Reconfigurable Antenna based Blind Interference Alignment

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ABSTRACT: In recent years, several experimental studies have come out to validate the theoretical findings of interference alignment (IA), but only a handful of studies have focused on blind interference alignment. Unlike IA and other interference mitigation techniques, blind IA does not require channel state information at the transmitter (CSIT). The key insight is that the transmitter uses the knowledge of channel coherence intervals and receivers utilize reconfigurable antennas to create channel fluctuations exploited by the transmitter. In this work, we present a novel experimental evaluation of a reconfigurable antenna system for achieving blind IA. We present a blind IA technique based on reconfigurable antennas for a 2-user multiple-input single-output (MISO) broadcast channel implemented on a software defined radio platform where each of the receivers is equipped with a reconfigurable antenna. We further compare this blind IA implementation with traditional TDMA scheme for benchmarking purposes. We show that the achievable rates for blind IA can be realized in practice using measured channels under practical channel conditions. Additionally, the average error vector magnitude and bit error rate (BER) performances are evaluated.

I. INTRODUCTION

Interference alignment is a promising technique for interference management, in which transmitter sides intend to find a DoF-optimal precoding manner. For any receiver, IA precoding compresses all undesired information-bearing signals in a small signal space while transmitting the desired signal in a maximized interference-free signal space. It is proved that, in a K-user interference channel with each node equipped with a single antenna, IA can achieve overall $K/2$ degrees of freedom (DoF) [1]. By contrast, only the DoF of 1 is achieved if applying TDMA technology.

However, IA is considered practically limited because global CSIT is normally required by IA implementations. Thanks to reconfigurable antenna technique, the interference channel could be constructed into some specially staggered pattern such that the implementation of IA needs no CSIT, also known as blind interference alignment (BIA) [2]. Since its commence, BIA has drawn increasing attention [3], [4], [5], [6], [7]. Recently, Zhou *et. al.* prove that, rather than resorting reconfigurable antenna, the implementation of BIA is also possible in K-user 2x1 homogeneous broadcast channels (BC) [8], [9]. By homogeneous, it means that the links connecting the two-antenna transmitter and the single-antenna receivers undergo independent block fading with identical coherence times. Combining the reconfigurable-antenna-based BIA method and the homogeneous-block-fading-based BIA method can simplify the BIA implementation for *K*-user 2x1 heterogeneous BC. In the simplified BIA method, each reconfigurable antenna only needs to tune its coherence time equal to the minimum coherence time among the *K* links.

Although in the simplified BIA implementation each reconfigurable antenna no needs to switch its mode as frequently as in the raw BIA method [2], each receive antenna still needs to consume energy on mode switching every round of minimum coherence time. From engineering perspective, the mode switching consumption should be jointly considered with the DoF gain achieved by BIA.

In this paper we try to answer the question above by modeling an utility function which simply deducts the modeswitching energy from the DoF gain. For simplicity of analysis, we only consider 3-user 2x1 heterogeneous BC. Our analysis shows that forming a 3-user 2x1 BC by BIA is not always optimal from the perspective of maximizing utility gain. On certain instance, the 3-user BC should be divided by TDMA into one 2-user 2x1 BC and one 2x1 point-to-point (p2p) channel in order to achieve the optimal utility measure, or even into three temporally orthogonal 2x1 p2p channels. The impact of coherence times on optimal utility measure is also extensively investigated.

Due to the increasing demand for high data rates and increasing density of wireless networks, there has been a growing interest in developing advanced interference mitiga-tion techniques such as interference alignment. Interference alignment (IA) is a relatively new interference mitigation technique that achieves significant increase in sum rate over traditional orthogonal schemes . In a nutshell, IA uses low-complexity precoding to align interfering signals at each receiver into an interference subspace, thereby allowing the intended signal to be decoded in its own signal space. Most of the existing approaches to IA place the precoding complexity at the transmitters, with the assumption of perfect, and sometimes global, Tx-Rx channel state information at the transmitter (CSIT). This assumption often falls short in practice, as obtaining accurate CSIT requires additional bandwidth and turn-around time that severely impacts the spectral efficiency of the system. As a result, the implementation of CSIT-based IA schemes have proven to be challenging.

To address these challenges, a novel technique called blind interference alignment, which does not require CSIT for a certain class of networks, was proposed in . Without knowledge of CSIT, the blind IA scheme is able to align interference based on the knowledge of only the channel autocorrelation structures of different users. In , blind IA was developed to exploit the staggered block fading nature of the upon this, blind IA schemes that leverage reconfigurable antennas to artificially create temporal correlations in the channels have been proposed To understand the impact of blind IA techniques on practical wireless networks, it is necessary to evaluate their performance in realistic settings. Simulation-based studies often reiterate over a set of simplistic channel models and scenarios, such as spatially uncorrelated channels, perfect timing and frequency synchronization and perfect channel estimation. There are only a few experimental evaluations of blind IA schemes in the literature.

The authors show improved performance in terms of ergodic sum rate and BER with the use of the ESPAR antenna. Again, this work relies on a simulation of the antenna and not measurements obtained using the ESPAR antenna. Although relevant, none of these works address practical issues such as short channel coherence time, spatially correlated channels and phase compensations at the receivers. For blind IA to be viable for practical communication systems, it is important to experimentally evaluate its performance in realistic channels using compact reconfigurable antennas that can be integrated in mobile devices.

In this work, we evaluate the performance of a reconfigurable antenna-based blind IA implementation on our multiple-input multiple-output orthogonal frequency division multiplexing (MIMO-OFDM) testbed. Reconfigurable antennas have gained significant attention in recent years for both single user systems , as well as multi-user IA based system and to the best of our knowledge, this is the first experimental blind IA work that utilizes reconfigurable antennas instead of simulating their behavior through multiple antennas. Reconfigurable antennas for blind IA allow more efficient system design (in terms of cost and space) and performance since a single antenna element on the receiver can generate the required channel fluctuations and removes the requirement for multiple antennas. The experimental setup consists of one transmitter with two conventional antennas and two users each equipped with a reconfigurable antenna, commonly referred to as a multiple-input single-output broadcast channel (MISO-BC). The proposed experiments are based on configurations that are similar to a 802.11-based 2.4 GHz WiFi system Through experimental measurements, we demonstrate that blind IA can indeed be realized in practice via reconfigurable antennas and our reconfigurable antenna based blind IA implementation significantly outperforms the rate achieved by TDMA.

2. SYSTEM MODEL

To evaluate the performance of reconfigurable antennas in a blind interference alignment implementation, we consider a K-user M _ 1 MISO BC scenario, where the transmitter has M antennas and each of K receivers have a reconfigurable antenna. The receivers are able to select one of the preset states of the reconfigurable antenna. Let h[k](m) 2 C2_1 denote the 1 _ M channel vector associated with the m-th state of user k's reconfigurable antenna. As stated in the introduction, blind IA does not require CSI at the transmitter. Furthermore, there are no special assumptions made about the channel coherence block structure. However, we do assume that the coherence times are large enough so that the channel vectors stay constant during the symbol extension period required for alignment, commonly referred to as a super symbol. During a super symbol, which is discussed in more detail in section II-B, the receivers switch between their antenna states in a predetermined pattern. Let us denote the state selected by receiver k at time t as m[k](t) and the corresponding channel for the user as h[k](m[k](t)). Suppose signal vector x(t) 2 CM_1 is sent from the transmitter. The received signal vector of user k at time t is given by

$$y^{[k]}(t) = \mathbf{h}^{[k]}(m^{[k]}(t))\mathbf{x}(t) + z^{[k]}(t)$$

where z[k] t (t) represents additive white Gaussian noise with zero mean and unit variance. The channel input is subject to an average power constraint E_[| x |]≤ P.

3. CONCLUSION :

In this paper, we presented an experimental study of a blind interference alignment scheme that employs a pattern reconfigurable antenna. Unlike other interference mitigation techniques such as beam forming or IA, our reconfigurable antenna-based blind IA implementation does not require CSIT. Using our MIMO-OFDM tested and the Reconfigurable Alford Loop Antenna, we validated the practicality of realizing blind IA with a reconfigurable antenna. Furthermore, we studied the performance of our implementation and how it compares to TDMA. Our measurement results show that the implementation with this antenna achieves significant gain in sum rates compared to TDMA. Due to the inherent interference of blind IA, our implementation incurs 5 dB degradation in terms of PP-SINR. However, for a given PP-SINR, both blind IA and TDMA have similar performance. Because the Reconfigurable Alford Loop antenna used in this work has several radiation patterns to choose from, a natural extension of our work is the study of optimal antenna pattern selection for blind IA.

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