI by nulling the spectrum of CR transmitted OFDM signal at carefully chosen frequencies in adjacent PU bands. However, it leads to degradation in BER performance of the system. In [15], a memoryless precoder that renders time continuity between successive OFDM symbols is proposed to reduce OBRI by projecting information symbols in a way that the Euclidean distance between the original information symbols and the precoded symbols is minimum. The precoder proposed in [16] keeps the OBRI below a prescribed radio frequency mask, and its BER performance is much better compared to the precoder in [14]. However, the precoder in [16] does not have a closed-form solution, and its performance can only be studied using numerical methods. The main advantage of the orthogonal precoder presented in [17] is that it does not affect the BER performance of the system. Although there is a slight reduction in system throughput, all benefits of the precoding operation are preserved. Based on the concept given in [17], the authors in [18] proposed a multiuser spectral precoding scheme that ensures independence among CR users (enabling the design of individual precoder for each CR user by nulling the spectrum at selected notched frequencies) and provides sufficient OBRI reduction. Further, since the precoding scheme in [18] is orthogonal, there is no loss in BER performance of the CR system. However, the computations involved in the execution of the given notched frequency selection algorithm adds to the overall complexity of the multiuser precoding scheme in [18].

As an another important issue, power allocation for OFDM-based CR systems has been studied extensively in the literature [19–25]. Most of these existing (conventional) power allocation strategies focus on enhancing the spectrum efficiency of the OFDM-based CR system while keeping the OBRI experienced by PUs below predefined interference thresholds (so that the performance of the PUs operating in adjacent bands is not affected). It is noted that the existing power allocation schemes do not consider any means for reducing OBRI. Consequently, by using these conventional power allocation schemes, an OFDM-based CR system may not be able to best harness its available power resources, since a higher OBRI may force the CR system to operate in an interference limited scenario. This suggests that a better utilization of the limited power budget may be achieved if the power allocation is augmented with some spectral shaping technique at the OFDM-based CR transmitter. However, it may be noted that, there is little work on power allocation augmented with spectral shaping for OFDM-based CR systems reported in the literature. Authors in [26] have studied joint spectral shaping and power control for OFDM-based CR systems with a constraint on total transmit power as well as the target signal-to-interference-plus-noise ratio (SINR) constraints corresponding to each symbol received at the CR receiver. However, this work does not consider any constraint on the interference (OBRI) introduced to PUs operating in adjacent frequency bands. Also, in this work, the spectral shaping is achieved by simply turning-off those OFDM subcarriers which are actively used by the licensed PUs. More recently, we have proposed optimal and suboptimal power allocation schemes augmented with spectral shaping for OFDM-based CR systems in [27,28]. However, in both these works, the system model is based on a single user OFDM-based CR system, and the spectral shaping is achieved via AIC technique. It is shown that the achievable transmission rate of the CR user improves significantly when power allocation is augmented with AIC-based spectral shaping. We find that power allocation in multiuser precoded OFDM (where spectral shaping is achieved through an appropriate precoding technique) CR systems is still largely unexplored, and needs to be investigated.

In this paper, we study the problem of power allocation for multiuser precoded OFDM CR systems and propose an optimal power allocation scheme that is augmented with precoding-based spectral shaping. The proposed scheme aims at maximizing the downlink sum data rate of all users in the OFDM-based CR system, while the interference introduced to PUs is maintained below some predefined interference thresholds and the transmit power of CR base station transmitter is kept within its power budget. The spectral shaping is achieved by applying an orthogonal precoding operation on the set of information symbols for each CR user such that the transmitted multiuser OFDM signal and its first few derivatives become time-continuous.

The key contributions of this work may be summarized as follows

- We consider the downlink of a multiuser OFDM-based CR system in our system model. Enlightened by the orthogonal multiplexing scheme given in [17], we develop a precoding technique for multiple OFDM-based CR users so as to reduce the interference (OBRI) caused to PUs operating in adjacent frequency bands. By constructing individual orthogonal precoders to render time continuity in the transmitted OFDM signal, we realize the precoding operation on an user basis.
- We formulate the power allocation problem that is augmented with precoding-based spectral shaping for multiuser OFDM CR systems.
- Assuming that the set of subcarriers assigned to each CR user is known at the CR base station transmitter through some subcarrier allocation algorithm, we propose an optimal power allocation scheme for multiuser precoded OFDM CR systems and investigate its performance. It is worthy to note that there are algorithms available in literature (e.g., in [20, 24]), which can be used to assign subcarriers to different CR users in a multiuser OFDM-based CR system. We further assume that the CR base station transmitter has the perfect knowledge of the channel fading coefficients between itself and each of the CR receivers, which may be acquired by assuming channel reciprocity [29,30] or can be estimated at the CR receivers and fed back to the CR base station transmitter perfectly [20]. We note that, because of this assumption of perfect channel fading coefficients knowledge at the CR base station transmitter, the obtained results by using our proposed (precoded OFDM) optimal power allocation scheme will serve as an upper bound on the achievable sum capacity with channel estimation errors.
- We compare the performance of the proposed (precoded OFDM) optimal power allocation scheme with the conventional (uncoded OFDM) optimal power allocation scheme on the basis of the achievable sum data rate of CR users as well as in terms of the computational complexities involved. Further, the performance of the proposed precoded OFDM optimal power allocation scheme is also compared to that of the uniform power allocation scheme for precoded OFDM-based CR systems.

Through simulation results, we demonstrate that the proposed precoded OFDM optimal power allocation scheme can deliver much higher sum data rate of CR users in comparison to the conventional uncoded OFDM optimal power allocation scheme and