SPECTRAL PRECODING TECHNIQUES FOR COGNITIVE RADIO SYSTEMS TO IMPROVE SPECTRUM UTILIZATION

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Abstract: Cognitive Radio (CR) is an, intelligent radio or system that automatically senses available channels in a wireless spectrum and change radio operating parameters enabling more communications to run concurrently and also improve radio operating behavior. CR system is allowed the unused spectra of the primary network under the condition of not imposing detrimental interference on the primary network. Two subspace-projection-based pre-coding schemes, namely, full projection (FP)- and partial-projection (PP)-based pre-coding are used in the primary system for a cognitive radio multiple input multiple- output (CR-MIMO) network to mitigate its interference to a primary time-division-duplexing (TDD) system. These schemes are capable of estimating interference channels between CR and primary networks through a novel sensing approach. We introduce an innovative approach called spectral pre-coding approach for multiple OFDM-based CR users to improve the spectrum efficiency. This technique helps to decrease the Out-of-band leakage and enhance spectrum compactness. By carefully selecting notched frequencies this approach can also improve bandwidth efficiency. Two simplified multiuser spectral pre-coding schemes are provided as a comprehensive application of the proposed approach, to reduce the computational complexity. These schemes effectively reduce the Out-of-band radiation and enable efficient spectrum sharing.

Keywords: Cognitive radio, Interference mitigation, Multiple input multiple output, Notched frequencies, Orthogonal frequency division multiplexing (OFDM), Out of band radiation, Spectral Recoding.

1. INTRODUCTION

Cognitive Radio Network consists of primary users (PUs) licensed to the spectrum, and secondary users (SUs) which access the spectrum opportunistically. Due to the characteristics of cognitive radio network, the study of throughput and delay scaling laws in cognitive radio network is challenging. Now a day as the number of wireless devices increases the radio spectrum is becoming scarce. But the assigned spectrum is not fully utilized. Therefore, with a opportunistic spectrum access together cognitive radio (CR) technology has become a solution to resolve this promising problem. Opportunistic spectrum access creates the opening of underutilized portions of the licensed spectrum for reuse, provided that the transmissions of secondary radios do not cause harmful interference to primary users. For secondary users to accurately detect and access the idle spectrum, CR has been proposed as an enabling technology.

Spectrum sharing is however challenging due to

uncertainty associated the with the aggregate interference in the network. Such uncertainty can be resulted from the unknown number of interferers and unknown locations of the interferers as well as channel fading, shadowing, and other uncertain environment-dependent conditions. Therefore, it is crucial to incorporate such uncertainty in the statistical interference model in order to quantify the effect of the cognitive network interference on the primary network system performance. A cognitive radio (CR) system may coexist with a primary network on an either interference-free or interferencetolerant basis. The CR system is allowed to share the spectra assigned to primary network under the condition of not imposing detrimental interference on the primary network. Therefore, the interference from the CR network to the primary system should be carefully managed and canceled in order to protect the operation of the primary system.

The perfect or partial channel state information (CSI) of CR interference channels to primary network

(CR-primary interference channels) is required at the CR transmitter (Tx) side to guarantee no/constrained interference to the primary system. Therefore, extra signaling between primary and CR networks is inevitable to obtain the channel state information, which jeopardizes the applicability of these beam forming and precoding schemes.

A more practical pre-coding scheme-sensing projection (SP)-based pre-coding, which learns the channel state information using subspace estimation and does not require a priori channel state information, has been proposed for a CR multipleinput multiple-output (MIMO) link coexisting with a primary time-division-duplexing (TDD) system. However, such a pre-coding scheme does not account for the interference from primary Txs to the CR receiver (Rx) (primary-CR interference), which leads to a CR throughput loss.

In order to improve bandwidth efficiency, Spectral precoding approaches is used to reduce OOB radiation significantly and are applicable to multiple users. The precoding matrix for these approaches is constructed from delicately designed basis sets or determined to render time continuity of adjacent OFDM symbols or spectrum nulls at notched frequencies. With a block diagonal precoding matrix, it is possible to ensure user independence. However, the correlative precoder, the projection precoder and the 1-continuous OFDM precoder are non-orthogonal and will cause significant bit-error rate (BER)² performance degradation when only a few subcarriers are available and utilized by CR users. Spectral precoding dealing with the above challenges in the multiuser CR system needs to be investigated.

2. LITERATURE SURVEY

[1] studies a downlink CR network where there are multiple primary users and secondary users occupying the same spectrum and a multi-antenna SU transmitter is communicating with multiple singleantenna SUs. It is aim to obtain the optimal robust beam forming solutions for maximizing the minimum of the SUs' SINRs, which is subjected to the constraints of the overall secondary user transmit power and the received interference power at the PUs, by exploiting CSI at the SU transmitter with its errors modeled by an ellipsoidal region in either channel matrices or channel covariance matrices. [2] Aims to maximize the service probability of the SU while controlling the interference levels to the primary user based on some preset probability constraints by optimizing the beam forming at the secondary user transmitter in accordance with imperfect CSI. The construction of the problem facilitates a soft tradeoff on the performance between the primary user and the secondary user, offering an analytical connection between a selfish non-robust secondary system and the conservative worst- case robust SU solution.

In [3], a single secondary user spectrum sharing based CR communication scenario, in which the secondary user uses a multiple-input single-output (MISO) channel and the primary user has one receive antenna is considered. Here assume that the channel state information (CSI) about the SU link is perfectly known at the SU transmitter (SU- Tx). However, due to less cooperation between the secondary user and the PU, only the mean and covariance of the channel between the SU-Tx and the primary user are available at the SU-Tx. With this set of channel state information, design objective is, for a given transmit power constraint, to determine the transmit signal covariance matrix that maximizes the rate of the SU while keeping the interference power to the PU below a threshold for all the possible channel realizations within an uncertainty set.

3. EXISTING METHOD

In the existing system, in order to reduce the interference two enhanced SP-based pre-coding schemes, namely, full-projection (FP)- and partialprojection (PP)- based pre-coding, are present for CR MIMO systems by incorporating the primary-CR interference. However perfect or partial channel state information (CSI) of CR interference channels to primary network (CR-primary interference channels) is required at the CR transmitter (Tx) side to guarantee no/constrained interference to the primary system. Therefore, extra signaling between primary and CR networks is inevitable to obtain the CSI, which jeopardizes the applicability of these beam forming and pre-coding schemes. A more practical pre-coding scheme sensing projection (SP)-based precoding, which learns the CSI using subspace estimation and does not require a priori CSI, has been proposed for a CR multiple- input multiple-output (MIMO) link coexisting with a primary timedivision-duplexing (TDD) system. The FP- based scheme nulls the CR transmission by fully projecting the transmission onto the estimated null space of the CR- primary interference channels. Instead of removing the primary-CR interference using nullspace Rx beam forming, the proposed pre-coding schemes account for the primary-CR interference via sensing. This, on one hand, improves the CR throughput, and on the other hand, introduces more flexibility into the CR deployment, i.e., the CR network does not have to work in a TDD mode. The PP-based pre-coding can further improve the CR throughput by projecting the CR transmission onto a subspace that partially spans the estimated null space of the CR-primary interference channels. As a result, the CR throughput is further improved at the cost of introducing extra interference to the primary network.

4. PROPOSED METHOD

In the proposed system, in order to improve the spectral pre-coding method is used. In this method a spectral pre-coding approaches for multiple OFDMbased CR users. Orthogonal frequency-division multiplexing (OFDM) is an attractive transmission technique for CR systems because it can turn off tones flexibly to avoid conflicts with licensed user activities and adapt to radio spectrum environment and available frequency resources. Furthermore, with orthogonal frequency-division multiple access (OFDMA) as the multiple access technique, CR users can utilize non-adjacent sub-bands by dynamic spectrum aggregation and support high data rate Although in-band interference is applications. avoided, out-of-band (OOB) leakage still exists, which affects the operation of licensed users in the adjacent bands. While OOB leakage cannot be completely eliminated, guard bands are usually required. In this method by constructing individual precoders to render selected spectrum nulls, this approach ensures user independence and provides sufficient OOB radiation suppression with low complexity. Meanwhile, no BER performance loss is introduced since orthogonal precoding matrix is used. Furthermore, our approach can improve bandwidth efficiency by carefully selecting notched frequencies.

4.1 OFDM system model

Consider the K-OFDM based CR users opportunistically

utilize part of the licensed spectrum identified via spectrum sensing as unoccupied by any licensed user. The utilized spectrum, either continuous or noncontiguous in frequency, such as the two portions marked to be with CR signal. The CR signal is divided into a set of N subcarriers $N=\{n_0, n_1...n_{N-1}\}$.

The Kth CR user $0 \le k \le K - 1$ utilizes a subset of subcarriers $N_k CN$ Where $N_k = \{n_0^k, n_1^k, n_{Nk-1}^k \text{ consists of N assume that each subcarrier is used by one CR user at a time, i.e., <math>N_k \cap N'_k \ne \emptyset$ for $k \ne k'$ and $U_{k=0}^{k-1}N_k = N$.Let

denote the transmitted symbol over the nth subcarrier. The downlink baseband OFDM signal within one symbol duration can be expressed as. $S t = {}_{n \in N} d_n e^{j2\pi \frac{n}{T_s} t I(t)}$ Where T_s is the effective symbol duration, and I(t) is an indicator function. For rectangular pulse shaping, we have. subcarriers. То minimize inter-user interference, we $I \ t = \{ \begin{matrix} 1, & -T_g \le t \le T_s \\ 0 & otherwise \end{matrix}$ when a cyclic prefix with to eliminate possible ISI and length is inserted reduce the sensitivity to synchronization. The Fourier transform of the OFDM signal can be expressed as. $S f = _{n \in \mathbb{N}} d_n a_n(f)$ The power spectrum density (PSD) of the OFDM signal is $P f = \frac{1}{r}E |S f|^2 = \frac{1}{r}a^T f E dd^H a^* f$,



Figure 1: Block Diagram of Proposed System

4.2 Spectral Precoding method

To suppress the OOB radiation of the OFDM signal from the CR system to licensed users, we should ideally minimize the overall emitted power in the adjacent bands over an optimization frequency range, which makes it difficult to determine the optimal spectral pre-coding coefficients. Instead, we consider suppressing the sum of the PSDs at a few frequencies selected in the adjacent bands. And we will show later that together with proper selection of the notched frequencies, the PSD of the CR user signal can be rendered under the spectral mask in the adjacent bands. To design individual spectral precoders independently, we select $f_1, l = 0, 1, ... L_K - 1$ to be the notched frequencies for the kth user. Specifically, we have $min_{GK} ||A_k G_k||_2$,

 G_k Should Satisfy, $G_k^H G_k = I_{M_k}$

Let the singular-value decomposition (SVD) of A_k be $A_k = U_k \ _k V_k^H$, Where is an unitary matrix, is an diagonal matrix with singular values, $\sigma_0, \sigma_1, \dots, \sigma_{\min \ L_k N_k} - 1$ in descending order on the diagonal, and V_k is an $N_k X N_k$ unitary matrix. Denote the last M_k columns of V_k corresponding to the smallest M_k singular values. Then the optimal spectral precoding matrix is computed as, $G_k = -[V_k^{(N_k-M_k)}]V_k^{N_k-M_k+1}$

The best suppression of the sum of PSDs at the selected frequencies is achieved and the corresponding coding rate of the spectral precoder for the kth user is,

$$\lambda_k = 1 - \frac{L_k}{N_k}.$$

And the overall coding rate for all the K users is

$$\lambda = 1 - \frac{\sum_{k=0}^{K-1} L_k}{N}$$

To recover the information symbols at the receiver, a decoder is needed to revert the spectral precoding operation. After FFT and frequency domain channel equalization, the receiver of the kth user obtains. Therefore, the individual decoder can be simply realized as,

$$\mathfrak{b}_k = G_k^H \mathfrak{d}_k$$

to recover the information symbols, which is essentially a zero-forcing equalizer. If SNR information is available at the receiver, a minimum mean-square error (MMSE) equalizer can be similarly applied as the decoder to minimize the error in the presence of noise.

4.3Selection of notched frequencies

When the number of utilized subcarriers is determined based on the available spectrum, we focus on the case that the number of information symbols in an OFDM symbol of the CR user is equal to the difference between the number of its utilized subcarriers and the number of notched frequencies, In this case, the best suppression of the sum of the PSDs at the selected frequencies is achieved. Since the overall system throughput will decrease when the number of notched frequencies, increases, it is preferable to reduce the number of notched frequencies and improve the bandwidth efficiency. The notched frequency selection algorithm can be summarized in the following:

- Initialize: $q=0, M_k=N_k$ and $G_k^{(0)}=I_{NK}$
- Evaluate the PSD of the user signal with

$$P^{a} f = \frac{1}{T} a_{k}^{T}(f) G_{k}^{q} G_{k}^{H} a_{k}^{*}(f)$$

• If the PSD is fully under the spectral mask, stop; if the PSD exceeds the spectral mask on the left side of the sub band, choose a pair of notched frequencies at the first violating point closest to the left edge of the sub band;

if the PSD exceeds the spectral mask on the right side of the sub band, choose a pair of notched frequencies at the first violating point closest to the right edge of the sub band

- Set q=q+1
- Update M_k and determine A_k based on the current selection of notched frequencies
- Compute the precoding matrix $G_k^{(q)}$
- Go back to step 2

For each side of the utilized sub band, one pair of notched frequencies can be placed near the edge so that the OOB radiation will drop quickly under the spectral mask, which can be computed by finding the violating point closest to the edge of the sub band in the first iteration of the above algorithm. Specifically, the pair is around f_1 such that $p^{(o)}f_l = n_f$ where n_f l_i represents the spectral mask requirement at f_{li} . Let d denote the bandwidth of the sub band. Then the other pair should be placed d/Q away from the edge so that the OOB radiation will not grow over the spectral mask, where Q is a design parameter depending on the PSD and can be computed by finding the violating point closest to the edge of the sub band in the

4.4 Multiuser spectral Precoding scheme

second iteration of the above algorithm.

In this scheme, spectral precoding maps the

information symbols of a user onto a group of subcarriers with the same precoding matrix. In this way, the users do not need to compute the precoding matrix repeatedly if some switch their groups of subcarriers due to channel state change and dynamic resource allocation. To suppress the sum of the PSDs at L frequencies selected in the adjacent bands, we formulate the following optimization problem,

 $\min_{G_o} ||A \operatorname{diag}(G_0, G_0, \ldots)||_2 G_o^H G_o = I_{M_o},$

Is an LXN matrix and G_o is an N_oXM_o matrix. Let the SVD of A be, $A = U \in V^H$

Where $^{\circ}U$ is a KL \times KL unitary matrix, \in is a KLX N_o diagonal matrix with singular values on the diagonal and, v N_oXN_o is unitary matrix.

5. SIMULATION RESULTS

Consider a scenario where a CR MIMO system coexists with a primary TDD system which has one 2- antenna BS and two single-antenna users. We assume that the number of antennas for primary users is known to the CR system. Each CR node is equipped with four antennas. The primary network works as a downlink- broadcast and an uplink multipleaccess system



Figure 2: BER for BPSK and QAM using OFDM for 1st user.

This graph shows that the Bit error ratio. In the X-axis is taken. The Bit error ratio is compared for the QPSK (Quadrature pulse shift keying) and QAM (Quadrature Amplitude Modulation) scheme. When compared to the QAM scheme, in the QPSK there is

less bit error ratio.



Figure 3: BER for BPSK and QAM using OFDM for 2nd user.

This graph shows the Bit error ratio for the second user with different spectral precoding schemes using QPSK and 16QAM without channel coding under additive white Gaussian noise (AWGN).



Figure 4: BER for BPSK and QAM using OFDM for 3rd user

This graph shows that the Bit error ratio for the third user. In the X-axis is taken. The Bit error ratio is compared for the QPSK (Quadrature pulse shift keying) and QAM (Quadrature Amplitude Modulation) scheme.



Figure 5: BER for BPSK and QAM using OFDM for 4th user

Eh/No_dE

This graph shows that the Bit error ratio for the fourth user. In the X-axis is taken. The Bit error ratio is compared for the QPSK (Quadrature pulse shift keying) and QAM (Quadrature Amplitude Modulation) scheme. When compared to the QAM scheme in the QPSK there is less bit error ratio. The BER performance of User 4 with different spectral precoding schemes using QPSK and 16QAM without channel coding under additive white Gaussian noise (AWGN) is shown in the graph. It can be noticed that the proposed spectral precoding scheme never introduces any BER performance loss to the OFDM system because of orthogonal precoding.





This graph shows that the power spectral density. The power spectral density is compared for the different users. The PSD curves are well below the spectral mask. Therefore suppression of OOB radiation is achieved taken.



Figure 7: BER comparison

The BER performance of existing system and proposed system are shown in the graph. The Projection precoder has significant BER performance loss. It can be noticed that the proposed spectral precoding scheme never introduces any BER performance loss to the OFDM system because of orthogonal precoding. But both the projection precoder and 1-continuous OFDM precoder bring significant BER performance loss in such a case.

6. CONCLUSION AND FUTURE ENCHANCEMENT.

The two sensing projection-based pre-coding schemes, namely, fully projection (FP) and partial projection (PP) pre-coding have been projected for cognitive radio MIMO systems to diminish the cognitive radio-primary interference and develop the cognitive radio (CR) throughput. These two pre-coding schemes are able of estimating the channel state information of primary-cognitive radio interference channels and can account for the primary-cognitive radio interference via a novel sensing approach. Therefore, no extra signaling is required between primary and cognitive radio (CR) systems, which consequently ease the deployment of cognitive radio networks. The performance of the proposed precoding schemes has also been evaluated. It has been demonstrated that the fully projection pre-coding can

boost the cognitive radio throughput without introducing extra cognitive radio-primary interference in the low INR regime. The partial projection precoding can further improve the CR throughput if the primary system can tolerate some extra interference. In the proposed system, a spectral pre-coding approaches for multiple OFDM-based cognitive radio users to reduce Out-of-band leakage and enhance spectrum compactness.

For future work we can study the resource allocation in OFDM-based cognitive radio (CR) networks, under the consideration of many practical limitations such as imperfect spectrum sensing, limited transmission power, different traffic demands of secondary users, etc. For the first step, we perform sub channel allocation to satisfy heterogeneous users' rate requirement roughly and remove the integer constraints of the optimization problem.

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