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Precoding design for interference mitigation in cognitive radio networks based on matrix distance☆

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ABSTRACT

In this paper, we present two novel interference management stratagems for coexisting one primary user (PU) and multiple secondary users (SUs) by exploiting the unused spatial directions at PU. The cognitive stations sense their environment to determine the users they are interfering with, and adapt to it by designing the corresponding precoders using interference alignment (IA) in order to avoid causing performance degradation to nearby PU and SUs. The first proposed approach judiciously designs the set of precoders based on an improved version of minimum weighted leakage interference algorithm. However, there are still leftover interference signals in SUs' desired signal space due to the limited iterative times in the first algorithm. To tackle this problem, another scheme combining the first one and power allocation method at the secondary stations is developed. Numerical results validate the effectiveness of the proposed algorithms.

1. Introduction

With the demands for high speed data communication and more bandwidth growing rapidly, the radio resource becomes a major problem which makes further improvement of wireless network's performance difficult. The cognitive radio (CR) concept [1] has been proposed to mitigate this spectrum crunch by relaxing the traditional fixed spectrum regulation and exploiting unused licensed spectrum bands that do not degrade the performance of the primary system. Various techniques have been provided to ensure that licensed and unlicensed users can share the radio resource. The design of CR networks mainly focuses on the secondary network since the goal is to increase spectrum efficiency without affecting the operation at the primary network [2]. There are two popular spectrum sharing schemes. The first one (spectrum underlay) allows the PUs and SUs access to the same channel simultaneously while constraining the transmitted power of secondary users so that it can be treated as background noise at primary users without exceeding the primary users noise floor. In the second scheme (spectrum overlay) secondary users need to detect spectrum holes and then access spectrum white space in a nonintrusive way [3]. As research goes deep, recognition of spectrum opportunity becomes rich. Communication opportunity exploited in multiple dimension is an important field. The availability of spectrum resource benefits from the application of multiple-input multiple output (MIMO) techniques [4]. So, the cognitive transmission which is considered as interference by primary user should lie in the subspace orthogonal to the useful signal space of the primary link. IA employs the above concepts.

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IA aims to allow coordinated transmission and reception in order to increase the total degree of freedom (DoF) of the network. IA generates overlapping user signal spaces occupied by undesired interference while keeping the desired signal spaces distinct [5]. Cadambe and Jafar introduced the idea of IA for K-user interference channel in [5]. They show that IA achieves the maximum multiplexing gain in a K-user interference channel such that nodes sharing the same interference channel can achieve rates equal to one half of their corresponding interference-free rates. For case of generic channel coefficients, significant progress has been made in relating the feasibility of a system of interference alignment to the properness of the related system of linear equations [6].

In order to obtain IA, various numerical algorithms that both compute the IA precoding and receive filter have been provided in [7–11]. In [7] an algorithm, based on the idea of IA introduced in [5], was proposed which strives to minimize the interference spill outside the interference subspace, resulting in low dimensional subspace spanned by interference signal. A similar algorithm without the reciprocity assumption was introduced in [8]. In [9] an extension of the algorithm in [8] was developed that achieved better sum rate performance. In order to maximize the available DoF, a rank constrained rank minimization algorithm (RCRM) has been introduced recently, where the rank of the subspace spanned by interference signals is minimized subjected to full rank signal space [10]. In [11] an algorithm similar to max-signal-to-interference-plus-noise ratio (SINR) algorithm is proposed that seeks to minimize the sum mean square error (MSE) of all the receivers. The MSE algorithm is slightly complicated since the Lagrange multipliers need to be computed to design the transmit precoders. Due to natural signal separation between the interference and the desired information in K-user interference channel, the IA method naturally applies itself to CR networks where the main goal is to suppress the interference to the primary link. However, its expansion to CR networks may not be an easy straightforward task.

In this paper, we present opportunistic spectrum usage of one primary link operating under the IA scheme. The primary link is modeled by a single-user MIMO channel since it must operate free of any additional interference produced by secondary systems. Then, assuming perfect CSI at transmitter and receiver ends, capacity is achieved by implementing a water-filling power allocation [22] over the spatial directions associated with singular values of its channel matrix. Interestingly, even if the primary transmitters maximize their transmission rates, power limitations generally lead them to leave some of their spatial direction unused. The unused spatial directions can therefore be reused by another system operating in the same frequency band. Indeed, the secondary transmitters can send their own data to their respective receivers by processing their signals in such a way that the interference produced on the primary link impairs only unused spatial directions. Hence, these spatial resources can be very useful for secondary systems when the available spectral resources are fully exploited over a certain period in a geographical area. In this paper, we consider the PU activity model which finding the unused spatial hole [5] rather than spectrum hole [12–15] to ensure secondary transmission and considering the different system model and problem metrics from our previous work [16,17]. We consider the system model composed of a secondary K-user interference network, while the primary link consists of one pair of transmit-receiver. It is assumed that the PU enables to use the whole achievable DoF with the idea of the IA [5]. Our aim is to design a CR transmission scheme using IA that utilizes the unused DoFs of the primary network for secondary transmission without extra cost to the primary networks. This is done by designing the secondary precoder and decoder matrices such that no interference is incurred to the primary link, while the subspace matrix distance at the secondary network is minimized to search the precoding and decoding matrices for SUs. Due to the limited iterative times of the numerical computation, the interference signal is still existed in SUs desired signal space, and then we derive an improved interference suppression method by jointly considering power allocation scheme and the first proposed interference mitigation scheme. Even though the primary and secondary transmissions are designed for the considered system model, our proposed schemes can be extended to the general system model considering in [18].

1.1. Related works

Considerable research has been done regarding the transceiver design based on IA in CR MIMO networks or similar system model. The authors in [19] propose an opportunistic scheme to utilize the unused eigenmodes of the primary channel, and introduce the secondary precoding and power allocation matrices that are separately designed to nullify the interference on the PU and maximize secondary transmission rates [19,20]. The method is introduced in [19] for single secondary link and then extended to multiple secondary links in [20] under the assumption of perfect CSI at all nodes. However, the method in [19,20] employs independent optimization. On the other hand, joint optimization designs can further improve the secondary rates by jointly designing the secondary matrices. In [21], an iterative method is proposed to nullify the interference on the PU and jointly design the secondary pre- and post-coders to minimize the interference between secondary links in case of perfect CSI. In [18], an improved version of cognitive IA scheme, which has better performance than method in [21], is derived to design the secondary precoders and receiver filters while causing no interference to PU. However, neither algorithm considers the strength of the direct signal to the intended SU. Although this does not matter in terms of the total DoF, it is however very important for practical values of signal-to-noise ratio. In [22], the authors proposed a cooperative IA algorithm to null out the interference between neighboring networks. They have formulated the problem as a coalitional game in partition form and proposed a distributed coalition formation algorithm, while accounting for the cost in terms of power for information exchange. Unfortunately, the authors restricted their work to deal only the co-tier interference and did not take the cross-tier interference into consideration, which is more dominant than co-tier interference in practice. In [23], the authors presented a cross-tier interference management strategy for two-tier networks by exploiting cognition and