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Multiple-Input/Multiple-Output (MIMO) Systems Using Cognitive Radio Frequency : A Review

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ABSTRACT

Multiple-input/multiple-output (MIMO) systems have a great potential to enhance the throughput in the framework of wireless cellular networks. In fact, when using M transmit antennas at the base station and N receive antennas at the mobile user, the capacity of a MIMO single user is equal to min{M,N} times the capacity of a single input/single-output (SISO) system. In the research work I have studied the different problems that are the optimization problem that is occurred during the transmission of data. The second problem is the complexity problem on multiple cognitive base station and PU. Other problems such as to interference channel scenario with multiple CBSs and PUs are of interest that is reviewed in the previous research work. These are resolved with the help of the interference channel scenario with multiple CBSs and PUs with channel state information at the transmitter.

Keywords : MIMO, SISO, PU, CBS.

I. INTRODUCTION

Dynamic spectrum access (DSA) is emerging as a promising solution to enable better utilization of the radio spectrum, by admitting more devices into underutilized frequency bands [1]. DSA categorizes wireless terminals as primary (licensed) users (PUs) and secondary users (SUs), where PUs have priority in accessing the shared spectrum. The underlay cognitive paradigm usually mandates that concurrent secondary and primary transmissions may occur only if interference at the PUs due to SUs is below some acceptable threshold [1]. Previous DSA work, like [2]-[4], generally considers single antenna SUs and assumes some knowledge of the channel state information at the transmitter (CSIT) from the cognitive base station (CBS) to the PU receiver (PU RX). In [5],single-antenna SUs were scheduled over multiple bands by the multi-antenna CBS based on graph theory. In [6], closed-form asymptotic average symbol error probabilities were derived for amplify and-forward (AF) dual-hop wireless networks with partial relay selection. In [7], a cognitive AF relay network with link selection according to destination signal-to-noise ratios (SNRs) was studied. In this work, we consider a general multiple-input multiple-output (MIMO) cognitive broadcast channel where the CBS, SUs, primary user transmitter (PU TX), and PU RX are all equipped with multiple antennas, and we also consider the novel scenario of completely unknown PU CSIT at the CBS for the channel from the CBS to the PU RX. The main contributions of this include the following:

- When CSIT from the CBS to the PU RX is perfectly or partially known to the CBS, we propose two computationally efficient SU selection schemes, and show their applications for both best-effort PU interference mitigation under hard interference temperature (IT) constraints[3].
- When CSIT from the CBS to the PU RX is completely unknown to the CBS, we propose two computationally efficient SU selection schemes based on modified spatial water-filling methods. To our best knowledge this scenario has not been considered previously in cognitive radio (CR) user selection[4].

Notation: Uppercase and lowercase boldface letters denote matrices and vectors, respectively; |A|F denotes the Frobenius norm of matrix A; AH is the conjugate transpose of matrix A; |A| is the cardinality of the set A, and CN (0;Z) is a complex Gaussian random vector with zero mean and covariance matrix Z[6].

Cognitive radio (CR) is a promising solution for efficient utilization of radio resources. The main idea of cognitive radio is to allow a class of radio devices, called secondary users (SUs), to opportunistically access certain portions of spectrum, called white spaces, that are not occupied by licensed users [1]. The white space can be associated with a specific frequency carrier, time slot, or spatial direction [2]. In applications where the primary link occupies entire frequency band and is intensively active, an efficient way to improve the spectrum efficiency is to explore the white spaces in spatial domain. Moreover, the performance of the network in such cases can be significantly boosted if a large number of SUs are in presence. Some SUs can be opportunistically selected to obtain the multi-user diversity gain [3]. In general, the selection of SUs is under one of the following two principles: 1. the SUs who generate minimum interference on primary receiver (PR) are selected [4]; 2. the SUs who achieve the highest throughput for the secondary network are selected, while keeping the interference on PR under certain constraints [5–8]. In [4], an opportunistic spatial orthogonalization scheme was proposed for the CR network where there exists multiple point-to point secondary links. One or several secondary links whose interference channels are most orthogonal to the primary link's channel are selected. In [5], the secondary network is a SIMO multiple access channel (MAC). Combining user selection with power allocation, an optimization problem is formulated to maximize the sum rate of secondary network. In [6], at first each ST adjusts its power so that the interference generated on PR is within a certain interference temperature constraint. Then, the secondary link with the highest signal to-interference-plus-noise-ratio (SINR) is selected. [6] showed that with sufficiently large power on each ST, multiuser diversity gain can be obtained. [7] investigated the multiuser diversity gain of the cognitive radio network where the secondary networks are multiple access channel, broadcast channel and parallel channels, respectively. In [8], a two-stage user scheduling scheme was proposed for a downlink secondary network. At first, SUs whose channels are nearly orthogonal to the primary link channel are selected so as to minimize the interference on PR. Then, some SUs whose channels are nearly orthogonal to each other are scheduled. In [9], both primary link and secondary link are point-to-point MIMO channels, and the signals of secondary link are opportunistically aligned on the unused spatial dimensions of primary link. This work is extended to multiple secondary links in [10]. In [11], a two-cell uplink network was studied, where an opportunistic interference alignment (OIA) scheme was proposed to achieve optimal degrees of freedom. [12] introduced the OIA scheme for multi-cell uplink networks where each user is equipped with single antenna. The OIA was later extended to multiple-antenna case in [13]. Further, the multiuser diversity gain of OIA schemes in multi-cell uplink network was analyzed in [4] and [5] in terms of degrees of freedom and sum rate, respectively. In this paper, we investigate the CR network in which the secondary link is a multi-user uplink MIMO network. Each SU has independent message intended to the secondary receiver (SR). The primary system is a point-to-point MIMO, whose capacity is maximized by implementing a water-filling power allocation scheme. As some spatial directions (SDs) are left unused by primary users, the signals from SUs could be aligned on the unused SDs as much as possible. A two-stage opportunistic user scheduling scheme is proposed, which enables the secondary link to take advantage of multiuser diversity while ensuring that the interference of primary link is under a certain threshold. Specifically, we first select some SUs that cause the interference at primary receiver (PR) less than a predetermined threshold. These pre-selected SUs are referred to as candidate users. In the second stage, Ns users are selected from the candidate users according to semi-orthogonal user selection (SUS) algorithm [6, 7] to transmit signals to SR, where Ns denotes the number of antennas on SR. It is shown that with large K, (the total number of SUs) the sum rate of secondary link scales as Ns log log K, i.e., the multiuser diversity gain can be obtained. Meanwhile, the interference caused on the primary link is constrained below a preset threshold.

Multiple-input/multiple-output (MIMO) systems have a great potential to enhance the throughput in the framework of wireless cellular networks [6], [7]. In fact, when using M transmit antennas at the base station and N receive antennas at the mobile user, the capacity of a MIMO single user is equal to min{M,N} times the capacity of a single input/single-output (SISO) system

[6],[7]. Multiple antennas can be applied to achieve many desirable goals for wireless communications, such as capacity increase without bandwidth expansion, transmission reliability enhancement via space-time coding, and co-channel interference suppression for multi-user transmission. By using multiple antennas in CR, one can allocate transmit dimensions in space and hence can obtain much design benefits to the MIMO cognitive network. In particular, we can obtain high spatial multiplexing gain by sending independent information streams over any transmit receive antenna pair simultaneously to increase the system throughput of the cognitive radio system [8]. Moreover, multiuser interference can be suppressed by applying transmit beam forming [9]. Multiple antennas can be usually deployed at the base station, but they cannot be used easily at the mobile terminals due to the size and cost constraints. This may limit the capacity of the system when a limited number of antennas at the receivers is considered. The problem can be addressed by serving multiple users with single antennas simultaneously, and in this case, the system can be viewed as a virtual MIMO system.

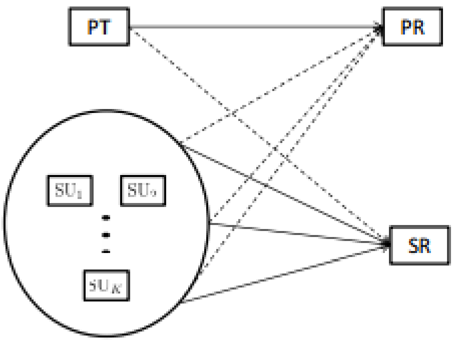

Figure 1. The cognitive radio network where the primary link is a point-to-point MIMO channel and the secondary link is a multi-user MIMO uplink with K secondary users.

II. MIMO WIRELESS COMMUNICATIONS

The biggest challenge for a reliable wireless communication system is to combat multipath fading. Spatial diversity introduced by deploying multiple antennas at the transmitter and/or the receiver is an effective technique to overcome the fading effect. In addition to reliability improvement through diversity, a MIMO system can also increase system throughput by transmitting multiple data streams. The result of improved reliability and/or throughput [3] is enhanced spectral efficiency and higher channel capacity. The information-theoretic foundation of MIMO systems was laid out by Foschini, Gans, and Telatar [2,4], who have shown that multiple antennas at the transmitter and the receiver provide significant capacity enhancement over single-antenna systems. To exploit MIMO channel capacity, space-time coding has been designed to achieve a specific tradeoff between diversity and multiplexing.

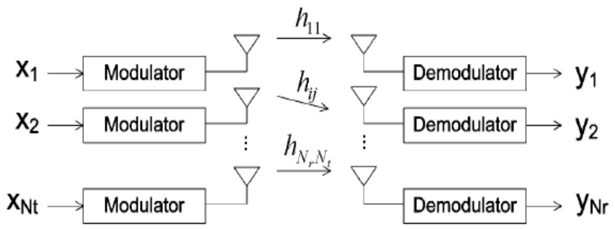

Figure 2: Diagram of a MIMO system

III. TRANSMITTER DESIGN WITH PARTIAL CSI

As shown in Fig. 1.3, the downlink transmitter receives partial CSI feedback f' from the receiver. The true channel matrix, which the transmitter does not fully know, can be modeled as a Gaussian random matrix (or vector) whose mean and covariance is given in the feedback. This section reviews the design of the optimal transmitter in a MISO channel, described in (4), where the transmitter knows that the channel vector is distributed as CN (μ, ∑).

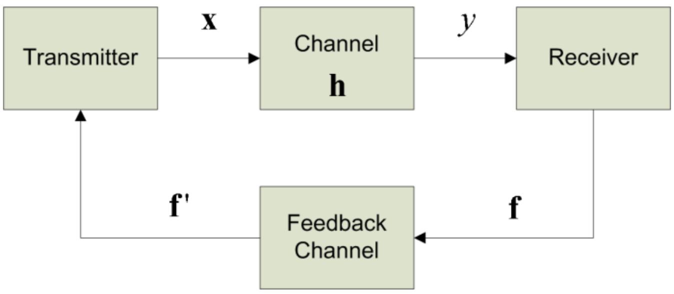

Figure 3: Feedback system model

The problem is, for h ~CN(μ,∑), to find the input distribution p(x) that maximizes the mutual information between x and y, subject to a power constraint Ekxk2 ≤ P. For the case of a fixed channel, the optimal input distribution is zero-mean Gaussian. The optimization problem is now one of finding the optimal choice of covariance matrix Q of x maximizing the mutual information between x and y averaged over h with power constraint P:

$$\max_{\boldsymbol{Q},\mathrm{trace}(\boldsymbol{Q})=P} E_{\boldsymbol{h}} \log\left(1+\frac{\boldsymbol{hQh}^H}{\sigma^2}\right),$$

where E_h denotes expectation with regard to the distribution of h. The transmission strategy is completely characterized by the covariance matrix Q. The strategy consists of transmitting independent complex Gaussian symbols along the directions specified by the eigenvectors of Q, with the corresponding eigen values specifying the powers allocated to each direction.

Acquisition of Partial CSI at the Transmitter

When the wireless channel is not reciprocal, i.e., when the uplink and downlink channels cannot be inferred from each other, as is the case in FDD, the receiver needs to feedback the downlink channel to the transmitter. Because the feedback channel is a scarce resource, the receiver needs to find an efficient way to represent the channel. Basically, this is a quantization problem. The difference from traditional quantization problems is that the distortion measure here is not mean-square error but the capacity penalty resulting from using non-perfect CSI instead of perfect CSI at the transmitter. We review the channel quantization schemes in the literature. Without loss of generality, we consider i.i.d. MIMO Rayleigh flat-fading channels.

IV. LITERATURE SURVEY

Karama Hamdi et.al. [2009] have studied cognitive users whose channels are nearly orthogonal to the primary user channel are pre-selected so as to minimize the interference to the primary user. Then, *M* best cognitive users, whose channels are mutually near orthogonal to each other, are scheduled from the preselected cognitive users. A lower bound of the proposed cognitive system capacity is derived. It is then shown that opportunistic spectrum sharing approach can be extended to the multiple input/multiple-output (MIMO) case, where a receive antenna selection is utilized in order to further reduce the computational and feedback complexity. Simulation results show that our proposed approach is able to achieve a high sum-rate throughput, with affordable complexity, when considering either single or multiple antennas at the cognitive mobile terminals.[1]

Lu Yang et.al. [2014] have studied multiuser diversity of uplink MIMO cognitive radio network and proposes a two-stage opportunistic user scheduling scheme. In the first stage, a cognitive beam forming design is proposed to ensure the interference caused by secondary signals is canceled or minimized on the spatial dimensions occupied by primary MIMO system. Then, some secondary users that cause minimal interference leakage at primary system are pre-selected as candidate users. In the second stage, some candidate users that produce maximum sum secondary rate are further selected for uplink scheduling. The proposed scheme enables the secondary link to take advantage of multiuser diversity while ensuring that the interference on primary link is within a certain threshold. Analytical results show that the sum rate of secondary uplink scales as *Ns* log log*K* for *K* secondary users and *Ns* antennas on secondary receiver for very large *K*.[2]

Wenhao Xiong et.al. [2015] have studied user selection strategies for downlink of multiple input and multiple output (MIMO) cognitive radio (CR) network. Underlay CR secondary users (SUs) are selected by cognitive base station (CBS) to share sub channel with primary users (PUs). It is assumed that the cross interference channel from cognitive radio base station to PUs is not known. CBS select underlay SUs based on the knowledge of SUs transmission channels in order to reduce the interference from base station to PUs. We propose and evaluate user selection schemes with low computational complexity and best-effort interference mitigation to PUs.[3]

Duoying Zhang et.al. [2016] have studied the spectrum sharing multiple-input multiple-output (MIMO) cognitive interference channel, in which multiple primary users (PUs) coexist with multiple secondary users (SUs). Interference alignment (IA) approach is introduced that guarantees that secondary users access the licensed spectrum without causing harmful interference to the PUs. A rank constrained beam forming design is proposed where the rank of the interferences and the desired signals is concerned. The standard interferences metric for the primary link, that is, *interference temperature*, is investigated and redesigned. The work provides a further improvement that optimizes the dimension of the interferences in the cognitive interference channel, instead of the power of the interference leakage. Due to the non convexity of the rank, the developed optimization problems are further approximated as convex form and are solved via choosing the transmitter precoder and receiver subspace iteratively. Numerical results show that the proposed designs can improve the achievable degree of freedom (DoF) of the primary links and provide the considerable sum rate for both secondary and primary transmissions under the rank constraints. [4].

Wenhao Xiong et.al. [2016] have studied user selection strategies for a multiple-input multiple-output (MIMO) cognitive radio (CR) downlink network, where the r-antenna underlay CR secondary users (SUs) coexist with a primary user (PU), and all terminals are equipped with multiple antennas. Two main scenarios are considered: (1) the t-antenna cognitive base station (CBS) has perfect or partial channel state information at the transmitter (CSIT) from the CBS to the PU receiver (RX), and (2) the CBS has absolutely no PU CSIT. For these scenarios, we propose and evaluate multiple SU selection schemes that are applicable to both best-effort PU interference mitigation and hard interference temperature constraints. The computational complexity of the proposed schemes can be significantly smaller than that of an exhaustive search with negligible performance degradation. For the selection of C SUs out of K candidates, They proposed sliding window scheme for example is of complexity O(Krt2), whereas an exhaustive search is of the order of O(K_CC4r3). When t and r are of the same order, the computational complexity of the proposed scheme can be K_C C4=K times smaller. Mathematical complexity analysis and numerical simulations are provided to show the advantage of our schemes.[5]

V. PROBLEM FORMULATION

In the research work I have studied the different problems that are given below:

- The first problem is the optimization problem that is occurred during the transmission of data.
- The second problem is the complexity problem on multiple cognitive base station and PU.
- Other problems such as to interference channel scenario with multiple CBSs and PUs are of interest.
- There is primary and secondary cognitive base station and User problem.
- Other problem is the transmission rank problem on multiple users.

VI. RESEARCH METHODOLOGY

The research work Consider a downlink MIMO CR network with a t-antenna CBS, a set K comprising K SUs with r multiple antennas each, and a PU with rp receive antennas as well as tp transmit antennas. Fig. 4.1 shows a block diagram of the system model considered. The assumption is that we can have multiple primary transmitter-receiver pairs, as shown in Fig. 4.1, but each PU pair uses different carrier frequencies, and the PU TX and PU RX are not co-located. A PU RX only receives and does not transmit. Interference from the CBS to another primary user receiver, say PU0 RX, and interference from the PU0 TX to the desirable SU RXs will be negligible because of different carriers. Hence, we focus on only a single pair of PU TX and PU RX.

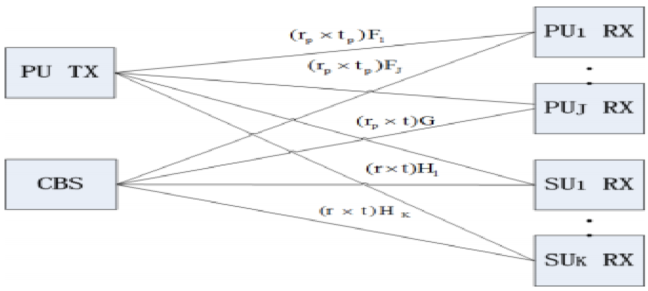

Figure 4. System Model

The CBS selects C out of K total SUs for simultaneous downlink transmission. The CBS transmit signal and the received signal at SUk can be written, respectively, as

$$\mathbf{x}_s = \sum_{j=1}^{C} \mathbf{W}_j \mathbf{u}_j, \text{ and}$$

$$\mathbf{y}_k = \mathbf{H}_k \mathbf{x}_s + \mathbf{n}_k = \mathbf{H}_k \mathbf{W}_k \mathbf{u}_k + \sum_{j=1, j \neq k}^{C} \mathbf{H}_k \mathbf{W}_j \mathbf{u}_j + \mathbf{n}_k$$

where Wk 2 Ct_lk is the linear precoding matrix, Hk is the (r t) complex channel matrix from the CBS to the kth SU RX with i.e. CN (0; 1) components, uk the (lk_1) is desired signal vector with E ukuHk = Ilk , and nkCN (0;Zk) is a colored additive Gaussian noise vector including interference from the PU TX.

VII. CONCLUSION

Dynamic spectrum access (DSA) is emerging as a promising solution to enable better utilization of the radio spectrum, by admitting more devices into underutilized frequency bands. DSA categorizes wireless terminals as primary (licensed) users (PUs) and secondary users (SUs), where PUs have priority in accessing the shared spectrum. In this paper I have studied in the previous work. It is implemented in the future with the help of Multiple CBS and multiple PU and SU .

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