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# Interference alignment and game-theoretic power allocation in MIMO Heterogeneous Sensor Networks communications

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ABSTRACT

Interference alignment (IA) can eliminate the interference among wireless nodes. In a multi-input multi-output (MIMO) heterogeneous sensor network (HSN), nodes need to send out their sensed information, and secondary nodes can coexist with primary nodes without generating any interference by using the IA technology. However, few works have considered the sum utility of secondary nodes. In this paper, we not only eliminate the interference by IA, but also maximize the sum utility of secondary nodes by using a game-theoretic power allocation algorithm in Heterogeneous Sensor Networks. Without losing generality, consider there are one primary node and $K$ secondary nodes in the network. Assuming perfect channel knowledge at the primary node, the rate of the primary node is maximized by a water-filling algorithm and the interference from secondary nodes to the primary node is aligned into the unused spatial dimension. Also, an improved maximum signal-to-interference-plus-noise algorithm using channel reciprocity is proposed for the secondary nodes to eliminate the interference between secondary nodes. In addition, the sum rate of the secondary nodes is maximized by a non-cooperative game-theoretic power allocation algorithm. Simulation results show the effectiveness of the proposed algorithms in terms of suppressed interference and maximized sum utility of secondary nodes.



## 1. Introduction

The proliferation of Heterogeneous Sensor Networks (HSN) has created a large amount of multi-sensor signals across multi-modality (e.g., optical, EO/IR, acoustic/seismic, RF, electromagnetic, mechanical, thermal, electrical, etc). Traditional approach on sensor network communications often treats sensor communications as peer to peer communications. In doing so, different sensor modality characteristic has lost, and bandwidth utilization is not efficient. The key feature of our heterogeneous sensor network communication is to partition heterogeneous sensor nodes into two classes, primary nodes (such as sink) and secondary nodes. The secondary nodes can opportunistically access a licensed spectrum that are left unused by the primary node as long as the secondary nodes will not affect the operation of the primary node adversely. For this point of view, our approach is very similar to cognitive radio approach [1]. This improves the spectral efficiency greatly due to that more nodes are allowed to coexist in the same frequency band. Due to the significantly increased channel capacity in MIMO systems, it has become a dominating technique in next generation wireless systems. It is thus quite natural to combine the MIMO and the Heterogeneous Sensor Networks to achieve higher spectral efficiency. This technological combination results in the so-called MIMO Heterogeneous Sensor Network Communication.

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Interference alignment (IA), a recent emergence idea for wireless networks, is an effective approach to manage interference. IA is a technique of signal construction that the interference casts overlapping shadows at the unintended receivers, while the desired signals can still be distinguished at the intended receivers free of interference [3]. Therefore, one can find a suitable precoding matrix by which all the interference can be constrained into one half of the signal spaces at each receiver, leaving the other half do not interfere with the desired signal, then the expected signal can be obtained using the simple zero-forcing method. The authors in [4–6] have introduced the concept of IA independently. Moreover, the idea of IA for the $K$-node interference channel has been introduced by Cadambe and Jafar in [6]. They showed the degrees of freedom (DoF), that is, the interference-free signaling dimensions of this channel are much more than previously thought. In order to achieve IA, in [7], two kinds of iterative distributed algorithms, minimum weighted leakage interference (MWLI) and maximum signal-to-interference-plus-noise (MSINR) were presented by exploiting the channel reciprocity. In [8], the authors have analyzed these two kinds of algorithms, and compared the bit error rate performance of them. In cognitive MIMO radio systems, interference alignment is a new research direction in recent years. In [9], the authors introduced the interference alignment techniques in cognitive radio systems for the first time. The study is under cognitive MIMO interference channel which has only one primary node and one secondary node who have the same antennas in the transmitting and receiving modes. An opportunistic interference alignment (IA) technique was proposed to allow a single secondary node to exploit the unused spatial directions by the primary node. One primary node and multi-secondary node network was proposed in [10]. In [11], the author has studied the relation between the DoF and the number of antennas in cognitive radio systems. Also, an imposed MWLI algorithm in cognitive radio networks with multi-primary node and multi-secondary node was proposed in [12]. In [13], a Stacklberg game was proposed between the primary node and multi-secondary node. All the researches above did not consider the sum utility of secondary nodes, and most of them have tried to maximize each of the utility by a water-filling algorithm without considering the competition between secondary nodes. In this paper, we will solve the conflict between secondary nodes by game theory.

Game theory, a suitable method for analyzing conflict and cooperation among rational decision makers, has been applied to solve the problem of power control [14] for providing the maximum throughput in cognitive radio networks according to the inherently competitive nature of multi-node cognitive radio networks, in recent years. The extension to the cognitive MIMO system was considered in [15,16]. Recently, game theory has attracted researchers' attention in wireless communications. The authors in [17] have studied the IA for overlay cognitive radio systems based on game theory, but few studies of IA for underlay cognitive radio systems based on game theory have been conducted.

In this paper, the case of multiple secondary nodes opportunistically exploiting the same frequency band utilized by a primary node is considered. We develop IA-based cognitive transmission schemes that secondary nodes can exploit the unused spatial dimensions left by the primary node so such that no interference is generated at the primary receiver. Furthermore, no interference from the primary transmitter or other secondary transmitters is generated to each of the secondary receiver [9]. We perform IA for the secondary links by an improved version of MSINR to find the precoders and reception filters. After the interference alignment, we consider the sum utility of secondary nodes in presence of the primary node. Due to the selfish nature of secondary nodes, every secondary node wants to achieve a better utility. Therefore, a non-cooperative game is used to analyze this situation and we considered the Nash equilibrium as the solution of this game. The main objective of this work is to eliminate the interference by IA and then to maximize the sum utility of secondary nodes by game theory.

The remaining of the paper is organized as follows: In Section 2, we introduce the system model and the IA problem for the primary node. In Section 3, we present an iterative distributed IA algorithm. Section 4 presents the game theory for secondary nodes in the case of a $K$-node symmetric secondary system. Simulation results are presented in Section 5, and finally, the paper is concluded in Section 6.

*Notation:* We use lower-case bold symbols for vectors and upper-case bold font to denote matrices. $\mathbf{I}_n$ represents the $n \times n$ identity matrix and the $m \times n$ null matrix is represented by $\mathbf{0}_{m\times n}$. $tr\{\mathbf{A}\}$, $rank\{\mathbf{A}\}$, $span\{\mathbf{A}\}$, $N\{\mathbf{A}\}$, $\|\mathbf{A}\|$ and $\mathbf{A}^H$ denote the trace, rank, range, nullspace, norm, and Hermitian transpose of the matrix, respectively, and $\mathbf{A}^{*i}$ denotes the $i$th column of the matrix. What is more, $E\{\cdot\}$ denotes the statistical expectation and $(p)^+ = \max\{0, p\}$.

## 2. System model

We consider a $(K+1)$-node MIMO interference channel in Heterogeneous Sensor Networks as shown in Fig. 1. We

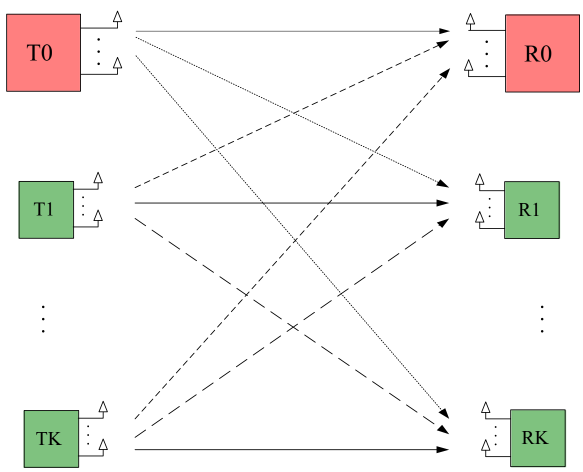


**Fig. 1.** MIMO cognitive radio system.